frontiers RESEARCH TOPICS

EMOTION AND AGING: RECENT EVIDENCE FROM BRAIN AND BEHAVIOR

Topic Editors
Natalie C. Ebner and Håkan Fischer

frontiers in PSYCHOLOGY

ISSN 1664-8714
ISBN 978-2-88919-425-4
DOI 10.3389/978-2-88919-425-4

ABOUT FRONTIERS

Frontiers is more than just an open-access publisher of scholarly articles: it is a pioneering approach to the world of academia, radically improving the way scholarly research is managed. The grand vision of Frontiers is a world where all people have an equal opportunity to seek, share and generate knowledge. Frontiers provides immediate and permanent online open access to all its publications, but this alone is not enough to realize our grand goals.

FRONTIERS JOURNAL SERIES

The Frontiers Journal Series is a multi-tier and interdisciplinary set of open-access, online journals, promising a paradigm shift from the current review, selection and dissemination processes in academic publishing.
All Frontiers journals are driven by researchers for researchers; therefore, they constitute a service to the scholarly community. At the same time, the Frontiers Journal Series operates on a revolutionary invention, the tiered publishing system, initially addressing specific communities of scholars, and gradually climbing up to broader public understanding, thus serving the interests of the lay society, too.

DEDICATION TO QUALITY

Each Frontiers article is a landmark of the highest quality, thanks to genuinely collaborative interactions between authors and review editors, who include some of the world's best academicians. Research must be certified by peers before entering a stream of knowledge that may eventually reach the public - and shape society; therefore, Frontiers only applies the most rigorous and unbiased reviews.
Frontiers revolutionizes research publishing by freely delivering the most outstanding research, evaluated with no bias from both the academic and social point of view.
By applying the most advanced information technologies, Frontiers is catapulting scholarly publishing into a new generation.

WHAT ARE FRONTIERS RESEARCH TOPICS?

Frontiers Research Topics are very popular trademarks of the Frontiers Journals Series: they are collections of at least ten articles, all centered on a particular subject. With their unique mix of varied contributions from Original Research to Review Articles, Frontiers Research Topics unify the most influential researchers, the latest key findings and historical advances in a hot research area!
Find out more on how to host your own Frontiers Research Topic or contribute to one as an author by contacting the Frontiers Editorial Office: researchtopics@frontiersin.org

EMOTION AND AGING: RECENT EVIDENCE FROM BRAIN AND BEHAVIOR

Topic Editors:
Natalie C. Ebner, University of Florida, USA
Håkan Fischer, Stockholm University, Sweden

Image created by Natalie Ebner. Ebner, N. C., Riediger, M., & Lindenberger, U. (2010). FACES—A database of facial expressions in young, middle-aged, and older women and men: Development and validation. Behavior Research Methods, 42, 351–362.
DOI: 10.3758/BRM.42.1.351

Emotions play a central role in every human life, from the moment we are born until we die. They prepare the body for action, guide decisions, and highlight what should be noticed and remembered. Since emotions are central to daily functioning and well-being, it is important to understand the extent to which aging affects the perception of, attention to, memory for, as well as experience and regulation of emotions.

An early scientific view of how people's emotions are affected by aging argued that aging led to a deterioration of emotional function. This theory, represented by for example Carl Jung (1875-1961), claimed that old age is a period of life when people feel an increased emotional sameness and less emotional energy. According to this scientific view, the aging emotional landscape was bleached, barren, and flattened. Current psychological research, however, shows that emotion is rather a psychological domain that is relatively unaffected by the aging process or even improves with age, in contrast to most cognitive functions. For example, even though there is evidence that aging is associated with deficits in emotion recognition, various emotional functions seem to remain intact or become better with age, such as the ability to regulate one's emotions or the extent of experiencing positive emotions. However, more research is needed to determine brain and behavior related, quantitative and qualitative age-related changes of different aspects of emotion processing and emotional functioning.

In the current Frontiers research topic we aim to present exciting new findings related to the effects of healthy aging on both more perceptually driven bottom-up as well as more cognitively driven top-down aspects of emotions. In particular, questions such as the following need to be raised and addressed: What neural and behavioral processes are underlying age differences in emotion perception and memory for emotional information? Are there differences between how older and younger adults experience and regulate their emotions, and what drives these differences? Is there a gradual reduction or more of a qualitative change of our emotional experiences over the life cycle, from the turbulent childhood and youth to the mellower old age? And what aspects of age-related changes in emotional processing can be explained by age-related changes in the brain, and which are more affected by other factors such as changes in other body systems, in experiential processes, or in overall life goals?

Table of Contents

frontiers in
PSYCHOLOGY

EDITORIAL
published: 09 September 2014
doi: 10.3389/fpsyg.2014.01007

Studying the various facets of emotional aging

Natalie C. Ebner[1]* and Håkan Fischer[2]

[1] Social-Cognitive and Affective Development Lab, Department of Psychology, University of Florida, Gainesville, FL, USA
[2] Department of Psychology, Stockholm University, Stockholm, Sweden
*Correspondence: natalie.ebner@ufl.edu

Edited and reviewed by:
Luiz Pessoa, University of Maryland, College Park, USA

Keywords: emotional aging, emotion perception, emotion-related cognition, emotion experience, emotion regulation, multi-faceted

To study emotional aging is to study a very multi-faceted concept. In particular, the study of emotion and aging covers a wide range of topics. Taking a closer look, domains of functioning can be differentiated such as pertaining to the experiential nature of emotion or its regulation, as well as social-cognitive processes associated with the perception of emotion in others or emotion-related attention and memory retrieval. Importantly, evidence over the last two decades suggests that not all of these functional domains are negatively affected by the aging process. Rather late-life development in emotion-related functional domains is characterized by multi-directionality, in that aging seems to be associated with deterioration in abilities related to emotion perception and increased difficulty remembering (particularly negative compared to positive) emotional information, while emotional experience and emotion-regulatory capacities appear to remain relatively preserved or even improve with age.

Also, the study of emotion and aging covers a wide range of theoretical orientations, paradigms, and methods to adequately capture the complexity of the phenomenon. In particular, emotional aging researchers use self-report, experience sampling, cognitive-behavioral observation, eye tracking, electro- and psychophysiological as well as different functional brain imaging techniques among their assessment tools to ensure recording from the multiple channels emotions can be expressed in, and to shed light on the phenomenon of interest from different angles.

In the current Frontiers research topic *Emotion and Aging: Evidence from Brain and Behavior*, 13 groups of researchers contributed with their expertise, and the included papers reflect the theoretical, methodological, and statistical diversity of this research field. In the following, we briefly introduce each paper contribution. For a more thorough discussion of the articles' theoretical innovation, methodological approach, and scientific advancement contextualized in the broader literature on emotional aging as well as for a constructive reflection about topics untouched in this research topic and future directions the field could take, see Ebner and Fischer (2014) in this Frontiers research topic.

EMOTIONAL EXPERIENCES

English and Carstensen (2014) used experience sampling in a community sample of young and older adults and underscore the importance of examining emotional aging in everyday life, thereby carefully considering the moderating roles of specific emotions sampled and assessment time during the day.

EMOTION REGULATION

Allard and Kensinger (2014) compared young and older adults in their use of emotion-regulatory strategies and provide neuroimaging evidence of less efficient cognitive control processing in aging. Also using functional magnetic resonance imaging, Dolcos et al. (2014) showed that older compared to young adults' spontaneous engagement of emotion control regions resulted in emotion-regulatory benefits. Opitz et al. (2014) used a multiple-channel approach that integrated self-reported emotional intensity, expressive behavior, and autonomic physiology and showed that fluid (but not crystallized) cognitive abilities predicted emotion-regulatory success, independent of age.

EMOTION PERCEPTION

Völkle et al. (2014) took a closer look at the interplay between mood fluctations and perceptions of emotion in others in an adult lifespan sample comprising young, middle-aged, and older adults and report supporting evidence for a mood-congruency effect that was particularly pronounced in older adults. Riediger et al. (2014) demonstrated that young adults outperformed older adults in their ability to identify emotional experiences accompanying smiles. Their findings furthermore show that age effects varied as a function of both the genuineness of smiles and the age of the smiling person. Studying emotion perception in a clinical-dyadic context with Parkinson's Disease patients and neurologically intact age-matched controls, Petrican et al. (2014) showed that the relationship between partner's proficiency in identifying emotions in others and spousal well-being was moderated by neurological status.

EMOTION-RELATED ATTENTION AND MEMORY

Svärd et al. (2014) examined emotion-related cognition. They confirmed a direct link between subjective ratings of emotional faces and attention to and memory for such faces, independent of age. Across two studies, effects of emotional content of information on working memory was examined. Truong and Yang (2014) observed that emotional targets facilitated working memory, while emotional distracters disrupted performance, for both young and older adults. Pehlivanoglu et al. (2014) confirmed an age-related deficit in unbinding task-irrelevant facial emotion information. Shedding light on the neural correlates of source memory for socioemotional information, Cassidy et al. (2014)

reported an age-related shift from dorsal to ventral medial prefrontal cortex activity during encoding that possibly reflects an increased focus on emotionally relevant information in aging.

Across the empirical contributions in this Frontiers research topic a variety of theoretical approaches are discussed. For example, some contributions conceptualize emotions as a multi-dimensional construct (Völkle et al., 2014), while others propose broad differentiation between positive and negative emotions (Pehlivanoglu et al., 2014; Petrican et al., 2014; Truong and Yang, 2014) and/or highlight the impact of other emotion dimensions than valence such as arousal or potency (Dolcos et al., 2014; English and Carstensen, 2014; Pehlivanoglu et al., 2014; Svärd et al., 2014; Truong and Yang, 2014). This research topic also specifically features two novel theoretical perspectives, with potential to inform future research. In particular, Kunzmann et al. (2014) propose a discrete emotions approach that considers multi-directional age differences in the specific emotions of anger and sadness. Synthesizing the literature, Fölster et al. (2014) emphasize the role of considering age-of-face effects in aging research on emotion perception. They conclude that age-congruency effects are particularly crucial in the context of face memory but may only play a minor role in facial emotion perception.

Taken together, this Frontiers research topic showcases the breadth of approaches when studying emotional aging, highlights common themes as well as topical diversity, and proposes avenues for future research. We regard the presented research as clearly underlining the scientific benefits arising from the broad and interdisciplinary perspective that characterizes emotional aging research today. We believe that the theoretical work, innovative empirical paradigms and methodological and statistical approaches presented in this research topic will constitute valuable tools to guide future research toward validation and extension of current research findings. In this spirit, we would like to conclude this introduction by reflecting on a selection of topics that remained untouched in the current research topic, offering great opportunities for exciting future research moving forward in this domain of inquiry. We argue that in order to obtain a comprehensive picture of emotion and aging, brain-behavior processes need to be directly linked to hormonal and genetic as well as contextual and motivational influences, an integration that is currently largely neglected in the literature. Also, a translation of research findings obtained in healthy aging populations to clinical contexts appears crucial to advance research in pathological aging associated with experience, regulation, and processing of emotion (e.g., in depression or apathy). Moreover, to overcome methodological heterogeneity between studies that complicates direct comparison across studies, future research that applies multiple methods to the same sample is warranted. We look forward to seeing this Frontiers research topic inspire exciting new research on emotion and aging in a multi-faceted and integrated manner.

REFERENCES

Allard, E. S., and Kensinger, E. A. (2014). Age-related differences in neural recruitment during the use of cognitive reappraisal and selective attention as emotion regulation strategies. *Front. Psychol.* 5:296. doi: 10.3389/fpsyg.2014.00296

Cassidy, B. S., Hedden, T., Yoon, C., and Gutchess, A. H. (2014). Age differences in medial prefrontal activity for subsequent memory of truth value. *Front. Psychol.* 7:87. doi: 10.3389/fpsyg.2014.00087

Dolcos, S., Katsumi, Y., and Dixon, R. A. (2014). The role of arousal in the spontaneous regulation of emotions in healthy aging: an fMRI investigation. *Front. Psychol.* 5:681. doi: 10.3389/fpsyg.2014.00681

Ebner, N. C., and Fischer, H. (2014). Emotion and aging: recent evidence from brain and behavior. *Front. Psychol.* 5:996. doi: 10.3389/fpsyg.2014.00996

English, T., and Carstensen, L. L. (2014). Emotional experience in the mornings and evenings: consideration of age differences in specific emotions by time of day. *Front. Psychol.* 5:185. doi: 10.3389/fpsyg.2014.00185

Fölster, M., Hess, U., and Werheid, K. (2014). Facial age affects emotional decoding. *Front. Psychol.* 5:30. doi: 10.3389/fpsyg.2014.00030

Kunzmann, U., Kappes, C., and Wrosch, C. (2014). Emotional aging: a discrete emotions perspective. *Front. Psychol.* 5:380. doi: 10.3389/fpsyg.2014.00380

Opitz, P. C., Lee, I. A., Gross, J. J., and Urry, H. L. (2014). Fluid cognitive ability is a resource for successful emotion regulation in older and younger adults. *Front. Psychol.* 5:609. doi: 10.3389/fpsyg.2014.00609

Pehlivanoglu, D., Jain, S., Ariel, R., and Verhaeghen, P. (2014). The ties to unbind: age-related differences in feature (un)binding in working memory for emotional faces. *Front. Psychol.* 5:253. doi: 10.3389/fpsyg.2014.00253

Petrican, R., Moscovitch, M., and Grady, C. (2014). Proficiency in positive vs. negative emotion identification and subjective well-being among long-term married elderly couples.*Front. Psychol.* 5:338. doi: 10.3389/fpsyg.2014.00338

Riediger, M., Studtmann, M., Westphal, A., Rauers, A., and Weber, H. (2014). No smile like another: adult age differences in identifying emotions that accompany smiles. *Front. Psychol.* 5:480. doi: 10.3389/fpsyg.2014.00480

Svärd, J., Fischer, H., and Lundqvist, D. (2014). Adult age-differences in subjective impression of emotional faces are reflected in emotion-related attention and memory tasks. *Front. Psychol.* 5:423. doi: 10.3389/fpsyg.2014.00423

Truong, L., and Yang, L. (2014). Friend or foe? Decoding the facilitative and disruptive effects of emotion on working memory in younger and older adults. *Front. Psychol.* 5:94. doi: 10.3389/fpsyg.2014.0009

Völkle, M. C., Ebner, N. C., Lindenberger, U., and Riediger, M. (2014). A note on age differences in mood-congruent versus mood-incongruent information processing in faces. *Front. Psychol.* 5:635. doi: 10.3389/fpsyg.2014.00635

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 21 August 2014; accepted: 24 August 2014; published online: 09 September 2014.

*Citation: Ebner NC and Fischer H (2014) Studying the various facets of emotional aging. Front. Psychol. **5**:1007. doi: 10.3389/fpsyg.2014.01007*

This article was submitted to Emotion Science, a section of the journal Frontiers in Psychology.

frontiers in PSYCHOLOGY

PERSPECTIVE ARTICLE
published: 09 September 2014
doi: 10.3389/fpsyg.2014.00996

Emotion and aging: evidence from brain and behavior

Natalie C. Ebner[1]* and Håkan Fischer[2]

[1] Psychology, Social-Cognitive and Affective Development Lab, Department of Psychology, University of Florida, Gainesville, FL, USA
[2] Department of Psychology, Stockholm University, Stockholm, Sweden

Edited by:
Marina A. Pavlova, Eberhard Karls Universität Tübingen, Germany

Reviewed by:
Nichole Lighthall, Duke University, USA
Antje Rauers, Max Planck Institute for Human Development, Germany

***Correspondence:**
Natalie C. Ebner, Psychology, Social-Cognitive and Affective Development Lab, Department of Psychology, University of Florida, Gainesville, FL 32611, USA
e-mail: natalie.ebner@ufl.edu

Emotions play a central role in every human life from the moment we are born until we die. They prepare the body for action, highlight what should be noticed and remembered, and guide decisions and actions. As emotions are central to daily functioning, it is important to understand how aging affects perception, memory, experience, as well as regulation of emotions. The Frontiers research topic *Emotion and Aging: Evidence from Brain and Behavior* takes a step into uncovering emotional aging considering both brain and behavioral processes. The contributions featured in this issue adopt innovative theoretical perspectives and use novel methodological approaches to target a variety of topics that can be categorized into three overarching questions: *How do cognition and emotion interact in aging in brain and behavior? What are behavioral and brain-related moderators of emotional aging? Does emotion-regulatory success as reflected in brain and behavior change with age?* In this perspective paper we discuss theoretical innovation, methodological approach, and scientific advancement of the 13 papers in the context of the broader literature on emotional aging. We conclude by reflecting on topics untouched and future directions to take.

Keywords: emotional aging, brain-behavior links, cognition–emotion interactions, age-of-face effects, emotion regulation

Emotions play a central role throughout human life. They highlight what is important and guide actions. As emotions are central to daily functioning, it is important to understand how aging affects them. An early scientific view argued that aging led to a deterioration of emotional function. This theory, represented by Carl Jung, claimed that old age is a period in life when people feel emotional sameness and the aging emotional landscape was described as bleached and barren. However, current psychological research shows that emotion is relatively unaffected by aging or even improves with age, in contrast to most cognitive functions (Scheibe and Carstensen, 2010). For example, aging is associated with improved emotional problem solving (Blanchard-Fields, 2007) and increased frequency of positive feelings (Carstensen et al., 2011). However, other emotional capacities, such as the ability to recognize other's emotions, decline with age (Ruffman et al., 2008). Such variations across emotional functional domains, and our limited understanding of mediating and moderating factors, call for more research. Given various representational levels of the phenomenon, an approach that combines brain and behavior in uncovering emotional aging seems promising.

The current Frontiers research topic takes a step into this direction. It comprises novel theoretical and methodological approaches and presents exciting new findings. The contributions evolve around three broader questions that have only recently received attention in the literature on emotional aging and answers to which will inform affective science research: (1) *How do cognition and emotion interact in aging in brain and behavior?* (2) *What are behavioral and brain-related moderators of emotional aging?* (3) *Does emotion-regulatory success as reflected in brain and behavior change with age?* Within those overarching questions, different emotion-related phenomena (emotion perception, emotion experience, attention and memory related to emotion, emotion regulation) will be addressed.

In the following, we will summarize the contributions. We will illustrate how they increase scientific understanding of emotional aging. In particular, we will emphasize how adoption of diverse theoretical and methodological approaches allow for a multi-faceted study of emotional aging and we will lay out how adopting an aging brain-behavior prespective increases understanding of cognition–emotion interactions, moderators of emotion processing, and emotion-regulatory success. We will conclude by raising topics not yet covered for exploration in future research.

NEW THEORETICAL AND METHODOLOGICAL APPROACHES IN THE STUDY ON EMOTION AND AGING

The research topic presents novel theoretical perspectives on emotional aging. Two of these are featured in perspective papers as summarized next. Other approaches are embedded in the context of the empirical paper contributions and integrated in the discussion below.

A DISCRETE EMOTIONS APPROACH THAT CONSIDERS MULTI-DIRECTIONAL AGE DIFFERENCES IN SPECIFIC EMOTIONS OFFERS NEW DIRECTIONS OF RESEARCH

Complementing lifespan theories of developmental regulation that define negative affect and positive affect broadly (e.g., Baltes and Baltes, 1990), Kunzmann et al. (2014) propose a discrete emotions perspective on emotional aging. This approach links emotions to goals, emphasizing person–context interactions in their impact on adaptiveness of specific emotions (Haase et al., 2012). The approach is illustrated by delineating differential adult lifespan trajectories in the experience of anger and sadness. It sheds light on the mechanisms related to cognitive and physiological resources that underlie adaptive consequences of anger reactions in young adulthood and sadness reactions in old age and may prove particularly useful in understanding multi-directionality of affective responses across the adult lifespan. Extending this theoretical perspective to other emotions and across the entire lifespan will guide future research. English and Carstensen (2014) and Svärd et al. (2014) in this issue adopted a discrete emotions perspective. In contrast, Völkle et al. (2014) promote the usefulness of a multi-dimensional emotions approach, proposing that more than just one emotion is represented in a face. Other contributions differentiate broadly between positive and negative emotions (Pehlivanoglu et al., 2014; Petrican et al., 2014; Truong and Yang, 2014) and/or highlight the impact of the emotion dimension of arousal (Dolcos et al., 2014; English and Carstensen, 2014; Svärd et al., 2014; Truong and Yang, 2014).

AGE OF THE FACE AFFECTS INTERPRETATION OF FACIAL EXPRESSIONS ACROSS THE ADULT LIFESPAN

The ability to read facial emotions in others declines with age (Ruffman et al., 2008). Fölster et al. (2014) propose that beyond effects of the age of the observer, effects of the age of the face, in interaction with the emotion expressed in the face, need to be considered in research on facial emotion perception. In particular, group differences in expressive style, higher familiarity with faces of in-group members (Elfenbein and Ambady, 2002) and increased motivation toward in-group faces (Thibault et al., 2006) may contribute to age-congruency effects. Fölster et al. (2014) importantly conclude that such effects are crucial in the context of face memory (Rhodes and Anastasi, 2012) but may play less of a role in facial emotion perception. The proposed perspective will facilitate future examination of how age stereotypes influence face recognition bias and how age differences in the frequency of experiencing certain emotions may affect change in facial features. Use of longitudinal approaches and ecologically valid stimuli, such as implemented in some contributions in this issue (Petrican et al., 2014; Riediger et al., 2014), appear particularly promising.

This issue is characterized by a wide selection of methodological approaches, reflecting the complexity of the emotional aging phenomenon. Employed approaches are experience sampling (English and Carstensen, 2014), subjective evaluations (Petrican et al., 2014; Riediger et al., 2014; Svärd et al., 2014; Völkle et al., 2014), cognitive-behavioral measures (Pehlivanoglu et al., 2014; Svärd et al., 2014; Truong and Yang, 2014), eye tracking (Pehlivanoglu et al., 2014), functional neuroimaging (Allard and Kensinger, 2014; Cassidy et al., 2014; Dolcos et al., 2014; Opitz et al., 2014), and electrophysiology (Opitz et al., 2014). Some of the contributions apply multiple methods to the same sample (Opitz et al., 2014; Pehlivanoglu et al., 2014), enabling integration of research findings. However, this research topic, as is characteristic of the current research field, also faces methodological heterogeneity between studies. While this allows for a multi-faceted reflection on emotional aging, a direct comparison across studies is difficult. Innovatively, several contributions leverage new statistical advancements in multi-level modeling to decompose intra-individual from inter-individual variability (English and Carstensen, 2014; Opitz et al., 2014; Petrican et al., 2014).

COGNITION–EMOTION INTERACTIONS IN AGING FROM A BRAIN-BEHAVIOR PERSPECTIVE

A growing number of studies are targeting cognition–emotion interactions. The majority of these studies examine behavioral age-related change (Isaacowitz and Riediger, 2011). Still little is known about the cognition–emotion interplay from an aging brain perspective (Fischer et al., 2010; Samanez-Larkin and Carstensen, 2011). Various contributions in this issue have addressed this research gap. As summarized next, Völkle et al. (2014) demonstrate a mood-emotion perception link across the adult lifespan. Svärd et al. (2014) show direct effects of emotion evaluations on emotion-related cognition. Cassidy et al. (2014), Pehlivanoglu et al. (2014), and Truong and Yang (2014) clarify age differences in working memory/source memory for information with emotional content.

MOOD INFLUENCES YOUNG AND OLDER ADULTS' EMOTION PERCEPTION AND EMOTION PERCEPTION IN TURN AFFECTS MOOD

In Völkle et al. (2014) young, middle-aged, and older adults indicated their current mood before providing facial ratings along prototypical emotional expressions, using a multi-dimensional approach to emotions. Crossed-random effects analyses supported a mood-congruency effect: after controlling for accurate recognition of the primary facial expression, better mood increased the likelihood of perceiving additional facial happiness, while it reduced the likelihood of perceiving additional negative facial expressions. A reversed pattern held for negative mood. These effects were primarily shown by older adults. By assessing naturally occurring fluctuations in mood this study addresses cognition–emotion interactions in aging in a more ecologically valid way than experimental mood manipulation studies typically conducted in this domain.

YOUNG AND OLDER ADULTS DIFFER IN SUBJECTIVE RATINGS OF EMOTIONAL FACES, WITH EFFECTS ON ATTENTION AND MEMORY FOR FACES

Svärd et al. (2014) adopted a three-dimensional approach to emotions by considering young and older adults' facial ratings of valence (pleasant/unpleasant), arousal (active/passive), and potency (weak/strong; Keil and Freund, 2009). They observed an age-related flattening of subjective impressions of facial emotions. Regression analyses confirmed a direct link between subjective ratings and task performance in that higher potency (but not arousal and valence) ratings of angry faces predicted better attention and memory for faces. This work contributes to the sparse knowledge on the interplay between subjective emotion ratings on emotion-related cognition in aging.

EMOTIONAL INFORMATION BOTH FACILITATES AND DISRUPTS WORKING MEMORY IN AGING

Emotional content of information should affect working memory pronouncedly in older adults, given increased emotion orientation

(Carstensen, 2006) and preserved emotion processing (Ebner et al., 2012) with age. Using a working memory paradigm for target information in the presence of distraction, Truong and Yang (2014) systematically varied valence and arousal of word stimuli. For both age groups emotional targets facilitated working memory, while emotional distracters disrupted performance. Emotional disruptive effects were limited to negative words and occurred only in older adults. By identifying situations in which older adults' preserved emotional processing as a helpful "friend" versus a hindering "foe" for cognition, this work adds to the growing literature on the emotion-cognitive control interplay in aging (Dolcos et al., 2011). It supports recent frameworks on competitive advantage of emotional information in aging (Carstensen, 2006) and the role of goal relevance of emotion within specific task contexts (Pessoa, 2008).

AGING IS ASSOCIATED WITH A DEFICIT IN UNBINDING IRRELEVANT EMOTIONAL INFORMATION FROM MEMORY

Pehlivanoglu et al. (2014) confirmed an age-related hyper-binding hypothesis according to which older compared to young adults show increased binding of task-irrelevant information (Campbell et al., 2010). This age-related deficit in unbinding task-irrelevant facial emotion information held beyond age-related differences in perception, attention, or short-term memory. Innovatively, the study employed pupil dilation and showed greater cognitive resource recruitment during attentional processing (Goldinger and Papesh, 2012) in older than young adults. Addition of neuroimaging data on the brain locus of the observed effects will further unwind the link between emotion and working memory in aging.

AGE DIFFERENCES IN ENCODING OF SOURCE INFORMATION ARE AMELIORATED FOR SOCIOEMOTIONAL INFORMATION

In Cassidy et al. (2014) young and older adults encoded statements that varied in perceived truth value, as a type of socioemotional information. In line with work suggesting that socioemotional information reduces age-related source memory deficits (Cassidy and Gutchess, 2012), there was an age-related increase in encoding-related ventral relative to dorsal mPFC recruitment in older compared to young participants. This work importantly contributes to age-differential mPFC function in emotion-related source memory and suggests an increased focus on processing of emotionally relevant information, as opposed to knowledge acquistion, in aging.

MODERATORS OF EMOTIONAL AGING FROM A BRAIN-BEHAVIOR PERSPECTIVE

Mechanisms underlying age deficits in the ability to read emotions in others are not well understood yet. The literature discusses age-related change in visual processing, brain structure and function, hormones, and neurotransmitters as possible explanations (Ruffman et al., 2008; Ebner et al., 2013). Recently, moderating factors such as arousal, emotion expressed, and face-age have received attention (Fölster et al., 2014). Accordingly, papers in this issue have taken up investigation of such moderating factors. As laid out next, Riediger et al. (2014) show moderator roles of age-of-face and genuineness of emotion in emotion perception. Studying proficiency in emotion perception as predictor of well-being, Petrican et al. (2014) provide evidence for a moderating function of neural degenerative disease. English and Carstensen (2014) demonstrate how specific emotions, variations in arousal, and variations in time of day moderate everyday life emotion experience.

In response to critique that the majority of studies on emotion perception use photographs of prototypic facial expressions (Isaacowitz and Stanley, 2011) and examine emotion in the artificial lab setting, several contributions in this issue increased the ecological validity of their stimuli by using dynamic emotion expressions (Riediger et al., 2014) and whole-body postures (Petrican et al., 2014), and by assessing emotion in everyday life (English and Carstensen, 2014) and with relevance in clinical-dyadic context (Petrican et al., 2014).

YOUNG AND OLDER ADULTS DIFFER IN THEIR ABILITY TO IDENTIFY EMOTIONAL EXPERIENCES ACCOMPANYING SMILES, WITH VARIATIONS BY GENUINENESS OF SMILES AND AGE OF THE SMILING PERSON

People show similar facial expressions in disparate situations. Riediger et al. (2014) developed an extensive set of dynamic video episodes of positive-affective, negative-affective, and affectively neutral smiles of young and older adults. Contrasting previous work (Murphy et al., 2010), young participants outperformed older participants at identification of emotional experiences accompanying smiles. This improved performance in young relative to older adults was attenuated for older faces. Older adults were less likely than young adults to attribute positive emotions to smiles, and more likely to indicate a smile as posed. However, young adults more frequently attributed positive emotions to smiles in older than young faces. Use of dynamic, content-valid smile expressions provide a promising venue for studying age differences in emotion recognition and consideration of age-of-face moderation further informs the picture.

PARTNER'S PROFICIENCY IN IDENTIFYING POSITIVE VERSUS NEGATIVE EMOTIONS IN OTHERS DIFFERENTIALLY PREDICTS WELL-BEING IN PARKINSON'S DISEASE (PD) PATIENTS VERSUS NEUROLOGICALLY INTACT AGE-MATCHED CONTROLS

Parkinson's disease is associated with reduced emotional expressivity (Simons et al., 2004). In a clinical-dyadic context, Petrican et al. (2014) used a pointlight walker paradigm that depicted emotions in whole-body postures. Spouses of PD patients were better in identifying positive emotions but worse in identifying negative emotions. Also, relative to controls, they underestimated the intensity in negative emotions, possibly as a compensatory mechanism. Greater expertise in identifying positive emotions was linked to greater spousal well-being in healthy elderly couples; for PD patients and their spouses greater proficiency in reading negative emotions predicted greater spousal well-being. This study is one of the few to shed light on the link between emotion recognition proficiency and close partner well-being in an intimate partnership (Gable et al., 2012), suggesting a moderating role of neurological status. The dynamic whole-body emotional stimuli were more naturalistic than the static facial emotional stimuli typically employed in this research field. Further scientific advancement will come from future implementation of longitudinal dyadic studies to assess emotion expressive habits of both spouses, their emotion expertise, and well-being over time.

AGE DIFFERENCES IN EVERYDAY LIFE EMOTIONAL EXPERIENCE VARY ACROSS EMOTIONS AND TIME OF DAY

English and Carstensen (2014) used experience sampling to assess emotional experience twice a day across 10 days in community-dwelling young and older adults. Both age groups felt less positive and more negative in the evenings than in the mornings. Older compared to young adults reported relatively more positive emotions at both times of day. They also reported greater experience of positive emotions with the exception of the two high-arousal emotions excitement and pride. In contrast, age-related reductions in negative experience were observed only for reports of low-arousal negative emotions. For some emotions (relaxed) age differences were stronger in the mornings, whereas for other emotions (enthusiastic) age differences were more pronounced in the evenings. These findings underscore the importance of examining emotional aging in everyday life, thereby carefully considering the moderating roles of emotions sampled and assessment time.

EMOTION-REGULATORY SUCCESS IN AGING FROM A BRAIN-BEHAVIOR PERSPECTIVE

Emotion regulation refers to promotion of helpful emotions while managing harmful emotions (Gross, 2013). Appropriately regulating one's feelings in favor of successful social interactions may become particularly relevant in old age, given increased dependency and social loss. There is behavioral evidence that older compared to young adults show improved emotion-regulatory capacity (Urry and Gross, 2010). Despite normative declines in various functional domains, improved emotion-regulatory capacities may contribute to high levels of life satisfaction in aging [English and Carstensen (2014) for qualification of these findings]. In contrast, neuroimaging evidence suggests that brain regions characterized by age-related decline in volumetric gray matter (Raz et al., 2004) are relevant for successful emotion regulation (Buhle et al., 2013). As summarized next, age-related change in emotion-regulatory success in brain and behavior were examined across three studies. Allard and Kensinger (2014) demonstrate age differences in efficient use of cognitive reappraisal. Dolcos et al. (2014) show emotion-regulatory benefits of spontaneous recruitment in emotion control regions in aging. Opitz et al. (2014) describe variations in emotion-regulatory success as a function of fluctuating resources across adulthood.

OLDER COMPARED TO YOUNG ADULTS USE EMOTION-REGULATORY STRATEGIES LESS EFFICIENTLY

Allard and Kensinger (2014) engaged young and older adults in emotion-regulatory strategies in response to negative film clips. When comparing regulation (selective attention, cognitive reappraisal) to passive viewing, young adults showed greater regulation-related activity in lateral and medial PFC while older adults showed greater dorsolateral PFC activity. Activity in dorsolateral PFC was increased for reappraisal compared to selective attention in older but not young adults, possibly reflecting a compensation for less efficient cognitive control processing in aging. Consistent with this interpretation, the timing of reappraisal-related activity in ventrolateral PFC was delayed for older adults. This research constitutes a first step toward identification of emotion-regulatory strategies that are effective in aging. The authors emphasize adoption of trial-by-trial approaches to determine success for particular emotion-regulatory attempts as fruitful for future brain-behavior investigations.

OLDER COMPARED TO YOUNG ADULTS SPONTANEOUS ENGAGEMENT OF EMOTION CONTROL BRAIN REGIONS RESULTS IN EMOTION-REGULATORY BENEFITS

Low-arousing negative stimuli engage controlled processes (Kensinger and Corkin, 2004), while high-arousing information captures attention automatically (Dolan, 2002), a process preserved in aging (Mather and Knight, 2006). In Dolcos et al. (2014) young and older participants viewed emotional pictures, that varied in arousal, and rated them for emotional content. Variations in amygdala and ventromedial PFC activity suggested that older adults engaged more automatic processes when evaluating high-arousing negative information, and more controlled processes in response to low-arousing negative information. Linking brain and behavior, spontaneous engagement of emotion control regions reduced subjective experience of low-arousing negative information in older adults, supporting the idea of chronic activation of emotion regulation in aging and delineating neural correlates underlying enhanced emotional well-being in aging.

FLUID COGNITIVE ABILITY INCREASES EMOTION-REGULATORY SUCCESS IN YOUNG AND OLDER ADULTS

Successful cognitive reappraisal recruits brain areas involved in working memory (McRae et al., 2010) and is most effective when initiated early in the emotion-generative cycle (Sheppes and Meiran, 2007). Consequently, age-associated decline in fluid cognitive abilities should negatively impact cognitive reappraisal success. Opitz et al. (2014) showed that both young and older participants reinterpreted the meaning of sad pictures (versus passive viewing). Emotional responding was measured using a multiple-channel approach that integrated self-reported emotional intensity, expressive behavior, and autonomic physiology. Multi-level modeling showed that fluid (but not crystallized) cognitive abilities predicted emotion-regulatory success, independent of age. The research importantly supports the role of fluctuating resources across adulthood on emotion-regulatory success on brain-behavior levels.

OPEN QUESTIONS AND FUTURE DIRECTIONS

The work discussed in this perspective paper provides novel insights into the study of emotional aging, providing responses to pressing research questions. However, various topics remain untouched, offering opportunities for exciting future research moving forward in this domain of inquiry. All articles in this issue adopted a cross-sectional approach. Longitudinal, lifespan research will allow examination of gradual quantitative and qualitative emotional change over the life-cycle, allowing to draw a comprehensive picture of emotional development. With one exception (Petrican et al., 2014), all papers used community-dwelling older research participants, prescreened to be free of serious affective or cognitive impairments. A promising future avenue is emotional aging research in clinical contexts such as in dementia, apathy, or social anxiety, pathologies with high relevance in aging (Goodkind et al., 2010). Expanding current research to more diverse samples coupled with continuous use of advanced methodology will move forward this emerging field. A thorough investigation of consequences of age-related emotional change on health and quality of social interactions is currently missing. Petrican et al. (2014) started exploring this territory and demonstrated an association between emotion recognition proficiency and well-being in elderly couples. Relatedly, a stronger research focus toward improvement of emotional aging is warranted such as through administration of medicinal products (Ebner et al., 2013; Campbell et al., 2014) or training of volitional brain activation associated with emotion-regulatory success (Caria et al., 2010). Several of the papers reflect a desirable development toward integration of positive and negative stimulus material (English and Carstensen, 2014; Riediger et al., 2014; Svärd et al., 2014; Völkle et al., 2014). Also, crucial to further advancement of the multi-faceted phenomenon of emotional aging will be an integration of brain-behavior links, thereby considering hormonal, genetic (Ebner et al., 2013) and contextual, motivational change (Carstensen, 2006). We look forward to integrative research advancements in this exciting domain.

ACKNOWLEDGMENTS

While working on this manuscript, NCE was in parts supported by the NIH-funded Claude D. Pepper Older Americans Independence Center (P30AG028740). The authors wish to thank Devon Weir for assistance with preparation of the manuscript.

REFERENCES

Allard, E. S., and Kensinger, E. A. (2014). Age-related differences in neural recruitment during the use of cognitive reappraisal and selective attention as emotion regulation strategies. *Front. Psychol.* 5:296. doi: 10.3389/fpsyg.2014.00296

Baltes, P. B., and Baltes, M. M. (1990). *Successful Aging: Perspectives From the Behavioral Sciences.* New York, NY: Cambridge University Press.

Blanchard-Fields, F. (2007). Everyday problem solving and emotion: an adult developmental perspective. *Curr. Dir. Psychol. Sci.* 16, 1, 26–31. doi: 10.1111/j.1467-8721.2007.00469.x

Buhle, J. T., Silvers, J. A., Wage, T. G., Lopez, R., Onyemekwu, O., Kober, H., et al. (2013). Cognitive reappraisal of emotion: a meta-analysis of human neuroimaging studies. *Cereb. Cortex* 1998, 1–10. doi: 10.1093/cercor/bht154

Campbell, A., Ruffman, T., Murray, J. E., and Glue, P. (2014). Oxytocin improves emotion recognition for older males. *Neurobiol. Aging* 35, 2246–2248. doi: 10.1016/j.neurobiolaging.2014.04.021

Campbell, K. L., Hasher, L., and Thomas, R. C. (2010). Hyper-binding: a unique age effect. *Psychol. Sci.* 21, 399–405. doi: 10.1177/0956797609359910

Caria, A., Sitaram, R., Veit, R., Begliomini, C., and Birbaumer, N. (2010). Volitional control of anterior insula activity modulates the response to aversive stimuli. A real-time functional magnetic resonance imaging study. *Biol. Psychiatry* 68, 425–432. doi: 10.1016/j.biopsych.2010.04.020

Carstensen, L. L. (2006). The influence of a sense of time on human development. *Science* 312, 1913–1915. doi: 10.1126/science.1127488

Carstensen, L. L., Turan, B., Scheibe, S., Ram, N., Ersner-Hershfield, H., Samanez-Larkin, G., et al. (2011). Emotional experience improves with age: evidence based on over 10 years of experience sampling. *Psychol. Aging* 26, 21–33. doi: 10.1037/a0021285

Cassidy, B. S., and Gutchess, A. H. (2012). Structural variation within the amygdala and ventromedial prefrontal cortex predicts memory for impressions in older adults. *Front. Psychol.* 3:319. doi: 10.3389/fpsyg.2012.00319

Cassidy, B. S., Hedden, T., Yoon, C., and Gutchess, A. H. (2014). Age differences in medial prefrontal activity for subsequent memory of truth value. *Front. Psychol.* 7:87. doi: 10.3389/fpsyg.2014.00087

Dolan, R. J. (2002). Emotion, cognition, and behavior. *Science* 298, 1191–1194. doi: 10.1126/science.1076358

Dolcos, S., Katsumi, Y., and Dixon, R. A. (2014). The role of arousal in the spontaneous regulation of emotions in healthy aging: an fMRI investigation. *Front. Psychol.* 5:681. doi: 10.3389/fpsyg.2014.00681

Dolcos, S., Sung, K., Denkova, E., Dixon, R. A., and Dolcos, F. (2011). Brain imaging investigation of the neural correlates of emotion regulation. *J. Vis. Exp.* 54, pii: 2430. doi: 10.3791/2430

Ebner, N. C., Johnson, M. K., and Fischer, H. (2012). Neural mechanisms of reading facial emotions in young and older adults. *Front. Psychol.* 3:223. doi: 10.3389/fpsyg.2012.00223

Ebner, N. C., Johnson, M. R., Rieckmann, A., Durbin, K. A., Johnson, M. K., and Fischer, H. (2013). Processing own-age vs. other-age faces: neuro-behavioral correlates and effects of emotion. *Neuroimage* 78, 363–371. doi: 10.1016/j.neuroimage.2013.04.029

Elfenbein, H. A., and Ambady, N. (2002). Is there an in-group advantage in emotion recognition? *Psychol. Bull.* 128, 243–249. doi: 10.1037/0033-2909.128.2.243

English, T., and Carstensen, L. L. (2014). Emotional experience in the mornings and evenings: consideration of age differences in specific emotions by time of day. *Front. Psychol.* 5:185. doi: 10.3389/fpsyg.2014.00185

Fischer, H., Nyberg, L., and Backman, L. (2010). Age-related differences in brain regions supporting successful encoding of emotional faces. *Cortex* 46, 490–497. doi: 10.1016/j.cortex.2009.05.011

Fölster, M., Hess, U., and Werheid, K. (2014). Facial age affects emotional decoding. *Front. Psychol.* 5:30. doi: 10.3389/fpsyg.2014.00030

Gable, S. L., Gosnell, C. L., Maisel, N. C., and Strachman, A. (2012). Safely testing the alarm: close others' responses to personal positive events. *J. Pers. Soc. Psychol.* 103, 963–981. doi: 10.1037/a0029488

Goldinger, S. D., and Papesh, M. H. (2012). Pupil dilation reflects the creation and retrieval of memories. *Curr. Dir. Psychol. Sci.* 21, 90–95. doi: 10.1177/0963721412436811

Goodkind, M. S., Gyurak, A., McCarthy, M., Miller, B. L., and Levenson, R. W. (2010). Emotion regulation deficits in frontotemporal lobar degeneration and Alzheimer's disease. *Psychol. Aging* 25, 30–37. doi: 10.1037/a0018519

Gross, J. J. (2013). Emotion regulation: taking stock and moving forward. *Emotion* 13, 359–365. doi: 10.1037/a0032135

Haase, C. M., Seider, B. H., Shiota, M. N., and Levenson, R. W. (2012). Anger and sadness in response to an emotionally neutral film: evidence for age-specific associations with well-being. *Psychol. Aging* 27, 305–317. doi: 10.1037/a0024959

Isaacowitz, D. M., and Riediger, M. (2011). When age matters: developmental perspectives on "cognition and emotion." *Cogn. Emot.* 25, 957–967. doi: 10.1080/02699931.2011.561575

Isaacowitz, D. M., and Stanley, J. T. (2011). Bringing an ecological perspective to the study of aging and recognition of emotional facial expressions: past, current, and future methods. *J. Nonverbal Behav.* 35, 261–278. doi: 10.1007/s10919-011-0113-6

Keil, A., and Freund, A. M. (2009). Changes in the sensitivity to appetitive and aversive arousal across adulthood. *Psychol. Aging* 24, 668–680. doi: 10.1037/a0016969

Kensinger, E. A., and Corkin, S. (2004). Two routes to emotional memory: distinct neural processes for valence and arousal. *Proc. Natl. Acad. Sci. U.S.A.* 101, 3310–3315. doi: 10.1073/pnas.0306408101

Kunzmann, U., Kappes, C., and Wrosch, C. (2014). Emotional aging: a discrete emotions perspective. *Front. Psychol.* 5:380. doi: 10.3389/fpsyg.2014.00380

Mather, M., and Knight, M. R. (2006). Angry faces get noticed quickly: threat detection is not impaired among older adults. *J. Gerontol. B Psychol. Sci. Soc. Sci.* 61, 54–57. doi: 10.1093/geronb/61.1.P54

McRae, K., Hughes, B., Chopra, S., Gabrieli, J. D. E., Gross, J. J., and Ochsner, K. N. (2010). The neural bases of distraction and reappraisal. *J. Cogn. Neurosci.* 22, 248–262. doi: 10.1162/jocn.2009.21243

Murphy, N. A., Lehrfeld, J. M., and Isaacowitz, D. M. (2010). Recognition of posed and spontaneous dynamic smiles in young and older adults. *Psychol. Aging* 25, 811–821. doi: 10.1037/a0019888

Opitz, P. C., Lee, I. A., Gross, J. J., and Urry, H. L. (2014). Fluid cognitive ability is a resource for successful emotion regulation in older and younger adults. *Front. Psychol.* 5:609. doi: 10.3389/fpsyg.2014.00609

Pehlivanoglu, D., Jain, S., Ariel, R., and Verhaeghen, P. (2014). The ties to unbind: age-related differences in feature (un)binding in working memory for emotional faces. *Front. Psychol.* 5:253. doi: 10.3389/fpsyg.2014.00253

Pessoa, L. (2008). On the relationship between emotion and cognition. *Nat. Rev. Neurosci.* 9, 148–158. doi: 10.1038/nrn2317

Petrican, R., Moscovitch, M., and Grady, C. (2014). Proficiency in positive vs. negative emotion identification and subjective well-being among long-term married elderly couples. *Front. Psychol.* 5:338. doi: 10.3389/fpsyg.2014.00338

Raz, N., Gunning-Dixon, F., Head, D., Rodrigue, K. M., Williamson, A., and Acker, J. D. (2004). Aging, sexual dimorphism, and hemispheric asymmetry of the cerebral cortex: replicability of regional differences in volume. *Neurobiol. Aging* 25, 377–396. doi: 10.1016/S0197-4580(03)00118-0

Rhodes, M. G., and Anastasi, J. S. (2012). The own-age bias in face recognition: a meta-analytic and theoretical review. *Psychol. Bull.* 138, 146–174. doi: 10.1037/a0025750

Riediger, M., Studtmann, M., Westphal, A., Rauers, A., and Weber, H. (2014). No smile like another: adult age differences in identifying emotions that accompany smiles. *Front. Psychol.* 5:480. doi: 10.3389/fpsyg.2014.00480

Ruffman, T., Henry, J. D., Livingstone, V., and Phillips, L. H. (2008). A meta-analytic review of emotion recognition and aging: implications for neuropsychological models of aging. *Neurosci. Biobehav. Rev.* 32, 863–881. doi: 10.1016/j.neubiorev.2008.01.001

Samanez-Larkin, G. R., and Carstensen, L. L. (2011). "Socioemotional functioning and the aging brain," in *The Handbook of Social Neuroscience*, eds J. T. Cacioppo and J. Decety (Oxford: Oxford University Press), 507–521.

Scheibe, S., and Carstensen, L. L. (2010). Emotional aging: recent findings and future trends. *J. Gerontol. B Psychol. Sci. Soc. Sci.* 65B, 135–144. doi: 10.1093/geronb/gbp132

Sheppes, G., and Meiran, N. (2007). Better late than never? On the dynamics of online regulation of sadness using distraction and cognitive reappraisal. *Pers. Soc. Psychol. Bull.* 33, 1518–1532. doi: 10.1177/0146167207305537

Simons, G., Pasqualini, M. C., Reddy, V., and Wood, J. (2004). Emotional and nonemotional facial expressions in people with parkinson's disease. *J. Int. Neuropsychol. Soc.* 10, 521–535. doi: 10.1017/S135561770410413X

Svärd, J., Fisher, H., and Lundgvist, D. (2014). Adult age-differences in subjective impression of emotional faces are reflected in emotion-related attention and memory tasks. *Front. Psychol.* 5:423. doi: 10.3389/fpsyg.2014.00423

Thibault, P., Bourgeois, P., and Hess, U. (2006). The effect of group-identification on emotion recognition: the case of cats and basketball players. *J. Exp. Soc. Psychol.* 42, 676–683. doi: 10.1016/j.jesp.2005.10.006

Truong, L., and Yang, L. (2014). Friend or foe? Decoding the facilitative and disruptive effects of emotion on working memory in younger and older adults. *Front. Psychol.* 5:94. doi: 10.3389/fpsyg.2014.00094

Urry, H. L., and Gross, J. J. (2010). Emotion regulation in older age. *Curr. Dir. Psychol. Sci.* 19, 352–357. doi: 10.1177/0963721410388395

Völkle, M. C., Ebner, N. C., Lindenberger, U., and Riediger, M. (2014). A note on age differences in mood-congruent versus mood-incongruent information processing in faces. *Front. Psychol.* 5:635. doi: 10.3389/fpsyg.2014.00635

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 09 July 2014; accepted: 21 August 2014; published online: 09 September 2014.
*Citation: Ebner NC and Fischer H (2014) Emotion and aging: evidence from brain and behavior. Front. Psychol. **5**:996. doi: 10.3389/fpsyg.2014.00996*
This article was submitted to Emotion Science, a section of the journal Frontiers in Psychology.

frontiers in PSYCHOLOGY

ORIGINAL RESEARCH ARTICLE
published: 06 March 2014
doi: 10.3389/fpsyg.2014.00185

Emotional experience in the mornings and the evenings: consideration of age differences in specific emotions by time of day

Tammy English[1]* and Laura L. Carstensen[2]

[1] Department of Psychology, Washington University in St. Louis, St. Louis, MO, USA
[2] Department of Psychology, Stanford University, Stanford, CA, USA

Edited by:
Natalie Ebner, University of Florida, USA

Reviewed by:
Hakan Fischer, Stockholm University, Sweden
Didem Pehlivanoglu, Georgia Institute of Technology, USA
Jennifer Tehan Stanley, University of Akron, USA

***Correspondence:**
Tammy English, Department of Psychology, Washington University in St. Louis, Campus Box 1125, One Brookings Drive, St. Louis, MO 63130-4899, USA
e-mail: tenglish@ wustl.edu

Considerable evidence points to age-related improvements in emotional well-being with age. In order to gain a more nuanced understanding of the nature of these apparent shifts in experience, we examined age differences in a range of emotional states in the mornings and evenings in a sample of 135 community-residing participants across 10 consecutive days. Participants ranged in age from 22 to 93 years. Each participant completed a diary in the morning and again in the evening every day for the study period. During each of the assessments, participants reported the degree to which they experienced emotions sampled from all four quadrants of the affective circumplex. Overall, participants felt less positive and more negative in the evenings than in the mornings. As expected, older adults reported a relatively more positive emotional experience than younger adults at both times of day. Importantly, however, age effects varied based on emotion type and time of day. Older adults reported experiencing more positive emotion than relatively younger adults across a range of different positive states (although age differences emerged most consistently for low arousal positive states). Age-related reductions in negative experience were observed only for reports of low arousal negative emotions. There were no age differences in anger, anxiety, or sadness. For some emotions, age differences were stronger in the mornings (e.g., relaxed) whereas for other emotions age differences were more pronounced in the evenings (e.g., enthusiastic). Findings are discussed in the context of adulthood changes in motivation and emotional experience.

Keywords: affect, emotional experience, discrete emotions, aging, circumplex model

INTRODUCTION

Emotional well-being appears to improve with age (see reviews by Consedine and Magai, 2006; Scheibe and Carstensen, 2010; Charles and Carstensen, 2013) and, importantly, age differences do not appear to be due to cohort effects since longitudinal evidence also points to improvements in emotional experience within individuals as they grow older (Charles et al., 2001; Carstensen et al., 2011). In order to gain a more nuanced understanding of age-differences in everyday life, in the present study we examined whether age differences in emotional experience are apparent across a range of emotions and at different points in the day.

One of the first reports of age-related improvements in emotional functioning was published by Mroczek and Kolarz (1998). Based on a cross-sectional comparison in a large representative sample of Americans, they observed that age was associated with more reported positive experience and less negative experience. Many replications of overall improvements in emotional experience have followed, although findings have been less consistent concerning the emotional changes that drive improvements in emotional well-being. Some studies find that age differences are driven by reductions in negative emotional experience (e.g., Carstensen et al., 2000) whereas others observe the differences to be due to increases in positive emotional experience (e.g., Riediger et al., 2009). In a very large scale cross-sectional study based on yesterday interviews[1], Stone et al. (2010) observed a peak in happiness in early old age, followed by relative constancy into more advanced ages, while negative emotions showed linear declines. A handful of large-scale studies have found small age-related increases in depressive symptoms (Fiske et al., 2003; Davey et al., 2004) and negative emotional experiences (Diener and Suh, 1998); however, studies that have controlled for physical health typically eliminate these effects suggesting that illness more than age is responsible for such findings (Gatz et al., 1996; Kunzmann et al., 2000; although see Fiske et al., 2003).

One explanation for differences in the published literature reflects the fact that researchers use a wide range of measures and procedures, which tap different aspects of emotional experience. While the variety in approaches adds support for the contention that emotional well-being improves with age, the same variability may account for discrepancies across studies in patterns of findings. Global measures, for example, tap deliberative evaluations

[1] Yesterday interviews asked respondents "Did you experience [emotions] a lot yesterday?"

of life more than emotional experience *per se*. Experience sampling, in contrast, typically considered the gold standard in the measurement of emotion in daily life, does an excellent job of characterizing daily life yet often misses low base rate emotions like surprise and anger. Thus, though experience sampling characterizes the emotional tone of daily life very well (most people are not routinely surprised, for example), it can downplay the role of short-lived but powerful emotional experiences. These types of low frequency emotional states might be better detected by global assessments or daily diary studies that ask individuals to reflect on specific experiences across an entire day. Memory based measures, such as, yesterday interviews, are susceptible to motivated reconstructions and can be influenced differentially by motivated processes (e.g., positivity effect, Mather and Carstensen, 2005; Reed and Carstensen, 2012).

The measures researchers adopt also vary in the degree to which they tap high and low arousal. Affective states have been found to vary along two independent dimensions: valence and arousal (Watson and Tellegen, 1985; Larsen and Diener, 1992). Excitement, for example, is both positive and arousing whereas contentment is positive and low in arousal. Traditionally, widely used measures of experience developed for use with young populations have focused mostly on high arousal emotional states, especially in regard to positive emotion (e.g., excitement, enthusiasm), creating an inadvertent conflation of arousal and valence.

These measurement issues are particularly troublesome because increasingly findings point to arousal as a key aspect of emotional development. Powell Lawton et al. (1992) observed many years ago that older adults are less likely to report high arousal or surgent emotions. Consistent with this observation, Kessler and Staudinger (2009) recently reported findings from a study comparing younger and older adults where age differences were observed when emotional composites were broken down by valence and arousal. Specifically, older adults only reported more low arousal positive states (e.g., relaxed), whereas they reported less negative emotion regardless of valence. In an experience sampling study, Scheibe et al. (2013) also observed age-related increases in the daily experience of low arousal positive emotion but no age differences for high arousal positive states.

One potential explanation for these findings comes from the strengths and vulnerabilities integration model (SAVI; Charles, 2010), which suggests that older adults avoid situations that elicit high arousal states because they are less able to recover from disruptions of physiological homeostasis. Therefore, as individuals age they may come to focus their emotional goals more on activities that engender low positive arousal states (e.g., calm) and avoid high arousal states, regardless of valence. Indeed, Scheibe et al. (2013), noted above, found that older adults reported a greater preference for low arousal positive emotions relative to high arousal positive emotions than younger adults. In addition, age-related decreases in negative emotions have been found consistently for high arousal negative states (e.g., anger, rage, despair; Lawton et al., 1992; Schieman, 1999; Phillips et al., 2008; Ross and Mirowsky, 2008; Stone et al., 2010), but it is less clear whether there are similar declines in the experience of low arousal negative states such as sadness. Thus, in order to better understand how emotional experience changes with age, it will be necessary to decompose emotion composites into more fine grained emotional states. Based on the extant literature, emotional benefits associated with age seem to come primarily in the form of increased experience of low arousal positive affective states coupled with a decrease in negative emotions, particularly those that are arousing (e.g., anger; Stone et al., 2010).

Another potential source of inconsistency in the literature on age differences in emotion is time of day. Studies have typically focused on either global reports of emotional experience (typically or on a given day) or momentary emotional experience averaged across various time points (in a day or a series of days). It is conceivable that age differences are stronger in the mornings than evening. Prior research suggests that cognitive performance varies by time of day, such that older adults perform better early in the day whereas younger adults perform better later in the day (Yoon et al., 1999; Knight and Mather, 2013). Emotion regulation, like many goal-directed processes, often demands cognitive resources (Muraven et al., 1998; Ochsner et al., 2012), so if emotion regulation plays a role in older adults relatively more positive emotional experience, then time of day may influence age differences in emotional experience as well. That is, it is conceivable that widely documented emotional advantages of older adults are strongest in the mornings. To our knowledge, however, although older people are more likely to describe themselves as "morning types" than younger adults (Biss and Hasher, 2012), age differences in emotion per se have not been examined as a function of time of day.

In order to gain a clearer picture of age differences in emotional life, we examined a range of specific emotions representing all four quadrants in the affective circumplex, in the mornings and in the evenings across a 10-day period. We hypothesized that older adults would show a more positive affective profile overall and, based on prior research, that older adults would report relatively more low arousal positive emotion and less high arousal negative emotion. We also hypothesized that age differences in emotional experience would be more pronounced in the mornings, consistent with prior research on cognitive performance. In addition, we examined two potential sources of differential age differences in morning versus evening emotional experience: sleep and individual differences in morningness. Older adults may report relatively more positive emotional experience in the morning because they are more likely to be "morning types" or have different sleep patterns than younger adults.

METHODS

PARTICIPANTS

The sample consisted of 135 participants (50% female) ranging in age from 22 to 93 years ($M = 53.87$, $SD = 19.23$). Participants were roughly evenly distributed across this age range. Sixty-seven percent of the participants were European American, 30% were African American, and 3% identified with multiple ethnicities. Socioeconomic status (SES) was determined by a survey research firm based on answers to questions about income, education and occupation. Thirty-two percent of participants were blue-collar workers, 64% were white-collar workers, and 4% were pink-collar workers. Gender, ethnicity, and SES were stratified across age.

PROCEDURE

After providing informed consent, participants completed a number of measures, including assessments of health, cognition, and morningness. The experimenter then explained the format and schedule of the daily diaries. For 10 consecutive days, participants completed an online diary in the morning and again in the evening. Participants were asked to complete the diaries as soon as they woke up and just before bedtime in the evening. Emotional experience was assessed at both time points (morning and evening) each day; sleep the previous night was assessed only in the morning. Reminder emails were sent each day around the time participants would be completing the diaries. Participants accessed the online diaries by logging into a secure website where they were presented with a series of questions. Prior to recruitment, this study was approved by the Institutional Review Board (IRB) at Stanford University.

MATERIALS

Daily emotional experience

In each of the morning and evening diaries, participants rated on a 7-point scale that ranged from *not at all* to *extremely* the degree to which they were currently feeling each of 14 emotions. The list of emotions included terms commonly used in emotion research and covered each quadrant of the affective circumplex. Specifically, there were 7 positive emotions, including happiness (a prototypical pleasant emotion), 3 high arousal states (enthusiastic, excited, proud), and 3 low arousal states (calm, content, relaxed), as well as 7 negative emotions, including sadness (a prototypical unpleasant emotion), 2 high arousal states (angry and anxious/worried), 2 low arousal states (bored and fatigued), and 2 other states of particular interest in old age (lonely and regretful). These emotion terms were presented together on one screen in a randomized order at each assessment point.

Daily sleep

At each morning assessment, participants rated the quality of their sleep the previous night ($1 =$ *very bad* to $7 =$ *very good*) and indicated their subjective sleep quantity by rating how much they slept the previous night ($1 =$ *not at all* to $5 =$ *a lot*). They also listed the number of hours they slept the previous night.

Physical health

Participants completed a comprehensive health questionnaire (Hultsch et al., 1993) that assessed multiple facets of physical health, including self-rated overall health ($M = 3.15$, $SD = 1.22$), illness episodes ($M = 2.41$, $SD = 1.82$), instrumental health ($M = 1.28$, $SD = 2.63$), chronic illnesses (weighted by severity rating, $M = 1.92$, $SD = 2.15$), and number of medications ($M = 1.51$, $SD = 1.54$). An index of physical health was computed by averaging scores across these five dimensions (alpha $= 0.70$). Higher scores indicate poorer physical health.

Verbal fluency

To assess verbal fluency, participants were asked to verbally list as many animals as possible in 90 s. This is a widely used measure that has been shown to be strongly associated with general intellectual ability (Lindenberger et al., 1993).

Morningness

Individual differences in morningness were assessed using the 5-item brief Morningness-Eveningness Questionnaire (MEQ; Adan and Almirall, 1991). This scale is well-validated and has been extensively used in younger and older adults samples. An example item is, "At what time of the day do you think that you reach your "feeling best" peak?" To determine overall ratings of morningness-eveningness, each question is given a scaled score and then these scores are summed. Higher scores indicate greater morningness.

RESULTS

DATA REDUCTION AND ANALYTIC APPROACH

Emotion indices

The data we report represent the intensity of emotion reports[2]. In addition to examining specific emotions, we computed composites to represent the degree to which participants reported positive and negative emotional experience on each occasion. The positive emotion composite was created by averaging momentary ratings across calm, content, enthusiastic, excited, happy, proud, and relaxed (alpha= 0.89). The negative emotion composite was created by averaging momentary ratings across angry, anxious/worried, bored, fatigued, sad, regretful, and lonely (alpha= 0.83). Descriptive statistics for these emotion composites and the specific emotions appear in **Table 1**.

Analytic approach

To examine age differences in daily emotion, we conducted multilevel modeling using the linear MIXED MODELS function in SPSS. We tested a three-level model, in which time of day (AM or PM) was nested within days and days were nested within persons. Maximum likelihood (ML) estimation was used to account for missing data. Age effects were tested with linear and quadratic age terms. Time of day (morning = 0, evening = 1) and its interaction with each of the age components were also included as predictors. Age was correlated with poorer physical health ($r = 0.25$, $p < 0.05$) and lower verbal fluency ($r = -0.20$, $p < 0.05$), so health and fluency were included in the models as time invariant covariates. Results are reported as unstandardized MLM coefficients in **Table 2**.

To better understand potential interactions between time of day and age, we also fit a model with random intercept, linear age, and quadratic age components separately for morning and evening emotion (controlling for physical health and verbal fluency). Results are reported as unstandardized MLM coefficients in **Table 3**.

[2]In our prior experience sampling work we report frequencies based on endorsements greater than 1 for specific emotions (Carstensen et al., 2000, 2011). A relatively similar pattern of findings emerged when using this frequency index rather than the intensity based one we focus on here. The most notable difference was fewer interactions between Age and Time of Day (the only one that remained significant was for enthusiasm). In addition, there were no longer Time of Day effects for pride, sadness, and anxiety, but all the other Time of Day effects remained significant and a new one emerged, namely contentment was reported more often in the morning than in the evening ($\gamma = -0.0125$, $p < 0.05$). Importantly, all the age effects remained significant except for happiness ($p = 0.16$).

Table 1 | Descriptive statistics for emotional experience in the morning and the evening.

	Intensity of experience				Frequency of experience			
	Mean	***SD***	**Min.**	**Max.**	**Mean**	***SD***	**Min.**	**Max.**
AM POSITIVE	**4.36**	**0.94**	**1.74**	**6.77**	**0.94**	**0.10**	**0.46**	**1.00**
Happy	4.74	1.13	1.33	7.00	0.97	0.11	0.22	1.00
Content	4.88	1.08	1.50	7.00	0.98	0.08	0.30	1.00
Calm	4.88	1.01	2.10	7.00	0.98	0.06	0.60	1.00
Relaxed	4.71	1.09	2.07	7.00	0.98	0.05	0.71	1.00
Enthusiastic	3.98	1.29	1.00	7.00	0.92	0.19	0.00	1.00
Excited	3.56	1.26	1.00	6.80	0.87	0.23	0.00	1.00
Proud	3.79	1.52	1.00	7.00	0.87	0.25	0.00	1.00
AM NEGATIVE	**1.76**	**0.63**	**1.00**	**3.99**	**0.35**	**0.27**	**0.00**	**1.00**
Sad	1.48	0.66	1.00	4.10	0.26	0.32	0.00	1.00
Bored	1.46	0.67	1.00	3.70	0.25	0.32	0.00	1.00
Fatigued	2.47	1.16	1.00	6.10	0.61	0.37	0.00	1.00
Anxious	2.37	1.16	1.00	5.60	0.57	0.37	0.00	1.00
Angry	1.32	0.54	1.00	4.00	0.17	0.27	0.00	1.00
Lonely	1.59	0.78	1.00	4.90	0.31	0.34	0.00	1.00
Regretful	1.62	0.98	1.00	5.30	0.29	0.37	0.00	1.00
PM POSITIVE	**4.30**	**0.92**	**2.06**	**6.57**	**0.93**	**0.11**	**0.49**	**1.00**
Happy	4.84	1.10	1.60	6.90	0.98	0.07	0.44	1.00
Content	4.90	1.06	1.30	7.00	0.98	0.08	0.30	1.00
Calm	4.86	1.04	2.22	7.00	0.98	0.07	0.60	1.00
Relaxed	4.74	1.04	1.78	7.00	0.98	0.06	0.56	1.00
Enthusiastic	3.57	1.31	1.00	6.60	0.88	0.22	0.00	1.00
Excited	3.24	1.22	1.00	6.40	0.83	0.26	0.00	1.00
Proud	3.93	1.47	1.00	7.00	0.89	0.23	0.00	1.00
PM NEGATIVE	**1.89**	**0.68**	**1.00**	**4.04**	**0.38**	**0.26**	**0.00**	**1.00**
Sad	1.56	0.81	1.00	5.36	0.27	0.33	0.00	1.00
Bored	1.58	0.81	1.00	4.20	0.30	0.35	0.00	1.00
Fatigued	3.23	1.39	1.00	6.60	0.76	0.32	0.00	1.00
Anxious	2.17	1.08	1.00	6.00	0.53	0.37	0.00	1.00
Angry	1.41	0.61	1.00	3.71	0.20	0.28	0.00	1.00
Lonely	1.69	1.05	1.00	5.40	0.30	0.38	0.00	1.00
Regretful	1.60	0.82	1.00	4.70	0.30	0.35	0.00	1.00

AM indicates the morning assessment and PM indicates the evening assessment. Intensity of experience represents average emotion ratings across the 10-day sampling period. Frequency of emotion represents the percent of occasions that participants reported experiencing an emotion to any degree (i.e., greater than the 1 on the rating scale) across the 10-day sampling period.

In preliminary analyses, we tested for effects of gender, SES and ethnicity on positive and negative emotion. There were no main effects of these demographic variables in predicting emotional experience, nor did they moderate the effects of age on emotion. However, there were gender differences in the effects of Time of Day for both positive emotion (Gender × Time of Day $= -0.1674$, $p < 0.05$) and negative emotion (Gender × Time of Day $= 0.1899$, $p < 0.01$). Compared to the morning, women reported feeling less positive emotion ($\gamma = -0.2196$, $p < 0.01$) and more negative emotion in the evening ($\gamma = 0.2220$, $p < 0.01$); however, there were no Time of Day effects for men (positive emotion: $\gamma = -0.0521$, $p = 0.24$; negative emotion: $\gamma = 0.0321$, $p = 0.35$). In addition, for negative emotion, the interaction between age and time of day varied based on gender (Gender × Age^2 × Time of Day: $\gamma = -0.0004$, $p < 0.05$; Age^2 × Time of Day for men: $\gamma = 0.0002$, $p < 0.01$; Age^2 × Time of Day for women: $\gamma = -0.0002$, $p < 0.05$), as well as based on SES (SES × Age × Time of Day: $\gamma = -0.0056$, $p < 0.01$) and ethnicity (Ethnicity × Age × Time of Day: $\gamma = 0.0058$, $p < 0.01$). Age moderated the effect of Time of Day on negative emotion among African-Americans ($\gamma = -0.0045$, $p < 0.05$) and blue collar workers ($\gamma = -0.0047$, $p < 0.01$), but not among European-Americans ($\gamma = 0.0002$, $p = 0.86$) and white collar workers ($\gamma = 0.0009$, $p = 0.39$); specifically, the tendency for participants to feel more negative emotion in the evening than in the morning was attenuated among older African-Americans and older blue-collar workers.

AGE EFFECTS

Age was linearly associated with more overall positive emotion ($\gamma = 0.0141$, $p < 0.01$) and less negative emotion ($\gamma = -0.0061$,

Table 2 | Results of multilevel analyses testing the effects of age and time of day on daily emotion.

Fixed effects estimates	Intercept	Age	Age^2	Time of Day	Time × Age	Time × Age^2	Health	Fluency
POSITIVE								
Happy	4.7056 (0.1309)	0.0140 (0.0048)**	0.0000 (0.0003)	−0.0063 (0.0496)	−0.0005 (0.0018)	0.0003 (0.0000)**	−0.5137 (0.1347)**	−0.1205 (0.0886)
Content	4.8204 (0.1281)	0.0153 (0.0047)**	0.0002 (0.0003)	−0.0716 (0.0525)	−0.0027 (0.0019)	0.0002 (0.0001)*	−0.4009 (0.1315)**	0.0078 (0.0865)
Calm	4.9099 (0.1225)	0.0151 (0.0045)**	0.0000 (0.0002)	−0.0903 (0.0575)	−0.0023 (0.0020)	0.0002 (0.0001)$^+$	−0.3326 (0.1248)**	0.0381 (0.0821)
Relaxed	4.8582 (0.1267)	0.0205 (0.0047)**	−0.0004 (0.0003)	−0.0944 (0.0591)	−0.0086 (0.0021)**	0.0004 (0.0001)**	−0.3029 (0.1291)*	0.0262 (0.0850)
Enthusiastic	4.0590 (0.1472)	0.0225 (0.0054)**	−0.0002 (0.0003)	−0.5139 (0.0576)**	0.0050 (0.0020)*	0.0003 (0.0001)*	−0.4827 (0.1513)**	−0.0713 (0.0995)
Excited	3.5770 (0.1492)	0.0048 (0.0055)	0.0000 (0.0003)	−0.3560 (0.0587)**	0.0040 (0.0021)$^+$	0.0000 (0.0001)	−0.4265 (0.1534)**	−0.1834 (0.1009)$^+$
Proud	3.9011 (0.1827)	0.0062 (0.0067)	−0.0003 (0.0004)	0.1625 (0.0410)**	−0.0044 (0.0018)*	0.0000 (0.0001)	−0.2324 (0.1897)	−0.3412 (0.1248)*
NEGATIVE								
Sad	1.5833 (0.0912)	−0.0022 (0.0034)	−0.0003 (0.0002)	0.1346 (0.0423)**	−0.0027 (0.0015)$^+$	−0.0002 (0.0000)$^+$	0.0761 (0.0930)	0.0432 (0.0612)
Bored	1.4836 (0.0919)	−0.0068 (0.0034)*	0.0000 (0.0002)	0.1050 (0.0390)**	−0.0021 (0.0014)	0.0000 (0.0000)	0.0268 (0.0941)	−0.0327 (0.0619)
Fatigued	2.4868 (0.1453)	−0.0145 (0.0053)**	0.0000 (0.0003)	0.6548 (0.0705)**	−0.0006 (0.0025)	0.0003 (0.0001)*	0.5508 (0.1478)**	0.1630 (0.0972)$^+$
Anxious	2.3964 (0.1396)	−0.0065 (0.0051)	0.0000 (0.0003)	−0.1869 (0.0573)**	0.0017 (0.0020)	0.0000 (0.0001)	0.0250 (0.1432)	−0.0698 (0.0942)
Angry	1.3914 (0.0703)	−0.0047 (0.0026)$^+$	−0.0002 (0.0001)	0.1341 (0.0420)**	−0.0015 (0.0015)	−0.0001 (0.0000)	0.1044 (0.0703)	−0.0590 (0.0463)
Lonely	1.6722 (0.1276)	−0.0029 (0.0047)	−0.0001 (0.0003)	0.0540 (0.0427)	−0.0011 (0.0015)	0.0000 (0.0000)	0.0802 (0.1319)	−0.0626 (0.0868)
Regretful	1.7191 (0.1002)	−0.0052 (0.0037)	−0.0004 (0.0002)$^+$	0.0021 (0.0431)	−0.0005 (0.0015)	0.0000 (0.0000)	0.1490 (0.1026)	−0.0062 (0.0675)

Unstandardized estimates are presented with standard errors in parentheses. Age is centered at age 54 years; Time of day coded 0 for morning, and 1 for evening; Physical health and verbal fluency Z-scored.

$^+p < 0.10$; $^*p < 0.05$; $^{**}p < 0.01$.

$p < 0.05$). In terms of positive specific emotions, older adults reported feeling more happy ($\gamma = 0.0140, p < 0.01$) and more of each of the low arousal positive emotions, including content ($\gamma = 0.0153, p < 0.01$), calm ($\gamma = 0.0151, p < 0.01$), and relaxed ($\gamma = 0.0205, p < 0.01$). In addition, there was an age-related increase in enthusiasm ($\gamma = 0.0225, p < 0.01$), but there were not significant age differences for the two other higher arousal positive emotions (excitement: $\gamma = 0.0048, p = 0.39$; pride: $\gamma = 0.0062, p = 0.36$). In terms of specific negative emotions, older adults only reported feeling less bored ($\gamma = -0.0068, p < 0.05$) and less fatigued ($\gamma = -0.0145, p < 0.01$) than did younger adults. Age was unrelated to reports of sadness ($\gamma = -0.0022, p = 0.51$), loneliness ($\gamma = -0.0029, p = 0.54$), and regret ($\gamma = -0.0052, p = 0.16$), as well as high arousal negative emotions, anxiety ($\gamma = -0.0065, p = 0.21$) and anger ($\gamma = -0.0047, p = 0.069$). There were no significant quadratic effects of age.

TIME OF DAY EFFECTS

Participants reported less positive emotion ($\gamma = -0.1372, p < 0.01$) and more negative emotion ($\gamma = 0.1288, p < 0.01$) in the evenings compared to mornings. Specifically, compared to the mornings, in the evenings participants' reported less enthusiasm ($\gamma = -0.5139, p < 0.01$) and excitement ($\gamma = -0.3560, p < 0.01$), as well as more sadness ($\gamma = 0.1346, p < 0.01$), boredom ($\gamma = 0.1050, p < 0.01$), fatigue ($\gamma = 0.6549, p < 0.01$), and anger ($\gamma = 0.1341, p < 0.01$). Two exceptions to the general pattern of reduced well-being at the end of the day were pride and anxiety. Pride was experienced more ($\gamma = 0.1625, p < 0.01$) and anxiety was experience less ($\gamma = -0.1869, p < 0.01$) in the evenings than in the mornings. Happiness ($\gamma = -0.0063, p = 0.90$) and low arousal positive emotions (content: $\gamma = -0.0716, p = 0.17$; calm: $\gamma = -0.0903, p = 0.12$; relaxed: $\gamma = -0.0944, p = 0.11$) did not differ by time of day, nor did loneliness ($\gamma = 0.0540, p = 0.21$) or regret ($\gamma = 0.0021, p = 0.96$).

MODERATION OF AGE EFFECTS BY TIME OF DAY

The effect of age on emotional experience varied somewhat as a function of when emotion as assessed, especially for positive states. There were significant interactions between time of day and age for all of the positive emotions (although the effects were only marginal for calm and excited). However, the nature of this interaction varied across the specific emotions. For instance, as shown in **Figure 1**, older adults enhanced experience of relaxation was greater in the morning than the evening (Time of Day × Age: $\gamma = -0.0086, p < 0.01$), whereas their increased experience of enthusiasm showed the reverse pattern (i.e., it was stronger in the evening; Time of Day × Age: $\gamma = 0.0050, p < 0.05$). Notably, as shown in **Table 3**, at both times of day older adults reported feeling significantly more relaxed (morning: $\gamma = 0.0201, p < 0.01$; evening: $\gamma = 0.0123, p < 0.05$) and enthusiastic (morning: $\gamma = 0.0224, p < 0.01$; evening: $\gamma = 0.0275, p < 0.05$) than younger people. Time also moderated the effect of age on happiness (Time of Day × Age^2: $\gamma = 0.0003, p < 0.01$) and contentment (Time of Day × Age^2: $\gamma = 0.0002, p < 0.05$), such that there was more of a quadratic (accelerated) age effect in the evening than in the morning (see **Figure 2**). However, there were significant linear effects of age on happiness and contentment at both time points

Table 3 | Results of multilevel analyses testing the effects of age on morning and evening emotion.

Fixed effects estimates	Intercept	Age	Age^2	Health	Fluency
AM POSITIVE					
Happy	4.7033 (0.1332)	0.0136 (0.0049)**	0.0001 (0.0003)	−0.5104 (0.1396)**	−0.1597 (0.0919)+
Content	4.8159 (0.1308)	0.0144 (0.0048)**	0.0002 (0.0003)	−0.3684 (0.1371)**	−0.0542 (0.0902)
Calm	4.9092 (0.1219)	0.0152 (0.0045)**	0.0000 (0.0002)	−0.3459 (0.1278)**	0.0234 (0.0841)
Relaxed	4.8576 (0.1282)	0.0201 (0.0047)**	−0.0004 (0.0003)	−0.3032 (0.1344)*	−0.0024 (0.0885)
Enthusiastic	4.0589 (0.1510)	0.0224 (0.0056)**	−0.0002 (0.0003)	−0.4996 (0.1583)**	−0.0846 (0.1042)
Excited	3.5805 (0.1547)	0.0046 (0.0057)	0.0000 (0.0003)	−0.4338 (0.1621)**	−0.1849 (0.1067)+
Proud	3.9012 (0.1853)	0.0058 (0.0068)	−0.0003 (0.0004)	−0.2404 (0.1943)	−0.3898 (0.1278)**
AM NEGATIVE					
Sad	1.5829 (0.0825)	−0.0024 (0.0030)	−0.0003 (0.0002)+	0.0666 (0.0864)	0.0223 (0.0569)
Bored	1.4816 (0.0832)	−0.0063 (0.0031)*	0.0000 (0.0002)	−0.0048 (0.0872)	−0.0241 (0.0574)
Fatigued	2.4868 (0.1410)	−0.0137 (0.0052)*	0.0000 (0.0003)	0.4161 (0.1478)**	0.0954 (0.0973)
Anxious	2.3930 (0.1463)	−0.0064 (0.0054)	0.0000 (0.0003)	−0.0142 (0.1534)	−0.1155 (0.1009)
Angry	1.3929 (0.0676)	−0.0045 (0.0025)+	−0.0002 (0.0001)	0.0713 (0.0709)	−0.0565 (0.0467)
Lonely	1.6725 (0.1247)	−0.0025 (0.0046)	−0.0001 (0.0003)	0.0526 (0.1307)	−0.0518 (0.0860)
Regretful	1.7168 (0.0974)	−0.0051 (0.0036)	−0.0004 (0.0002)+	0.1317 (0.1021)	−0.0179 (0.0672)
PM POSITIVE					
Happy	4.7009 (0.1299)	0.0139 (0.0048)**	0.0004 (0.0003)	−0.5158 (0.1361)**	−0.0812 (0.0896)
Content	4.7525 (0.1269)	0.0135 (0.0047)**	0.0004 (0.0003)	−0.4309 (0.1330)**	0.0689 (0.0875)
Calm	4.8197 (0.1270)	0.0128 (0.0047)**	0.0001 (0.0003)	−0.3149 (0.1331)*	0.0529 (0.0876)
Relaxed	4.7633 (0.1275)	0.0123 (0.0047)*	0.0000 (0.0003)	−0.2975 (0.1338)*	0.0561 (0.0880)
Enthusiastic	3.5436 (0.1511)	0.0275 (0.0056)**	0.0000 (0.0003)	−0.4644 (0.1584)**	−0.0572 (0.1042)
Excited	3.2169 (0.1486)	0.0089 (0.0055)	0.0000 (0.0003)	−0.4192 (0.1557)**	−0.1818 (0.1025)+
Proud	4.0631 (0.1817)	0.0023 (0.0067)	−0.0004 (0.0004)	−0.2238 (0.1905)	−0.2921 (0.1254)*
PM NEGATIVE					
Sad	1.7190 (0.1004)	−0.0047 (0.0037)	−0.0004 (0.0002)*	0.0848 (0.1052)	0.0645 (0.0693)
Bored	1.5902 (0.1007)	−0.0093 (0.0037)*	0.0000 (0.0002)	0.0584 (0.1055)	−0.0410 (0.0695)
Fatigued	3.1408 (0.1633)	−0.0158 (0.0060)*	0.0002 (0.0003)	0.6816 (0.1711)**	0.2306 (0.1126)*
Anxious	2.2126 (0.1371)	−0.0048 (0.0051)	−0.0001 (0.0003)	0.0631 (0.1437)	−0.0228 (0.0946)
Angry	1.5247 (0.0752)	−0.0065 (0.0028)*	−0.0003 (0.0002)+	0.1365 (0.0787)+	−0.0611 (0.0519)
Lonely	1.7270 (0.1325)	−0.0044 (0.0049)	−0.0001 (0.0003)	0.1071 (0.1390)	−0.0734 (0.0914)
Regretful	1.7227 (0.1028)	−0.0057 (0.0038)	−0.0003 (0.0002)	0.1638 (0.1077)	0.0054 (0.0709)

Unstandardized estimates are presented with standard errors in parentheses. Age is centered at age 54 years; Physical health and verbal fluency Z-scored.
*+$p < 0.10$; *$p < 0.05$; **$p < 0.01$.*

(no quadratic age effects): older adult felt happier and more content than relatively younger adults in both the mornings (happy: $\gamma = 0.0136$, $p < 0.01$; content: $\gamma = 0.0144$, $p < 0.01$) and in the evenings (happy: $\gamma = 0.0139$, $p < 0.01$; content: $\gamma = 0.0135$, $p < 0.01$). For pride, the effect of age was weaker in the evening than in the morning ($\gamma = -0.0044$, $p < 0.05$), but there were not significant age differences at either point in the day (morning: $\gamma = 0.0058$, $p = 0.40$; evening: $\gamma = 0.0023$, $p = 0.74$). Both younger and older people experienced more pride in the evenings than mornings.

Age differences in negative emotion varied less based on time of assessment. There was only a significant interaction for fatigue (Time × Age^2: $\gamma = 0.0003$, $p < 0.05$). As shown in **Figure 2**, the age-related decrease in fatigue flattened at advanced ages for evening emotion more so than for morning emotion (although there were significant linear age effects at both time points). For sadness, age effects were somewhat stronger in the evening: there was a significant quadratic effect of age in the evening (Age^2: $\gamma = -0.0004$, $p < 0.05$) but this effect was not significant in the morning (Age^2: $\gamma = -0.0003$, $p = 0.09$). However, there was not a significant interaction between time of day and age for sadness (Time × Age: $\gamma = -0.0027$, $p = 0.07$; Time × Age^2: $\gamma = -0.0002$, $p = 0.07$). Regardless of age and time of day, individuals reported relatively low levels of sadness (see **Figure 2**). There were not significant interactions between time of day and age for the other negative emotions either, including the higher arousal negative states (anger and anxiety).

ANCILLARY ANALYSES: SLEEP AND MORNINGNESS

We ran additional models that included the measures of sleep (quantity and quality the previous night) and individual differences in morning along with the core predictors (i.e., linear and quadratic age terms, Time of Day, and the interaction between Time of Day and each of the age components) to test whether

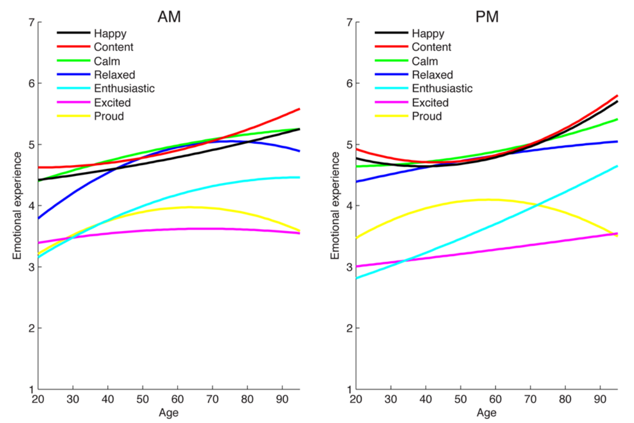

FIGURE 1 | Age differences in positive emotional experience in the morning (AM) and evening (PM).

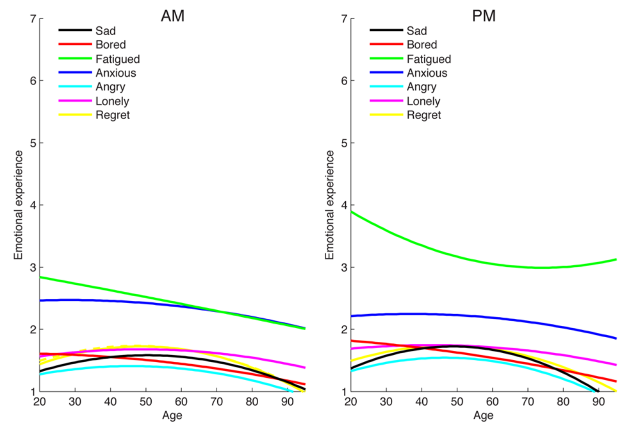

FIGURE 2 | Age differences in negative emotional experience in the morning (AM) and evening (PM).

these variables might explain the effects of Age or the interaction between Age and Time of Day. The sleep variables were included together as day-level predictors; morningness was included as a person-level predictor along with its interaction with Time of Day.

Older adults reported better subjective sleep quantity (Age: $\gamma = 0.0091$, $p < 0.001$) and quality (Age: $\gamma = 0.0109$, $p < 0.01$); for number of hours slept, there was a quadratic age effect indicating that middle-aged adults slept fewer hours than did relatively younger and older adults (Age: $\gamma = -0.0049$, $p = 0.27$; Age^2: $\gamma = 0.0008$, $p < 0.01$). Individuals who reported better sleep quality the previous night felt more of each of the positive emotions (happy: $\gamma = 0.0795$, $p < 0.01$; content: $\gamma = 0.0849$, $p < 0.01$; calm: $\gamma = 0.1062$, $p < 0.001$; relaxed: $\gamma = 0.0867$, $p < 0.01$; enthusiastic: $\gamma = 0.0882$, $p < 0.01$; excited: $\gamma = 0.0920$, $p < 0.01$; pride: $\gamma = 0.0592$, $p < 0.05$) and less of each of the negative emotion (sadness: $\gamma = -0.1059$, $p < 0.001$; anger: $\gamma = -0.0442$, $p < 0.05$; boredom: $\gamma = -0.0398$, $p < 0.05$; fatigue: $\gamma = -0.1713$, $p < 0.001$; lonely: $\gamma = -0.0572$, $p < 0.01$; regret: $\gamma = -0.0732$, $p < 0.01$) except anxiety ($\gamma = -0.0474$, $p = 0.083$). Importantly, however, the effects of Age and the Age × Time of Day interactions remained intact when the sleep variables were included as covariates. Only the age effect for boredom became marginal when controlling for sleep ($\gamma = -0.0065$, $p = 0.059$).

As expected, older adults scored higher on morningness ($r = 0.40$). However, when both Age and Morningness were included as predictors of emotional experience, all the effects of Age and the Age × Time of Day interactions remained significant. The only significant main effect of Morningness was for anger: individuals higher on morningness reported feeling less angry ($\gamma = -0.1052$, $p < 0.05$). There were also significant Morningness × Time of Day interactions for calm ($\gamma = 0.1135$, $p < 0.01$), relaxed ($\gamma = 0.1013$, $p < 0.05$), and enthusiastic ($\gamma = -0.0861$, $p < 0.05$): individuals higher in morningness reported feeling relatively more calm and relaxed in the evening (compared to the morning) and more enthusiastic in the morning (compared to the evening). Overall, these findings suggest that sleep patterns and individual differences in morningness do not explain the age differences in emotional experience observed in this study.

DISCUSSION

Consistent with previous findings, older adults in the present study reported relatively more positive daily emotional experiences than did younger adults. Older adults characterized their emotional experiences as more positive and less negative in both the mornings and evenings. This finding contributes to a compelling literature on age-related improvements in the emotion domain. Older adults' relatively greater emotional well-being has been observed across a wide range of samples and in studies using a wide variety of methods. Whether emotions are sampled randomly throughout the course of a week, studied in the laboratory or recalled at the end of the day or from the day before, age advantages reliably appear. Evidence about the specific motions that drive these age differences is far more mixed. In some studies, greater positive experience accounts for age differences. In others, less negative experience accounts for differences. Findings from several recent studies suggest that these variations may be due to differences in methodological approaches and the measures used to assess emotion.

In the present study, we aimed to capture a more differentiated view of emotional experience across specific positive and negative emotions early and late in the day. We expected that age differences would be more pronounced for low arousal emotions, given previous findings (Kessler and Staudinger, 2009; Scheibe et al., 2013) and theory (Charles, 2010), specifically contentions stemming from the strengths and vulnerabilities integration model (SAVI) that high arousal states may be unpleasant for older adults. Sampling a range of emotions that represented all four quadrants of the affective circumplex, we asked participants spanning in age from young adulthood to very old age to describe how calm, content, enthusiastic, excited, happy, proud, relaxed, angry, anxious/worried, bored, fatigued, sad, regretful, and lonely they felt every morning and evening across ten days. The hypothesis that age differences would be most apparent for low arousal positive emotions was largely supported. Of the seven positive emotions sampled, older people reported greater experience of all of them except two high arousal emotions, namely excitement and pride. However, among negative emotions, only two distinguished age: older adults reported feeling less bored and less fatigued. No differences by age were observed for any of the high arousal negative emotions (viz., anger, anxiety/worry). We expect that this may be due, in part, to a relatively lesser reports of negative emotions. Notably, these age differences in emotional experience held when taking into account physical health and cognition, as well as sleep patterns and individual difference in morningness.

Considering time of day, even more complexity was observed. Participants generally felt more negative and less positive in the evenings than they did in the mornings. However, interactions between age and time of day did not follow a conceptually meaningful pattern. The age benefit for relaxation was stronger in the mornings than evenings, for example, but this interaction was not observed for calm or content. In addition, older adults were more likely to report increased enthusiasm compared to younger adults in the evening, but other high arousal positive emotions did not show this same trajectory. The time of day effects also varied somewhat based on demographic factors. Only women showed a decline in emotional well-being across the day (i.e., less positive emotion and more negative emotion in the evening than in the morning). In addition, the increase in negative emotional experience at the end of the day was attenuated in old age for African Americans and blue-collar workers, but not for European Americans and white collar workers. Thus, the present set of findings leave answers to many questions about time of day equivocal. Still, they suggest that some of the seeming inconsistencies across findings related to aging and emotion might be at least partially be explained by the specific emotions sampled and time of day. Measures that focus exclusively on high arousal terms (e.g., PANAS) can be expected to find weaker age differences, missing important age-related increases in lower arousal positive emotion, perhaps especially so if sessions are run later in the day.

Past work based on experience sampling suggested that age differences are weaker for emotional intensity than emotion frequency (e.g., Carstensen et al., 2000, 2011). Carstensen et al. concluded that although older adults may experience negative emotions less often, when they do experience these emotions they are felt just as intensely. In the present study, however, we observed differences in intensity of emotional experience in the mornings and evenings and the pattern of findings did not change when we analyzed frequency instead of intensity. Unlike Carstensen et al.'s experience sampling project, in the present study, we compared only two time points: emotional experience upon waking in the morning and immediately before bedtime. One of the advantages of focusing on waking and bedtime is that age differences in environmental factors are likely smaller than in the middle of day (when younger and older adults engage in very different types of activities). Still, many interesting experiences in life occur in between mornings and evenings (indeed, the most intense emotional experiences likely occur then), and age differences may be more pronounced mid-day (when older adults have relatively more opportunities to be selective).

Differences in findings as a function of sample size and related statistical power also merit thoughtful consideration. Studies that rely on very large samples (e.g., Mroczek and Kolarz, 1998; Stone et al., 2010) are more likely to find significant age differences because they have the statistical power to detect very small effects. For instance, the widely reported increase in positive emotion observed by Mroczek and Kolarz (1998) was not meaningfully different from the non-significant increase reported by Carstensen et al. (2000, 2011). Thus, some apparent difference in findings about age-related shifts in emotion reflect statistical power. Similarly, in the present study and prior experience sampling research from our group, we observe very low rates of high arousal negative emotions regardless of age. Non-significant findings in frequency and intensity may mask other potential differences in the nature and influence of such emotions in daily life.

In the present study, age was largely unrelated to the experience of high arousal states, regardless of valence. For instance, age differences in negative emotional experience were driven by less intense, low arousal emotions, rather than declines in anger or anxiety. Reasoning from the vantage point of SAVI (Charles, 2010), low arousal emotions may be easier to manage and, thus, older adults are more successful in regulating them. This interpretation is also consistent with findings that suggest a lack of age differences in high arousal positive emotions (Lawton et al., 1992; Kessler and Staudinger, 2009; Scheibe et al., 2013). Scheibe et al. (2013), for example, found that older adults reported a greater preference for experiencing low arousal positive emotion relative to high arousal positive emotion than did younger adults. Whether or not high and low arousal emotions show distinct developmental trajectories and, if confirmed, the reasons for such differences remains highly speculative and demands targeted investigation.

Overall, the findings from the present study underscore the importance of carefully considering the emotions sampled and the time of assessment when examining emotional experience. Age-related changes in emotional well-being may be more pronounced for certain emotional states and at certain times of day.

ACKNOWLEDGMENTS

This research was supported by National Institute on Aging grant R37 AG008816 awarded to Laura L. Carstensen and F32 AG034783 awarded to Tammy English. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institute on Aging or the National Institutes of Health.

REFERENCES

Adan, A., and Almirall, H. (1991). Horne and ostberg morningness-eveningness questionnaire: a reduced scale. *Pers. Individ. Dif.* 12, 241–253. doi: 10.1016/0191-8869(91)90110-W

Biss, R. K., and Hasher, L. (2012). Happy as a lark: Morning-type younger and older adults are higher in positive affect. *Emotion* 12, 437–441. doi: 10.1037/a0027071

Carstensen, L. L., Pasupathi, M., Mayr, U., and Nesselroade, J. R. (2000). Emotional experience in everyday life across the adult life span. *J. Pers. Soc. Psychol.* 79, 644–655. doi: 10.1037/0022-3514.79.4.644

Carstensen, L. L., Turan, B., Scheibe, S., Ram, N., Ersner-Hershfield, H., Samanez-Larkin, G. R., et al. (2011). Emotional experience improves with age: evidence based on over 10 years of experience sampling. *Psychol. Aging* 26, 21–33. doi: 10.1037/a0021285

Charles, S. T. (2010). Strength and vulnerability integration: a model of emotional well-being across adulthood. *Psychol. Bull.* 136, 1068–1091. doi: 10.1037/a0021232

Charles, S. T., and Carstensen, L. L. (2013). "Emotion regulation and aging," in *Handbook of Emotion Regulation, 2nd Edn.,* ed J. J. Gross (New York, NY: Guilford Press), 203–218.

Charles, S. T., Reynolds, C. A., and Gatz, M. (2001). Age-related differences and change in positive and negative affect over 23 years. *J. Pers. Soc. Psychol.* 80, 136–151. doi: 10.1037/0022-3514.80.1.136

Consedine, N. S., and Magai, C. (2006). "Emotional development in adulthood: a developmental functionalist review and critique," in *Handbook of Adult Development and Learning,* ed C. Hoare (New York, NY: Oxford University Press), 123–148.

Davey, A., Halverson, C. F., Jr., Zonderman, A. B., and Costa, P. T. Jr. (2004). Change in depressive symptoms in the baltimore longitudinal study of aging. *J. Gerontol. Ser. B Psychol. Sci. Soc. Sci.* 59, P270–P277. doi: 10.1093/geronb/59.6.P270

Diener, E., and Suh, E. M. (1998). "Subjective well-being and age: an international analysis," in *Annual Review of Gerontology and Geriatrics, Vol. 17, Focus on Emotion and Adult Development,* eds K. W. Schaie and M. P. Lawton (New York, NY: Springer), 304–324.

Fiske, A., Gatz, M., and Pedersen, N. (2003). Depressive symptoms and aging: the effects of illness and non-health-related events. *J. Gerontol. Ser. B Psychol. Sci. Soc. Sci.* 58, P320–P328. doi: 10.1093/geronb/58.6.P320

Gatz, M., Kasl-Godley, J. E., and Karel, M. J. (1996). "Aging and mental disorders," in *Handbook of the Psychology of Aging, 4th Edn.,* eds J. E. Birren and K. W. Schaie (San Diego, CA: Academic Press), 365–382.

Hultsch, D. F., Hammer, M., and Small, B. J. (1993). Age differences in cognitive performance in later life: relationships to self-reported health and activity life style. *J. Gerontol. Psychol. Sci.* 48, 1–11. doi: 10.1093/geronj/48.1.P1

Kessler, E. M., and Staudinger, U. M. (2009). Affective experience in adulthood and old age: the role of affective arousal and perceived affect regulation. *Psychol. Aging* 24, 349–362. doi: 10.1037/a0015352

Knight, M., and Mather, M. (2013). Look out—it's your off-peak time of day! Time of day matters more for alerting than for orienting or executive attention. *Exp. Aging Res.* 39, 305–321. doi: 10.1080/0361073X.2013.779197

Kunzmann, U., Little, T. D., and Smith, J. (2000). Is age-related stability of subjective well-being a paradox? Cross-sectional and longitudinal evidence from the Berlin Aging Study. *Psychol. Aging* 15, 511–526. doi: 10.1037/0882-7974.15.3.511

Larsen, R. J., and Diener, E. (1992). "Promises and problems with the circumplex model of emotion," in *Review of Personality and Social Psychology: Emotion*, ed M. S. Clark (Newbury Park, CA: Sage), 25–59.

Lawton, M. P., Kleban, M. H., Rajagopal, D., and Dean, J. (1992). Dimensions of affective experience in three age groups. *Psychol. Aging* 7, 171–184. doi: 10.1037/0882-7974.7.2.171

Lindenberger, U., Mayr, U., and Kliegl, R. (1993). Speed and intelligence in old age. *Psychol. Aging* 8, 207–220. doi: 10.1037/0882-7974.8.2.207

Mather, M., and Carstensen, L. L. (2005). Aging and motivated cognition: the positivity effect in attention and memory. T*rends in Cognitive Science,* 9, 496–502. doi: 10.1016/j.tics.2005.08.005

Mroczek, D. K., and Kolarz, C. M. (1998). The effect of age on positive and negative affect: a developmental perspective on happiness. *J. Pers. Soc. Psychol.* 75, 1333–1349. doi: 10.1037/0022-3514.75.5.1333

Muraven, M., Tice, D. M., and Baumeister, R. F. (1998). Self-control as a limited resource: regulatory depletion patterns. *J. Pers. Soc. Psychol.* 74, 774–789. doi: 10.1037/0022-3514.74.3.774

Ochsner, K. N., Silvers, J. A., and Buhle, J. T. (2012). Functional imaging studies of emotion regulation: a synthetic review and evolving model of the cognitive control of emotion. *Ann. N.Y. Acad. Sci.* 1251, E1–E24. doi: 10.1111/j.1749-6632.2012.06751.x

Phillips, L. H., Henry, J. D., Hosie, J. A., and Milne, A. B. (2008). Effective regulation of the experience and expression of negative affect in old age. *J. Gerontol. Psychol. Sci.* 63B, 138–145. doi: 10.1093/geronb/63.3.P138

Reed, A. E., and Carstensen, L. L. (2012). The theory behind the age-related positivity effect. *Front. Psychol.* 3:339. doi: 10.3389/fpsyg.2012.00339

Riediger, M., Schmiedek, F., Wagner, G. G., and Lindenberger, U. (2009). Seeking pleasure and seeking pain: differences in prohedonic and contra-hedonic motivation from adolescence to old age. *Psychol. Sci.* 20, 1529–1535. doi: 10.1111/j.1467-9280.2009.02473.x

Ross, C. E., and Mirowsky, J. (2008). Age and the balance of emotions. *Soc. Sci. Med.* 66, 2391–2400. doi: 10.1016/j.socscimed.2008.01.048

Scheibe, S., and Carstensen, L. L. (2010). Emotional aging: recent findings and future trends. *J. Gerontol. Psychol. Sci.* 65B, 135–144. doi: 10.1093/geronb/gbp132

Scheibe, S., English, T., Tsai, J. L., and Carstensen, L. L. (2013). Striving to feel good: ideal affect, actual affect, and their correspondence across adulthood. *Psychol. Aging* 28, 160–171. doi: 10.1037/a0030561

Schieman, S. (1999). Age and anger. *J. Health Soc. Behav.* 40, 273–289. doi: 10.2307/2676352

Stone, A. A., Schwartz, J. E., Broderick, J. E., and Deaton, A. (2010). A snapshot of the age distribution of psychological well-being in the United States. *Proc. Natl. Acad. Sci. U.S.A.* 107, 9985–9990. doi: 10.1073/pnas.1003744107

Watson, D., and Tellegen, A. (1985). Toward a consensual structure of mood. *Psychol. Bull.* 98, 219–235. doi: 10.1037/0033-2909.98.2.219

Yoon, C., May, C. P., and Hasher, L. (1999). "Aging, circadian arousal patterns, and cognition," in *Cognition, Aging, and Self-reports,* eds N. Schwarz, D. C. Park, B. Knaúper, and S. Sudman (Hove: Psychology Press/Erlbaum (UK) Taylor & Francis), 117–143.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 23 December 2013; accepted: 15 February 2014; published online: 06 March 2014.

Citation: English T and Carstensen LL (2014) Emotional experience in the mornings and the evenings: consideration of age differences in specific emotions by time of day. Front. Psychol. ***5****:185. doi: 10.3389/fpsyg.2014.00185*

This article was submitted to Emotion Science, a section of the journal Frontiers in Psychology.

frontiers in PSYCHOLOGY

ORIGINAL RESEARCH ARTICLE
published: 10 April 2014
doi: 10.3389/fpsyg.2014.00296

Age-related differences in neural recruitment during the use of cognitive reappraisal and selective attention as emotion regulation strategies

Eric S. Allard* and Elizabeth A. Kensinger

Cognitive and Affective Neuroscience Laboratory, Department of Psychology, Boston College, Chestnut Hill, MA, USA

Edited by:
Natalie Ebner, University of Florida, USA

Reviewed by:
Natalie Ebner, University of Florida, USA
Nichole Lighthall, Duke University, USA
Brittany Shane Cassidy, Brandeis University, USA

****Correspondence:***
Eric S. Allard, Cognitive and Affective Neuroscience Laboratory, Department of Psychology, Boston College, 140 Commonwealth Avenue, Chestnut Hill, MA 02467, USA
e-mail: eric.allard@bc.edu

The present study examined age differences in the timing and neural recruitment within lateral and medial PFC while younger and older adults hedonically regulated their responses to unpleasant film clips. When analyses focused on activity during the emotional peak of the film clip (the most emotionally salient portion of the film), several age differences emerged. When comparing regulation to passive viewing (combined effects of selective attention and reappraisal) younger adults showed greater regulation related activity in lateral PFC (DLPFC, VLPFC, OFC) and medial PFC (ACC) while older adults showed greater activation within a region DLPFC. When assessing distinct effects of the regulation conditions, an ANOVA revealed a significant Age × Regulation Condition interaction within bilateral DLPFC and ACC; older adults but not young adults showed greater recruitment within these regions for reappraisal than selective attention. When examining activity at the onset of the film clip and at its emotional peak, the timing of reappraisal-related activity within VLPFC differed between age groups: younger adults showed greater activity at film onset while older adults showed heightened activity during the peak. Our results suggest that older adults rely more heavily on PFC recruitment when engaging cognitively demanding reappraisal strategies while PFC-mediated regulation might not be as task-specific for younger adults. Older adults' greater reliance on cognitive control processing during emotion regulation may also be reflected in the time needed to implement these strategies.

Keywords: aging, emotion regulation, fMRI, selective attention, reappraisal

INTRODUCTION

Despite normative declines in several areas of functioning (e.g., cognition and health) older adults report relatively high levels of emotional well-being (Carstensen and Mikels, 2005). One prevailing theory in the psychology of human aging suggests that older adults are motivated to maximize emotional well-being due to limits in future time perspective (Carstensen et al., 1999). Self-report studies have shown that older adults are more motivated to regulate emotion as compared to their younger counterparts (Kennedy et al., 2004; Kliegel et al., 2007). Furthermore, this enhanced motivation can be shown in reported attempts to actively enhance well-being through the use of particular emotion regulation strategies (Gross et al., 1997).

One of the most studied regulatory strategies is cognitive reappraisal. Cognitive reappraisal is a strategy that involves the reinterpretation of a stimulus/situation in order to change its meaning and emotional impact. Reappraisal draws upon processes associated with cognitive control and executive functioning (Ochsner and Gross, 2005). Several neuroimaging studies have identified a series of brain systems involved in active attempts to reappraise affect including dorsolateral, ventrolateral, and dorsomedial prefrontal cortex (PFC) and posterior parietal cortex (Ochsner et al., 2004; Kalisch, 2009; Winecoff et al., 2011; Silvers et al., 2013). These aforementioned regions have been shown to correspond with specific cognitive control processes likely to support emotion regulation (Ochsner and Gross, 2008). In a recent meta-analysis, Buhle et al. (2013) observed activity in regions of dorsolateral (DLPFC), ventrolateral (VLPFC), and dorsomedial (DMPFC) prefrontal cortex during reappraisal tasks. Their results supported predictions that DLPFC activation may support the manipulation of affective appraisals in working memory, VLPFC may aid the selection and inhibition of appraisals (e.g., selecting a non-affective appraisal or positive reappraisal while trying to inhibit a negative appraisal), and DMPFC may reflect processes related to updating the success of chosen appraisals (e.g., was the desired affective state obtained?). Older age is associated with declines in volumetric gray matter in several PFC regions (Raz et al., 2004; Grieve et al., 2005; Fjell et al., 2009), raising questions regarding whether older adults are able to use reappraisal strategies as successfully as younger adults (see Gross et al., 1997; John and Gross, 2004; Urry and Gross, 2010 for this debate).

Very few studies have directly assessed age differences in neural recruitment when performing specific emotion regulation strategies. Current evidence suggests that older adults activate PFC regions to a lesser extent than younger adults during hedonic regulation (e.g., diminishing negative affect) and that this limited activation might relate to older adults' reduced success at deploying reappraisal-type strategies. For instance, Opitz et al.

(2012) had a group of younger and older adults perform hedonic and non-hedonic reappraisal (decrease and increase emotional reactions) in response to negative images in a series of fMRI tasks. In this study, older adults showed reduced DMPFC and VLPFC activation when reappraising negative images as compared to younger adults. Furthermore, diminished activation in VLPFC among older adults was accompanied by difficulty in decreasing negative responses to those images. Similar results were observed in another recent study in which older adults reported more negative affect in response to negative images when attempting to downreglate negative reactions as compared to younger adults (Winecoff et al., 2011). Furthermore, in this study, older adults showed reduced activation in a region of VLPFC when reappraising negative images as compared to younger adults. Taken together, these results suggest that older adults may be less effective than their younger adult counterparts in using reappraisal strategies to decrease negative affect (see also Tucker et al., 2012), perhaps because reappraisal relies on cognitive processes within lateral PFC that diminish with age (e.g., diminished VLPFC recruitment corresponding to a difficulty with inhibiting prepotent negative responses; Silvers et al., 2013).

Although past research has examined the effect of aging on neural mechanisms supporting cognitive reappraisal, less work has assessed the effects of aging on other antecedent strategies that may be less cognitively demanding. In their SOC-ER (selective optimization with compensation in emotion regulation) model, Urry and Gross (2010) proposed that older adults use less cognitively demanding regulatory strategies, such as situation selection/modification or attention deployment, rather than strategies such as reappraisal or suppression that rely heavily on cognitive control processing. This model fits well with evidence that older adults show a "positivity effect" (either positive engagement or negative avoidance) in visual attention in response to emotional stimuli (Isaacowitz et al., 2006), perhaps reflecting older adults' attempts to use selective attention as a regulatory strategy (Isaacowitz et al., 2008, 2009b) because it does not heavily impinge on cognitive resources (Allard et al., 2010). In cases where cognitive resources are constrained (e.g., in divided attention tasks), there is research suggesting that older adults will not/cannot preferentially engage with information in line with presumed emotion regulation goals (see Mather and Knight, 2005; Knight et al., 2007). Thus, emotion regulation processes might proceed more efficiently for older adults in situations where a full complement of cognitive control resources is available.

For the current study, we compared younger and older adults' neural recruitment while implementing two different types of antecedent emotion regulation strategies. We asked participants to regulate their emotions using selective attention or cognitive reappraisal. Given past research demonstrating older adults' diminished recruitment of lateral and medial PFC regions for certain forms of reappraisal as compared to younger adults, and their difficulty in using reappraisal to successfully regulate in real time (Opitz et al., 2012), we expected older adults in our sample to display reductions in the speed or level of recruitment of lateral and medial PFC during emotion regulation. However, it was less clear how the type of emotion regulation strategy would affect younger and older adults' recruitment of PFC regions. We used relatively long (40 s) film clips so we could examine a more protracted time course of emotion regulation. By using stimuli with a long duration, we could adjudicate between three plausible alternative outcomes regarding age-related changes in PFC recruitment. First, there may be a main effect of age, such that regardless of the strategy used, older adults may chronically under-recruit PFC when regulating their emotions, even when given time to implement the strategy. Second, there may be an interaction between age and time course for strategy implementation, such that older adults may require more time to recruit PFC processes, but when given sufficient time, they may recruit them in the same manner as younger adults. This prediction is based on previous evidence suggesting that the implementation of processes assumed to be in the service of emotion regulation (e.g., cognitive disengagement from negative stimuli) might take some time to execute for older adults (Isaacowitz et al., 2009a). Third, older adults' implementation of PFC processes may be affected by the task demands (i.e., type of regulatory strategy), yielding different effects of age and time course for cognitive reappraisal and selective attention.

To examine these alternatives, we recruited a group of younger (18–34) and older (55–85) adults to complete selective attention and cognitive reappraisal tasks during an fMRI scan session. We presented participants with a series of positive, negative, and neutral film clips within three scanning conditions: passive viewing, selective attention, and reappraisal. Emotional film clips were used in order to provide a dynamic, emotionally evocative stimulus set for examining age differences in neural recruitment in response to specific emotion regulation strategies. We focus our main analyses on the downregulation of negative affect in response to negative videos, consistent with the focus of the majority of studies that have compared younger (see meta-analysis by Diekhof et al., 2011) and older adults' neural responsivity to emotional inputs (particularly in the context of reappraisal: Urry et al., 2006, 2009; van Reekum et al., 2007; Opitz et al., 2012).

MATERIALS AND METHODS

PARTICIPANTS

Forty-five younger (25 female, *range* = 18–35 years; $M = 23.40$, $SD = 4.39$) and 42 older adults (25 females, *range* = 55–85; $M = 69.21$, $SD = 8.62$) participated in this study. Eleven younger adults and 12 older adults were excluded from subsequent analyses due to poor data quality (i.e., excessive motion artifacts: greater than ±5 mm of head motion; <20 motion outliers within each scan run as determined by an artifact correction procedure) or a failure to complete all three functional scans. The final sample included 34 younger (16 females, $M = 23.79$, $SD = 4.33$) and 30 older adults (20 females, $M = 68.47$, $SD = 8.14$) who had no history of psychiatric, neurological, or learning disorders nor any history or current use of psychiatric medication. Younger and older adults performed somewhat similarly on a variety of cognitive ability measures (younger adults outperformed older adults on only 2 out of 5 tasks assessing frontal lobe functioning derived from

Table 1 | Additional demographic and cognitive variables.

Variable/Test	Young adults		Older adults		*F*
	M	***SD***	***M***	***SD***	
Education	16.27	1.96	16.37	2.44	0.031
Shipley	33.54	3.01	35.37	3.17	5.07*
Digit back[a]	8.39	2.36	7.87	2.33	0.729
FAS[b]	48.07	10.82	48.03	12.59	0.00
WISC[c]	5.89	0.42	5.23	1.43	5.51*
Arithmetic[d]	15.68	3.39	15.03	2.75	0.638
Mental control[e]	30.69	4.15	26.10	5.49	7.24*

[a–e] *Glisky frontal lobe tasks (Glisky et al., 1995).*

$*p < 0.05$.

Glisky et al. (1995); see **Table 1**). Informed consent was obtained from all participants in accordance with the Boston College Institutional Review Board. All participants received $25/h. for their participation.

STIMULI

We used a series of emotional and neutral film clips as stimuli for the fMRI scan sessions. We focused our analysis for the present study on the neural activity to the negative stimuli. The clips were obtained from television programs, feature films, and documentaries. Positive and negative clips included a variety of emotional scenarios. For instance, positive videos included amusing situations (e.g., standup comedy routine) or more tender/heartwarming scenarios (e.g., a married couple talking about how they first met). Negative videos included fear/sad/disgust scenarios (e.g., a woman being threatened on the phone; a man comforting his dying dog; a man digging through a messy toilet). A separate group of 14 younger and 14 older adults rated each clip on dimensions of valence and arousal. Ratings were made on a scale from 1 (*highly unpleasant, non-arousing*) to 9 (*highly pleasant, highly arousing*). Based on these ratings, a total of 45 clips (18 positive, 18 negative, 9 neutral) were selected for inclusion in the study. Positive and negative videos were matched on ratings of valence and arousal between younger and older adults: Positive-Valence ($M_{young} = 7.31$, $SD = 0.63$; $M_{old} = 7.46$, $SD = 0.81$; $p = 0.45$); Positive-Arousal ($M_{young} = 6.19$, $SD = 0.46$; $M_{old} = 6.60$, $SD = 0.82$; $p = 0.10$); Negative-Valence ($M_{young} = 2.19$, $SD = 0.79$; $M_{old} = 2.12$, $SD = 1.14$; $p = 0.76$); Negative-Arousal ($M_{young} = 7.05$, $SD = 0.79$; $M_{old} = 7.19$, $SD = 0.69$; $p = 0.46$); Neutral-Valence ($M_{young} = 5.28$, $SD = 0.26$; $M_{old} = 5.47$, $SD = 0.39$; $p = 0.20$). For each scan session, the order in which a particular clip was presented (whether it appeared in the passive viewing, selective attention, or reappraisal condition) was randomized across participants. Presentation of the clips was also pseudorandomized within each condition with the caveat that no more than three clips of the same valence were presented consecutively. Stimulus presentation was accomplished using SR Research EyeLink 1000 software (Kanata, Ontario, CA) during the scan session; although this presentation program acquired eye tracking data from participants, the eye tracking data are not reported here.

PROCEDURE

Before entering the MRI scanner, participants were instructed that they would view a series of emotional and neutral film clips during three functional scan runs. Within each run, six positive, six negative, and three neutral clips were presented. Participants were told that they would be given specific instructions on how to view the film clips with a series of instructions presented to them while in the scanner. Each regulation task (passive viewing, selective attention, and reappraisal) was performed within separate scan runs. For the "passive viewing" task, participants were instructed that they would view a series of 15 film clips; they should "view the clips naturally, as if at home watching television." For the selective attention condition, participants were instructed to "focus on areas of the screen that would help increase positive and decrease any negatives feelings/reactions in response to the clips." For the reappraisal condition, participants were provided with hedonic regulation instructions. When presented with negative clips, participants were instructed to utilize their choice of two strategies: detached reappraisal ("Try to distance yourself from the events being portrayed by reminding yourself that what you are viewing is a fictional event; these are just actors portraying a role.") and positive reappraisal ("Try to put a positive spin on the outcome of the event being portrayed. For example, if you see a clip of a car accident, try to imagine that no one was seriously injured/killed, and everyone walked away from the accident relatively unharmed."). We provided these strategies as options for participants given that certain clips might lend themselves to be more easily reinterpreted with one strategy or the other (or perhaps even both).

TRIAL STRUCTURE

A black fixation cross was shown on the center of a gray screen for 10, 12, 14, 16, or 18 s. Each video was presented for 40 s[1]. During the passive viewing condition, the instruction "view" was presented on the bottom of the screen 4-s post-stimulus onset and remained on the screen for 3 s. This timing for the instruction phase has been used in previous research (see Opitz et al., 2012). Using the same timing and screen placement, for the selective attention condition, the instruction "avoid negative" was presented along with the negative videos and for the reappraisal condition, "decrease negative" was presented. In all three conditions, each video was followed by an inter-trial interval consisting of a black fixation cross for an average of 14 s (jittered between 10 and 18 s). The presentation order of the three conditions was varied across participants.

DATA ACQUISITIONAND ANALYSIS

Images were acquired on a 3 Tesla Siemens Tim Trio MRI scanner using a 12-channel head coil. Stimuli were projected onto a screen located at the back of the magnet bore, and

[1]The instructions were embedded within videos for 14 younger and 13 older adults participants across all three conditions, while reappraisal instructions were embedded within videos for all participants. When assessing results from the remaining 20 younger and 17 older adult participants who did not have visual prompts within the selective attention and passive viewing videos, our main results remained relatively unchanged.

participants viewed stimuli using a mirror attached to the head coil. T1-weighted localizer images and a T1-weighted inversion recovery echo planar image required for auto-alignment were collected. Anatomical data were collected with a multiplanar rapidly acquired gradient-echo (MEMPRAGE) sequence ($TR = 2200$ ms; $TEs = 1.64, 3.5, 5.36, 7.22$; flip angle $= 7°$; FOV $= 256 \times 256$ mm; slice thickness $= 1$ mm, no gap; $1 \times 1 \times 1$ mm resolution). Functional images were collected using a T2*-weighted echo-planar imaging (EPI) sequence with the following parameters: $TR = 2000$ ms, $TE = 30$ ms, FOV $= 216$ mm, flip angle $= 85°$. Thirty interleaved near axial slices were collected in a $3 \times 3 \times 3.6$ mm matrix (slice thickness $= 3$ mm with a 20% skip).

Preprocessing and data analysis were conducted in SPM8 (Welcome Department of Cognitive Neurology, London). Preprocessing steps were as follows: slice timing correction; motion correction using a six parameter, rigid body transformation algorithm; normalization to the Montreal Neurological Institute (MNI) template (resampling at 2 mm isotropic voxels); and spatial smoothing using a 8 mm full-width half maximum isotropic Gaussian kernel.

We first incorporated a slow event-related design anchored to the onset of the most emotionally salient portion of each film clip, what we will refer to as the "emotional peak" portion. This peak (assessed in seconds) was determined by the researchers and corroborated by two younger and two older adult naïve raters. An interclass correlation analysis was conducted to assess inter-rater reliability. There was adequate agreement amongst raters for determining the emotional peak ($\alpha = 0.79$). Final peak ratings were determined by the majority consensus among raters (e.g., 3/5 or 4/5 raters) agreeing on a peaks falling within a range of 1–3 s, whereby the average of that range was used as the peak value (in whole seconds). For this first set of analysis, we used a general linear model incorporating task effects for the negative films in the three viewing conditions (passive, selective attention, reappraisal), along with three linear regressors to account for the three runs, at the single subject level. These models were used to create contrasts between conditions of interest. All contrasts utilized an explicit mask that encompassed all of the PFC, anterior cingulate gyrus, and the amygdala (created using MARINA; Walter et al., 2003) in order to focus our analyses on apriori regions of interest.

We contrasted the combined effects of the two regulation conditions relative to passive viewing (selective attention + reappraisal > passive viewing and passive viewing > selective attention + reappraisal), conducting these contrasts both collapsing across the age groups and also separately for each age group. We also conducted an Age × Condition [regulation (selective attention + reappraisal) vs. passive viewing] ANOVA. These first analyses determined potential age similarities and/or differences in neural recruitment when asked to regulate vs. passively view the clips. These initial analyses also addressed our general prediction that older adults would show diminished activation in response to the regulation conditions relative to younger adults.

Next, we assessed distinct effects of the two regulation conditions for younger and older adults. These analyses specifically addressed whether younger and older adults differed in their activity profile as a function of the specific regulatory strategy used. We first examined activation for each age group in contrasts comparing the two regulatory conditions (selective attention > reappraisal and reappraisal > selective attention). To reveal regions that showed an Age (young vs. old) × Regulation Condition (selective attention vs. reappraisal) interaction, we conducted a separate ANOVA.

Although these prior analyses were based on activity at the peak emotional moment of the film clip, a final analytical approach was used to assess whether age differences in the timing of neural activation might contribute to the observed effects. This analytic approach modeled both the instruction-related activity (modeled as an event starting 4-s post-stimulus onset; see Opitz et al., 2012) and peak-emotion activity (modeled as an event occurring at the most emotionally salient portion of the film clip) for the film clips in the selective attention and reappraisal conditions. An ANOVA was used to reveal regions within the amygdala-PFC mask that showed an Age (young vs. old) × Condition (selective attention vs. reappraisal) × Phase (instruction-onset vs. peak-emotion).

For all analyses, differences in activation are reported for regions consisting of at least 10 voxels, active at $p < 0.005$, unless otherwise specified. This combination of threshold and voxel extent has recently been justified as appropriate in studies equally concerned with Type I and Type II error (see Lieberman and Cunningham, 2009), and in the present study represents a more conservative combination because we limited our search space to the amygdala-PFC mask. AlphaSim (B.D. Ward) revealed a slightly higher voxel extent threshold, of 17 voxels, each active at $p < 0.005$, was required to correct for multiple comparisons across this search space at $p < 0.05$. Notations are provided throughout the results tables to indicate clusters that did not reach this voxel extent. For regions that emerged from a Two or Three-Way interaction in any of our ANOVA analyses, we extracted parameter estimates and plotted the activity within a *post-hoc* region of interest (ROI), defining ROIs within Marsbar (Brett et al., 2002) and plotting the activity using REX (downloaded from http://web.mit.edu/swg/rex/) to reveal the basis for the interaction.

RESULTS

IMAGING RESULTS

Effects of passive viewing and emotion regulation separately for younger and older adults at the emotional peak

Again, all analyses focused on negative film clip presentation. We first examined the passive viewing > emotion regulation and emotion regulation > passive viewing contrasts separately for each age group (See **Tables 2A,B** for results when collapsing across age groups). Older adults showed greater activity in left DLPFC, left VLPFC, and OFC for passive viewing relative to emotion regulation (See **Table 2C**). Only one cluster within DLPFC was revealed in the emotion regulation > passive viewing contrast for older adults (See **Table 2D**). For younger adults, the contrast resulting in greater PFC activity was reversed. Only one region of right precentral gyrus was more active in the passive viewing > selective attention contrast (See **Table 2E**). However, several regions emerged in the emotion regulation > passive viewing contrast for younger adults (See **Table 2F**). These included left ACC, left VLPFC, bilateral DLPFC, and bilateral OFC.

Table 2 | Activation across emotion regulation conditions relative to passive viewing.

Brain region	BA	*X*	*Y*	*Z*	*K* extent	*t*-score	$p_{uncorrected}$
A. REGIONS OBSERVED IN THE PASSIVE VIEWING > EMOTION REGULATION CONTRAST (COLLAPSED ACROSS AGE)							
Left post-central gyrus	2	−42	−20	19	40	3.23	0.001
Left precentral gyrus	6+	−40	2	12	11	3.24	0.001
Left superior frontal gyrus (DLPFC)	8+	−16	31	37	14	2.89	0.003
	8/9+	−16	45	36	14	2.96	0.002
B. REGIONS OBSERVED IN THE EMOTION REGULATION > PASSIVE VIEWING CONTRAST (COLLAPSED ACROSS AGE)							
Left superior frontal gyrus*	6	−20	−3	50	30	3.75	0.000
Right middle frontal gyrus	6+	24	−1	48	12	3.12	0.001
Right precentral gyrus*	6	34	2	31	101	3.66	0.000
C. REGIONS OBSERVED IN THE PASSIVE VIEWING > EMOTION REGULATION CONTRAST FOR OLDER ADULTS							
Left inferior frontal gyrus (VLPFC)	45	−51	20	10	33	3.22	0.002
Left superior frontal gyrus (DLPFC)	9	−10	50	36	212	4.03	0.000
Left medial frontal gyrus (DLPFC)	9+	−8	51	18	12	3.12	0.002
Orbitofrontal cortex	10	0	56	3	224	3.89	0.000
D. REGIONS OBSERVED IN THE EMOTION REGULATION > PASSIVE VIEWING CONTRAST FOR OLDER ADULTS							
Middle frontal gyrus (DLPFC)	9	32	15	31	28	3.74	0.000
E. REGIONS OBSERVED IN THE PASSIVE VIEWING > EMOTION REGULATION CONTRAST FOR YOUNGER ADULTS							
Right precentral gyrus	4+	42	−6	18	11	3.30	0.001
F. REGIONS OBSERVED IN THE EMOTION REGULATION > PASSIVE VIEWING CONTRAST FOR YOUNGER ADULTS							
Left anterior cingulate cortex (ACC)	32	−10	21	38	192	4.10	0.000
Left inferior frontal gyrus (VLPFC)	11/47	−34	25	−6	53	3.50	0.001
Left middle frontal gyrus (DLPFC)	46	−44	29	34	44	3.41	0.001
Right middle frontal gyrus (DLPFC)	9/46	42	33	37	252	3.69	0.000
Left orbitofrontal cortex (OFC)	10	−48	48	−9	32	3.48	0.001
Right orbitofrontal cortex (OFC)	10	8	67	10	28	4.19	0.000
G. REGIONS SHOWING AN AGE × CONDITION INTERACTION (COMBINED EMOTION REGULATION VS. PASSIVE VIEWING)							
Left middle frontal gyrus (DLPFC)	9/46	−46	31	42	35	*F-score* 11.89	0.001
Right superior frontal gyrus (DLPFC)	9/46+	44	35	33	11	9.70	0.002
	9/46	28	52	29	152	15.42	0.000

Stereotaxic coordinates based on the Talairach atlas (Talairach and Tournoux, 1988). All coordinates correspond to clusters that met a voxel extent threshold = 17, $p < 0.005$.

**Nearby cluster observed within a separate conjunction analysis (reappraisal > passive viewing masked with selective attention > passive viewing).*

+Cluster did not reach 17-voxel extent threshold to correct for multiple comparisons at $p < 0.005$.

Regions showing an Age × Condition (combined regulation vs. passive viewing) interaction at the emotional peak

An ANOVA confirmed a different activity profile for younger and older adults within three regions of DLPFC (**Table 2G**; **Figure 1A**). When the parameter estimates from these regions were examined, within two regions of right DLPFC (BA 9/46, peak at Talairach coordinates: 28 52 29; BA 9/46, peak at Talairach coordinates: 44 35 33), older adults showed greater activity than younger adults during passive viewing but less activity than younger adults during emotion regulation. Within the region of left DLPFC (BA 9/46, peak at Talairach coordinates: −46 31 32), younger adults but not older adults showed greater activity for emotion regulation relative to passive viewing[2].

Comparing effects of reappraisal and selective attention for younger and older adults at the emotional peak

The previous analysis suggested greater PFC activity for emotion regulation in younger as compared to older adults. However, this could reflect less overlapping activity within the two regulation conditions for older adults. Thus, we next examined activation patterns between the selective attention and reappraisal condition for younger and older adults. Significant activation patterns occurred for different contrast analyses for each age group: reappraisal > selective attention for older adults and selective

[2]It was possible that results of the Age × Condition interactions (both collapsing across regulation condition and separately for selective attention and reappraisal) were primarily driven by age differences in activation within the passive viewing condition. We examined older adult > younger adult and younger adult > older adult contrasts for just the passive viewing condition. Only one significant cluster emerged in these analyses (DLPFC, BA 45/46; Talairach coordinates: 36 26 24), and was observed in the older adult > younger adult contrast. When we used this result as an exclusive mask and reran our interaction analyses, our previous results remained unchanged. This suggests that the observed Age × Condition interactions were not primarily the result of age differences in activation within the passive viewing condition.

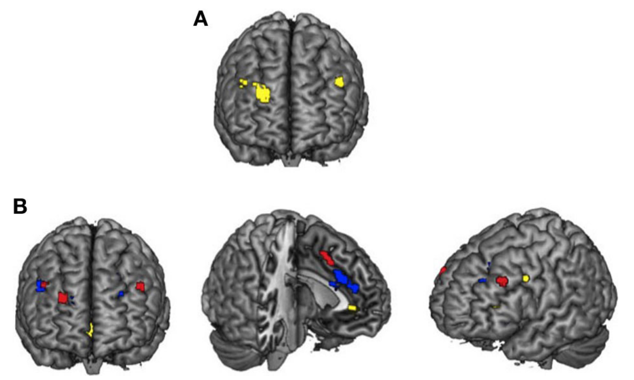

FIGURE 1 | PFC engagement during emotion regulation. DLPFC activation observed for the Age × Combined Regulation interaction analyses **(A)** and overlays of activity for selective attention > reappraisal for younger adults in blue, reappraisal > selective attention for older adults in yellow, and the Age × Regulation Condition interaction in red **(B)**.

attention > reappraisal for younger adults (no significant clusters were observed in the respective opposite contrast for both age groups; **Figure 1B**). For older adults, activation was greater for reappraisal relative to selective attention in posterior cingulate, ACC, bilateral VLPFC, and OFC (See **Table 3A**). For younger adults, activity was greater for selective attention relative to reappraisal in bilateral DLPFC, VLPFC, and DMPFC (See **Table 3B**, **Figure 1B**).

Regions showing an Age × Regulation Condition interaction

A significant Age × Regulation Condition interaction (**Table 3C**, **Figure 1B**) was observed within a region of ACC (BA 32; peak at Talairach coordinate: −4 12 45), right DLPFC (BA 46; peak at Talairach coordinate: 46 31 33), and left DLPFC (BA 9/46; peak at Talairach coordinate: −44 33 32).Although these regions were similar to those revealed in the younger adults' contrast of selective attention > reappraisal, the regions were not overlapping (compare red and blue regions in **Figure 1B**). In each of the regions identified by this ANOVA, younger adults showed similar activation for the two regulation conditions while older adults showed greater activity for reappraisal as compared to selective attention, particularly within the right DLPFC region. Thus, this ANOVA revealed that older adults showed greater differentiation in PFC recruitment for the two regulatory strategies than did younger adults.

Phase analysis: activity at film-onset and emotional-peak

To clarify whether differences noted above might be due to age differences in the timing of regulatory processes, the next analysis examined age differences in activity at instruction-onset and at the emotional peak of the negative videos across the two regulation conditions. An Age × Condition × Phase ANOVA was assessed. Focusing on the three-way interaction, activation was revealed within two regions of VLPFC, although the voxel extent in neither region reached the 10-voxel cutoff ($K = 5$ voxels and 8 voxels); thus, this activity must be interpreted tentatively. Parameter estimates extracted from each VLPFC region(BA 47, peak at Talairach coordinates: 24 25 −13, $p_{\text{uncorrected}} = 0.003$, 8 voxels; −22 31 −8, $p_{\text{uncorrected}} = 0.008$, 5 voxels) revealed that activity was greater for reappraisal than for selective attention during the onset of the video relative to the emotional peak for younger adults (activity at the peak was greater for selective attention than for reappraisal). For older adults, activity within right VLPFC was greater at the emotional peak during reappraisal than selective attention, while activity was greater at the onset for selective attention than reappraisal. Within left VLPFC, onset and peak activity was slightly greater for reappraisal compared to selective attention for older adults (**Figure 2**). These results suggest that, particularly within right VLPFC, compared to younger adults, older adults may have delayed engagement of regulatory processes during reappraisal.

DISCUSSION

The current study investigated the neural mechanisms underlying the hedonic regulation of negative affect in a sample of younger and older adults, examining the effect of regulation strategy (reappraisal vs. selective attention) and the time course of strategy implementation on activity within PFC. We first examined potential overlap across the two age groups in activity that was stronger for emotion regulation relative to passive viewing. These results revealed little overlap in PFC regions supporting regulation relative to passive viewing when collapsing our results across age. More age differences than similarities emerged when we examined the age groups separately. The combined effects of the two regulation strategies relative to passive viewing were more robust for younger adults, with activation observed within lateral and medial PFC. This suggests that younger adults may have more common activation within regions implicated in cognitive emotion regulation networks for both strategies than older adults. Thus, older adults might be showing more differentiation with selective attention and reappraisal.

Indeed, when examining distinct effects for each regulation strategy, further age differences emerged. In some PFC regions, there was a complete age-related reversal in the strategy that utilized the most activity: older adults recruited lateral and medial PFC regions more for reappraisal relative to selective attention while younger adults recruited lateral and medial PFC regions more for selective attention relative to reappraisal. Older adults' greater reliance on lateral and medial PFC activation for reappraisal than selective attention could relate to the heightened cognitive demand that older adults must meet in order to engage these challenging reappraisal strategies. If older adults' implementation of reappraisal processes is less efficient, they may require greater neural engagement than younger adults in order to achieve the same successful regulatory outcome.

Partial support for the interpretation that older adults' reappraisal processes may be engaged less efficiently than younger adults' comes from our phasic analysis of the time course of strategy implementation. This analysis revealed that within two regions of VLPFC, activity was greater for reappraisal than for selective attention during the instruction onset of negative videos for younger adults but not until the emotional-peak of the videos for older adults.

Table 3 | Activation within the reappraisal and selective attention conditions for younger and older adults.

Brain region	BA	X	Y	Z	K extent	t-score	$p_{uncorrected}$
A. REGIONS OBSERVED IN THE REAPPRAISAL > SELECTIVE ATTENTION CONTRAST FOR OLDER ADULTS							
Left posterior cingulate cortex	31	−16	−33	40	28	4.34	0.000
Left inferior frontal gyrus (VLPFC)	44+	−50	9	35	15	3.21	0.002
	45	−38	34	11	55	3.81	0.000
Left orbitofrontal cortex (OFC)	11	−20	40	−12	41	3.92	0.000
Right inferior frontal gyrus (VLPFC)	47	32	42	−12	25	3.60	0.001
Anterior cingulate cortex (ACC)	32	6	43	−2	302	4.35	0.000
B. REGIONS OBSERVED IN THE SELECTIVE ATTENTION > REAPPRAISAL CONTRAST FOR YOUNGER ADULTS							
Left middle frontal gyrus (DLPFC)	6	−22	10	47	68	3.57	0.001
	9/46	−24	40	27	25	3.13	0.002
Anterior cingulate cortex (ACC)*	32	−10	21	30	282	4.06	0.000
Left inferior frontal gyrus (VLPFC)*	47	−36	25	−5	119	3.53	0.001
Right middle frontal gyrus (DLPFC)*	9/46	48	29	30	45	3.37	0.001
Left superior frontal gyrus (DMPFC)	8	−12	31	43	62	3.79	0.000
C. REGIONS SHOWING AN AGE × REGULATION CONDITION INTERACTION (REAPPRAISAL VS. SELECTIVE ATTENTION)							
Left middle frontal gyrus (DLPFC)	9/46	−44	33	32	19	*F*-score 7.00	0.001
Right middle frontal gyrus (DLPFC)	46+	46	31	33	11	6.13	0.003
Anterior cingulate gyrus (ACC)	32	−4	12	45	77	6.47	0.002

Stereotaxic coordinates based on the Talairach atlas (Talairach and Tournoux, 1988). All coordinates correspond to clusters that met a voxel extent threshold = 17, $p < 0.005$ (no significant clusters revealed in the opposite contrast for each age group).

**Nearby cluster observed within a separate conjunction analysis (selective attention > reappraisal masked with selective attention > passive viewing).*

+Cluster did not reach 17-voxel extent threshold to correct for multiple comparisons at $p < 0.005$.

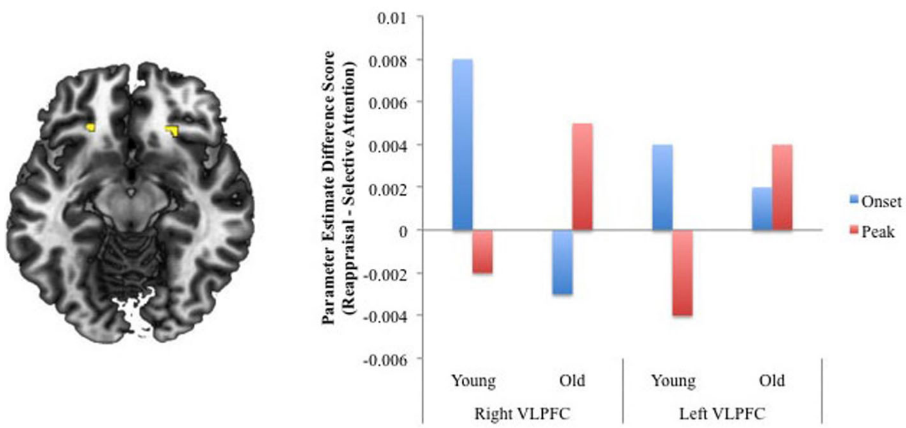

FIGURE 2 | Regions revealed in the Age × Regulation × Phase interaction analysis. For ease of presentation, we created difference scores for activity at the onset and emotional peak for the selective attention and regulation conditions separately for younger and older adults. Scores greater than 0 indicate greater reappraisal-related activity and scores less than zero indicate greater selective attention-related activity.

This time course shift might reflect different possibilities for older adults' reappraisal deployment. For one, it is possible that delayed reappraisal-related recruitment in PFC reflects neural decrements related to cognitive slowing (Salthouse, 1995). Such neural decrements would suggest that reappraisal processes require significant effort for older adults to deploy, consistent with behavioral evidence arguing that older adults need sufficient time to recruit cognitive resources for preferentially avoiding negative stimuli (Isaacowitz et al., 2009a). It is plausible that older adults needed more time to select out their preferred reappraisal tactic once they made the initial appraisal (Wager et al., 2008), or they might have had difficulty inhibiting prepotent negative affective responses when attempting to reappraise (Winecoff et al., 2011). Because reappraisal is often most effective when processes are deployed before the emotional response has reached its peak (Goldin et al., 2008), older adults may need to recruit more processes than younger adults because they are attempting to regulate a more intense or mature emotional response. In contrast, by engaging processes earlier, younger adults may successfully curtail the development of a strong emotional response and thereby minimize the cognitive resources required for reappraisal. This latter explanation may also relate to why, for younger adults, selective attention may recruit more activity within PFC regions at the emotional peak than reappraisal: early-acting reappraisal may negate the need for subsequent reappraisal during a film clip, whereas attentional selection of hedonic information at an early time point within a film is unlikely to meaningfully impact the need to select hedonic information at a later time point.

In contrast to a neural-limitation account for the timing effects among older adults, it is possible that the time course of PFC recruitment reflects intentional discretion in terms of strategy deployment. While it is possible that reappraisal is more effective before an emotional response reaches its peak, older adults might be sophisticated enough to wait for the necessary moment when a reappraisal strategy needs to be deployed (i.e., when the most emotionally salient portion of an event/stimulus has emerged). Previous studies assessing reappraisal strategies have not done so over a protracted time course (typically only 2–8 s for stimulus presentation; Winecoff et al., 2011; Opitz et al., 2012) or with more dynamic stimuli (static images as opposed to video stimuli). Thus, older adults might be more motivated to engage in proficient reappraisal strategies with stimuli that are particularly engaging and over a time course suited for full reappraisal deployment. Overall, while these timing effects should be interpreted with caution given the small cluster extents revealed in the analysis, the results are suggestive of the importance of considering age differences not only in the magnitude of recruited PFC processes but also in the time course over which the processes are recruited. Future research should attempt to adjudicate how potential age-related differences in the timing of regulation deployment reflects aspects of ability vs. motivation in the successful use of particular emotion regulation strategies.

In addition to revealing that there are some PFC regions that show age reversals in strategy recruitment, the results also demonstrated that there are PFC regions (namely DLPFC and ACC) in which older adults show more differentiation in the strategy (i.e., reappraisal) that elicits the most activity. Younger adults recruited these to downregulate negative affect by both reappraisal and selective attention. Although prior research has not compared reappraisal and selective attention, this general recruitment in younger adults is consistent with studies that have observed heightened lateral PFC, particularly DLPFC, both when reappraising negative stimuli (Ochsner et al., 2002; Phan et al., 2005; McRae et al., 2010) and when examining attentional deployment strategies (including selective attention; see Silvers et al., 2013, and see Corebetta and Shulman, 2002, for a review of the role of DLPFC in attentional control). Conversely, older adults did not show much in the way of overlapping effects of the two regulation strategies within PFC regions. At first glance, these results seem to be in line with recent work suggesting that older adults do not activate lateral PFC regions to the same extent as younger adults when instructed to regulate negative affective responses (Winecoff et al., 2011; Opitz et al., 2012). However, the lack of PFC recruitment when examining common activation of the two regulation conditions as compared to passive viewing appears instead to relate to discrepant activation patterns across the two strategies when compared to passive viewing for older adults and may suggest that the method of hedonic regulation has a greater impact on the neural processes recruited by older adults than by younger adults.

To our knowledge, only two studies (Winecoff et al., 2011; Opitz et al., 2012) have compared samples of younger and older adults during fMRI investigations of cognitive emotion regulation, and both of these studies employed conditions examining age differences in neural activation when hedonically regulating via reappraisal. Results from these two studies revealed greater lateral and medial PFC activation during reappraisal of negative stimuli in younger as compared to older adults. Conversely, our results suggest that older adults show greater reappraisal related activity within lateral and medial PFC. Although our findings could be consistent with work suggesting that emotion regulation is particularly taxing to cognitive control resources for older adults (see Kryla-Lighthall and Mather, 2009; Urry and Gross, 2010), thus requiring more PFC processes, and more time, for older adults to achieve regulation, the question remains as to why our results seem at odds with those of Opitz et al. and Winecoff et al. One possibility, as mentioned earlier, could be the timing of neural recruitment observed. Whether older adults seem to under-recruit or over-recruit PFC regions during reappraisal may depend on whether activity is measured early in a trial or late in a trial. There are also other design and methodological differences that could lead older adults in our study to implement PFC processes in the service of reappraisal. Most notably, we employed dynamic, emotional film clips, as opposed to static IAPS images. Not only were these films temporally extended, allowing older adults time to implement the regulatory strategies, they might have been particularly engaging. This might have enhanced older adults' ability or motivation to utilize a reappraisal strategy that they report using effectively in their daily lives (see Gross et al., 1997; John and Gross, 2004). Support for this possibility, that older adults successfully use reappraisal when motivated to do so, comes from behavioral evidence revealing that older adults might actually be more successful than younger adults at down-regulating affective responses to negative videos (Scheibe and Blanchard-Fields, 2009). It will be interesting for future research to compare older adults' regulatory processes across different time courses and with stimuli that elicit varying motivations for regulation.

LIMITATIONS AND FUTURE DIRECTIONS

Some limitations should be noted. For one, we did not control the type of reappraisal tactic used by younger and older adults. This provides potential confounds in determining differences in activation patterns across age groups for reappraisal. It is possible that the different age groups were utilizing different strategies (see Shiota and Levenson, 2009, for a discussion), but we have no way of knowing which strategy was most preferred or if more than one strategy was engaged during any specific trial. Whether older adults recruit regulatory control regions within the PFC when utilizing more of a positive reframing rather than a distancing/detached reappraisal tactic needs to be addressed further in the future.

We were also limited by our assessment of regulatory outcomes. We did not examine regulation success on a trial-by-trial basis, which would help determine how well individuals engaged a particular strategy when the efficacy of that strategy was likely to still be in mind. We did assess self-reported affect at the end of each scan run, whereby both younger and older adults showed a modest increase in mood after the regulation runs as compared to passive viewing. However, no effects of age or interactions with age and regulation condition emerged. Furthermore, when we assessed stimulus ratings for the video clips after the fMRI session, there was no effect of regulation condition on the ratings. Although it could be susceptible to demand characteristics, assessing affect (i.e., self-reported mood and stimulus ratings) at the end of each trial might have provided a more accurate portrayal as to how well individuals actually performed the strategy and whether the strategy was effective in eliciting the desired regulatory response/outcome.

Finally, while positive videos were also presented to participants, they were not included in the present paper. This was mainly for logistical reasons and to keep our focus on testing hypotheses relevant to the limited literature in this area that has focused on the regulation of negative affect. However, future analyses will include an assessment of age effects on hedonic regulation of positive stimuli to more fully assess how individuals regulate toward positive affective states (by either increasing positive and/or decreasing negative affect).

In spite of the aforementioned limitations, the present study emphasizes that older adults do recruit lateral and medial PFC regions in response to regulatory instructions. They recruit PFC regions more for reappraisal than for selective attention, perhaps reflecting their need to compensate for less efficient or effective cognitive control processing in order to engage challenging regulation strategies. Consistent with this interpretation that older adults' PFC recruitment during reappraisal may be less efficient than younger adults', the timing of reappraisal-related activity in VLPFC was delayed for older adults compared to younger adults. While older adults implemented VLPFC processes the moment reappraisal instructions were given, older adults did not deploy them until the experienced emotion was likely at its peak. The present findings suggest a need for future research to disentangle age differences in the neural underpinnings involved in executing a variety of cognitive emotion regulation strategies and to examine the implementation of these processes over extended time intervals. This line of research may help to explain which strategies are going to be more or less effective for younger and older adults in achieving regulatory success and enhanced emotional well-being.

ACKNOWLEDGMENTS

This research was supported in part by NIMH Grant MH080833, the Dana Foundation, and a Searle Scholar Program Grant awarded to Elizabeth A. Kensinger. We would like to thank Halle Zucker, Jenny Wong, John Morris, Kelly Durham, Meghan Horn, Sarah Scott, John Ksander, and Nadia Haddara for their assistance with participant recruitment and data collection. The authors have no competing interests to disclose.

REFERENCES

Allard, E. S., Wadlinger, H. A., and Isaacowitz, D. M. (2010). Positive gaze preferences in older adults: assessing the role of cognitive effort with pupil dilation. *Aging Neuropsychol. C* 17, 296–311. doi: 10.1080/13825580903265681

Brett, M., Anton, J. L., Valbregue, R., and Poline, J. B. (2002). "Region of interest analysis using an SPM toolbox [abstract]," in *8th International Conference on Functional Mapping of the Human Brain* (Sendai), CD-ROM in *Neuroimage* 16.

Buhle, J. T., Silvers, J. A., Wager, T. D., Lopez, R., Onyemekwu, C., Kober, H., et al. (2013). Cognitive reappraisal of emotion: a meta-analysis of human neuroimaging studies. *Cereb. Cortex*. doi: 10.1093/cercor/bht154. [Epub ahead of print].

Carstensen, L. L., Isaacowitz, D. M., and Charles, S. T. (1999). Taking time seriously: a theory of socioemotional selectivity. *Am. Psychol.* 54, 165–181. doi: 10.1037/0003-066X.54.3.165

Carstensen, L. L., and Mikels, J. A. (2005). At the intersection of emotion and cognition. *Curr. Dir. Psychol. Sci.* 14, 117–121. doi: 10.1111/j.0963-7214.2005.00348.x

Corebetta, M., and Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nat. Rev. Neurosci.* 3, 201–215. doi: 10.1038/nrn755

Diekhof, E. K., Geier, K., Falkai, P., and Gruber, O. (2011). Fear is only as deep as the mind allows: a coordinate-based meta-analysis of neuroimaging studies on the regulation of negative affect. *Neuroimage* 58, 275–285. doi: 10.1016/j.neuroimage.2011.05.073

Fjell, A. M., Walhovd, K. B., Fennema-Notestine, C., McEvoy, L. K., Hagler, D. J., Holland, D., et al. (2009). One-year brain atrophy evident in healthy aging. *J. Neurosci.* 29, 15223–15231. doi: 10.1523/JNEUROSCI.3252-09.2009

Glisky, E. L., Polster, M. R., and Routhieaux, B. C. (1995). Double dissociation between item and source memory. *Neuropsychology* 9, 229–235. doi: 10.1037//0894-4105.9.2.229

Goldin, P. R., McRae, K., Ramel, W., and Gross, J. J. (2008). The neural bases of emotion regulation: reappraisal and suppression of negative emotion. *Biol. Psychiatry* 63, 577–586. doi: 10.1016/j.biopsych.2007.05.031

Grieve, S. M., Clark, C. R., Williams, L. M., Peduto, A. J., and Gordon, E. (2005). Preservation of limbic and paralimbic structures in aging. *Hum. Brain Mapp.* 25, 391–401. doi: 10.1002/hbm.20115

Gross, J. J., Carstensen, L. L., Pasupathi, M., Tsai, J., Gottestam, K., and Hsu, A. Y. C. (1997). Emotion and aging: experience, expression, and control. *Psychol. Aging* 12, 590–599. doi: 10.1037/0882-7974.12.4.590

Isaacowitz, D. M., Allard, E. S., Murphy, N. A., and Schlangel, M. (2009a). The time course of age related preferences toward positive and negative stimuli. *J. Gerontol. B Psychol. Sci. Soc. Sci.* 64B, 188–192. doi: 10.1093/geronb/gbn036

Isaacowitz, D. M., Toner, K., Goren, D., and Wilson, H. R. (2008). Looking while unhappy: mood congruent gaze in young adults, positive gaze in older adults. *Psychol. Sci.* 19, 848–853. doi: 10.1111/j.1467-9280.2008.02167.x

Isaacowitz, D. M., Toner, K., and Neupert, S. D. (2009b). Use of gaze for real-time mood regulation: effects of age and attentional functioning. *Psychol. Aging* 24, 989–994. doi: 10.1037/a0017706

Isaacowitz, D. M., Wadlinger, H. A., Goren, D., and Wilson, H. R. (2006). Selective preference in visual fixation away from negative images in old age? an eye tracking study. *Psychol. Aging* 21, 40–48. doi: 10.1037/0882-7974.21.1.40

John, O. P., and Gross, J. J. (2004). Healthy and unhealthy emotion regulation: personality processes, individual differences, and lifespan development. *J. Pers.* 72, 1301–1334. doi: 10.1111/j.1467-6494.2004.00298.x

Kalisch. R. (2009). The functional neuroanatomy of reappraisal: time matters. *Neurosci. Biobehav. Rev.* 33, 1215–1226. doi: 10.1016/j.neubiorev.2009.06.003

Kennedy, Q., Mather, M., and Carstensen, L. L. (2004). Aging and emotional memory: the forgettable nature of negative images for older adults. *Psychol. Sci.* 15, 208–214. doi: 10.1111/j.0956-7976.2004.01503011.x

Kliegel, M., Jäger, T., and Phillips, L. H. (2007). Emotional development across adulthood: differential age-related emotional reactivity and emotion regulation in a negative mood induction procedure. *Int. J. Aging Hum. Dev.* 64, 217–244. doi: 10.2190/U48Q-0063-3318-1175

Knight, M., Seymour, T. L., Gaunt, J. T., Baker, C., Nesmith, K., and Mather, M. (2007). Aging and goal-directed emotional attention: distraction reverses emotional biases. *Emotion* 7, 705–714. doi: 10.1037/1528-3542.7.4.705

Kryla-Lighthall, N., and Mather, M. (2009). "The role of cognitive control in older adults' emotional well-being," in *Handbook of Theories of Aging, 2nd Edn,* eds V. Berngtson, D. Gans, N. Putney, and M. Silverstein (New York, NY: Springer Publishing), 323–344.

Lieberman, M. D., and Cunningham, W. A. (2009). Type I and Type II error concerns in fMRI research: re-balancing the scale. *Soc. Cogn. Affect. Neuroscie.* 4, 423–428. doi: 10.1093/scan/nsp052

Mather, M., and Knight, M. (2005). Goal-directed memory: the role of cognitive control in older adults' emotional memory. *Psychol. Aging* 20, 554–570. doi: 10.1037/0882-7974.20.4.554

McRae, K., Hughes, B., Chopra, S., Gabrieli, J. D., Gross, J. J., and Ochsner, K. N. (2010). The neural bases of distraction and reappraisal. *J. Cognitive Neurosci.* 22, 248–262. doi: 10.1162/jocn.2009.21243

Ochsner, K. N., Bunge, S. A., Gross, J. J., and Gabrieli, J. D. (2002). Re-thinking feelings: an fMRI study of the cognitive regulation of emotion. *J. Cognitive Neurosci.* 14, 1215–1229. doi: 10.1162/089892902760807212

Ochsner, K. N., and Gross, J. J. (2005). The cognitive control of emotion. *Trends Cogn. Sci.* 9, 242–249. doi: 10.1016/j.tics.2005.03.010

Ochsner, K. N., and Gross, J. J. (2008). Cognitive emotion regulation: insights from social cognitive and affective neuroscience. *Curr. Dir. Psychol. Sci.* 17, 153–158. doi: 10.1111/j.1467-8721.2008.00566.x

Ochsner, K. N., Ray, R. D., Robertson, E. R., Cooper, J. C., Chopra, S., Gabrieli, J. D. E., et al. (2004). For better or for worse: neural systems supporting the cognitive down- and up-regulation of negative emotion. *Neuroimage* 23, 483–499. doi: 10.1016/j.neuroimage.2004.06.030

Opitz, P. C., Rauch, L. C., Terry, D. P., and Urry, H. L. (2012). Prefrontal mediation of age differences in cognitive reappraisal. *Neurobiol. Aging* 33, 645–655. doi: 10.1016/j.neurobiolaging.2010.06.004

Phan, K. L., Fitzgerald, D. A., Nathan, P. J., Moore, G. J., Uhde, T. W., and Tancer, M. E. (2005). Neural substrates for voluntary suppression of negative affect: a functional magnetic resonance imaging study. *Biol. Psychiatry* 57, 210–219. doi: 10.1016/j.biopsych.2004.10.030

Raz, N., Gunning, F. M., Head, D., Rodrigue, K. M., Williamson, A., and Acker, J. D. (2004). Aging, sexual dimorphism, and hemispheric asymmetry of the cerebral cortex: replicability of regional differences in volume. *Neruobiol. Aging* 25, 377–396. doi: 10.1016/S0197-4580(03)00118-0

Salthouse, T. A. (1995). Influence of processing speed on adult age differences in learning. *Swiss J. Psychol.* 54, 102–112.

Scheibe, S., and Blanchard-Fields, F. (2009). Effects of regulating emotions on cognitive performance: what is costly for young adults is not so costly for older adults. *Psychol. Aging* 24, 217–223. doi: 10.1037/a0013807

Silvers, J. A., Buhle, J. T., and Ochsner, K. N. (2013). "The neuroscience of emotion regulation: basic mechanisms and their role in development, aging, and psychopathology," in *The Handbook of Cognitive Neuroscience, Vol. 1*, eds K. N. Oshsner and S. M. Kosslyn (New York, NY: Oxford University Press), 52–78. doi: 10.1093/oxfordhb/9780199988709.013.0004

Shiota, M., and Levenson, R. (2009). Effects of aging on experimentally instructed detached reappraisal, positive reappraisal, and emotional behavior suppression. *Psychol. Aging* 24, 890–900. doi: 10.1037/a0017896

Talairach, J., and Tournoux, P. (1988). *Co-planar Stereotaxic Atlas of the Human Brain: 3-D Proportional System: An Approach to Cerebral Imaging*. New York, NY: Thieme.

Tucker, A. M., Feuerstein, R., Mende-Siedlecki, P., Ochsner, K. N., and Stern, Y. (2012). Double dissociation: circadian off-peak times increase emotional reactivity; aging impairs emotion regulation via reappraisal. *Emotion* 12, 869–874. doi: 10.1037/a0028207

Urry, H. L., and Gross, J. J. (2010). Emotion regulation in older age. *Curr. Dir. Psychol. Sci.* 19, 352–357. doi: 10.1177/0963721410388395

Urry, H. L., van Reekum, C. M., Johnstone, T., and Davidson, R. (2009). Individual differences in some (but not all) medial prefrontal regions reflect cognitive demand while regulating unpleasant emotion. *Neuroimage* 47, 852–863. doi: 10.1016/j.neuroimage.2009.05.069

Urry, H. L., van Reekum, C. M., Johnstone, T., Kalin, N. H., Thurow, M. E., Schaefer, H. S., et al. (2006). Amygdala and ventromedial prefrontal cortex are inversely coupled during regulation of negative affect and predict the diurnal pattern of cortisol secretion among older adults. *J. Neurosci.* 26, 4415–4425. doi: 10.1523/JNEUROSCI.3215-05.2006

van Reekum, C. M., Johnstone, T., Urry, H. L., Thurow, M. E., Schaefer, H. S., Alexander, A. L., et al. (2007). Gaze fixations predict brain activation during the voluntary regulation of picture-induced negative affect. *Neuroimage* 36, 1041–1055. doi: 10.1016/j.neuroimage.2007.03.052

Wager, T. D., Davidson, M., Hughes, B. L., Lindquist, M. A., and Ochsner, K. N. (2008). Prefrontal-subcortical pathways mediating successful emotion regulation. *Neuron* 59, 1037–1050. doi: 10.1016/j.neuron.2008.09.006

Walter, B., Blecker, C., Kirsch, P., Sammer, G., Schienle, A., Stark, R., et al. (2003). "MARINA: an easy to use tool for the creation of masks for region of interest analyses [abstract]," in *Presented at the 9th International Conference on Functional Mapping of the Human Brain* (New York, NY), CD-Rom in *Neuroimage* 19.

Winecoff, A., LaBar, K. S., Madden, D. J., Cabeza, R., and Huettel, S. A. (2011). Cognitive and neural contributors to emotion regulation in aging. *Soc. Cogn. Affect. Neurosci.* 6, 165–176. doi: 10.1093/scan/nsq030

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 09 November 2013; accepted: 21 March 2014; published online: 10 April 2014.

Citation: Allard ES and Kensinger EA (2014) Age-related differences in neural recruitment during the use of cognitive reappraisal and selective attention as emotion regulation strategies. Front. Psychol. ***5****:296. doi: 10.3389/fpsyg.2014.00296*

This article was submitted to Emotion Science, a section of the journal Frontiers in Psychology.

frontiers in PSYCHOLOGY

ORIGINAL RESEARCH ARTICLE
published: 28 July 2014
doi: 10.3389/fpsyg.2014.00681

The role of arousal in the spontaneous regulation of emotions in healthy aging: a fMRI investigation

Sanda Dolcos[1]*, Yuta Katsumi[1] and Roger A. Dixon[2]

[1] Department of Psychology, University of Illinois at Urbana-Champaign, Champaign, IL, USA
[2] Department of Psychology, University of Alberta, Edmonton, AB, Canada

Edited by:
Natalie Ebner, University of Florida, USA

Reviewed by:
Hakan Fischer, Stockholm University, Sweden
Heather L. Urry, Tufts University, USA
Anne Krendl, Indiana University Bloomington, USA

***Correspondence:**
Sanda Dolcos, Department of Psychology, University of Illinois at Urbana-Champaign, 603 E. Daniel Street, Champaign, IL 61820, USA
e-mail: sdolcos@illinois.edu

Despite ample support for enhanced affective well-being and emotional stability in healthy aging, the role of potentially important dimensions, such as the emotional arousal, has not been systematically investigated in neuroimaging studies. In addition, the few behavioral studies that examined effects of arousal have produced inconsistent findings. The present study manipulated the arousal of pictorial stimuli to test the hypothesis that preserved emotional functioning in aging is modulated by the level of arousal, and to identify the associated neural correlates. Young and older healthy participants were presented with negative and neutral pictures, which they rated for emotional content, while fMRI data were recorded. There were three main novel findings regarding the neural mechanisms underlying the processing of negative pictures with different levels of arousal in young and older adults. First, the common engagement of the right amygdala in young and older adults was driven by high arousing negative stimuli. Second, complementing an age-related reduction in the subjective ratings for low arousing negative pictures, there were opposing patterns of activity in the rostral/ventral anterior cingulate cortex (ACC) and the amygdala, which showed increased vs. decreased responses, respectively, to low arousing negative pictures. Third, increased spontaneous activity in the ventral ACC/ventromedial prefrontal cortex (vmPFC) in older adults was linked to reduced ratings for low arousing negative pictures. Overall, these findings advance our understanding of the neural correlates underlying processing of negative emotions with different levels of arousal in the context of enhanced emotional functioning in healthy aging. Notably, the results support the idea that older adults have emotion regulation networks chronically activated, in the absence of explicit induction of the goal to regulate emotions, and that this effect is specific to low arousing negative emotions.

Keywords: emotion control, spontaneous emotion regulation, brain imaging

INTRODUCTION

Aging is associated with well-known co-morbidities and losses, but also with relatively high levels of emotional well-being. The idea of relatively well-preserved emotional processing in aging is supported by evidence showing that older adults tend to (a) pay attention to and remember more positive information (Charles et al., 2003; Mather and Carstensen, 2003; Isaacowitz et al., 2006) and (b) show reduced processing of negative information compared to young adults (Wood and Kisley, 2006; Gruhn et al., 2007).

Prominent models of emotion identify valence and arousal as fundamental components of emotion (see Bradley and Lang, 2000, for a review). Valence refers to the direction of an emotional response (positive or negative), whereas arousal refers to the magnitude of the response (exciting, agitating, or calming, subduing; Russell, 1980). Empirical evidence shows that these two emotional dimensions are not independent of each other (Ito et al., 1998; Lang et al., 1998; Libkuman et al., 2007; but see Ribeiro et al., 2007). Rather, they form a V ("boomerang")-shaped function, with the unpleasant pictures tending to be more highly arousing than pleasant stimuli, and both pleasant and unpleasant pictures being more arousing than neutral stimuli. Considerable evidence supports the "boomerang" shape in averaged data on arousal and valence ratings of people's reactions to affective visual stimuli, such as the International Affective Picture System (IAPS) (e.g., Lang et al., 1992, 1998; Lang, 1995; Bradley and Lang, 2007). Despite substantial support for the preserved emotional function in aging, the role of emotional arousal has not been systematically investigated in neuroimaging studies. Moreover, the few behavioral studies that included examinations of arousal have produced inconsistent findings. For instance, a study investigating age-differences in memory for arousing and non-arousing words (Kensinger, 2008) showed that older adults remembered more positive than negative low-arousing words, whereas young adults showed the reverse pattern. There were no differences in the ratio of high-arousing positive vs. negative words remembered by young and older adults. A study examining age-differences in the relation between valence and arousal ratings

(Keil and Freund, 2009) showed that in young adults both pleasantness and unpleasantness increased with emotional arousal, whereas in older adults low-arousing stimuli were experienced as most pleasant, and the high-arousing ones as most unpleasant. Finally, a study investigating age-differences in emotional reactions to stimuli differing in arousal and age-relevance (Streubel and Kunzmann, 2011) showed that older adults rated unpleasant low-arousing pictures as less unpleasant compared to young adults, while there were no age-related differences in unpleasant ratings for unpleasant pictures that were high in arousal. Despite these inconsistent findings, these behavioral studies indicate that age-related changes are more likely to influence the response to stimuli low in arousal. This idea is also suggested by recent neuroimaging evidence (St. Jacques et al., 2010) showing that older adults tend to rate some negative pictures as neutral more frequently than young adults (thus suggesting a negative-to-neutral shift in older adults). However, the latter study did not explicitly manipulate the level of arousal.

Previous evidence has shown that processing of low and high arousing emotional stimuli relies on distinct processes. On the one hand, low arousing negative stimuli activate more goal-driven processes, which tend to engage controlled, resource-demanding processes (Kensinger and Corkin, 2004) and the prefrontal cortex (PFC). On the other hand, high arousing information activates more stimulus-driven processes (Mather and Knight, 2006), which tend to capture attention automatically and require reduced cognitive effort (Dolan, 2002). There is evidence for the idea that the automatic processing of high-arousing stimuli is relatively preserved in older adults (Mather and Knight, 2006). One structure typically associated with the relatively automatic processing of emotional information is the amygdala. Amygdala, a region involved in basic emotion processing, is involved in two related and important abilities: (a) to rapidly detect emotional information presented with a rapid stream of stimuli (Anderson and Phelps, 1998) and (b) to detect emotional stimuli even when attentional resources are drained (reviewed by Dolan and Vuilleumier, 2003). These observations suggest that the role of the amygdala in emotional processing is not heavily dependent on the availability of extensive cognitive resources. Despite a relative structural preservation of the amygdala in healthy aging (Allen et al., 2005; Brabec et al., 2010), functional magnetic resonance imaging (fMRI) evidence reveals different patterns of activation in the amygdala. For instance, some fMRI studies have found an age-related decrease in activation in response to negative stimuli (Iidaka et al., 2002; Gunning-Dixon et al., 2003; Mather et al., 2004; Tessitore et al., 2005; Erk et al., 2008). One study reported robust amygdala activity in both young and older adults during the perception of novel fearful faces (vs. familiar neutral ones) (Wright et al., 2006), while another study found enhanced amygdala activity to negative compared to neutral stimuli in both young and older adults (St. Jacques et al., 2010). Importantly, the latter study also showed that the amygdala activation in older adults involved overlapping areas with young adults, thus suggesting that amygdala functions similarly in healthy young and older adults. This makes it unlikely that an age-related decline in the amygdala (as suggested by the aging-brain model: Cacioppo et al., 2011) would account for the reduced amygdala activity to negative stimuli in older adults reported in some of the previous studies.

A more probable explanation for the inconsistent findings regarding age-related differences in amygdala activation to negative stimuli may be that the pictures used in those studies differed in emotional arousal. This explanation is in line with previous evidence in older adults showing (a) preserved amygdala responses to positive (Mather et al., 2004) or novel stimuli (Moriguchi et al., 2011), (b) reduced responses selectively to negative stimuli, and (c) decreased amygdala activity for the trials in which older participants subjectively experienced negative pictures as neutral (negative-to-neutral shift), but not for the negative pictures subjectively rated as negative (St. Jacques et al., 2010). Taken together, these findings suggest the possibility of age-related differential engagement of the amygdala by stimuli with different levels of arousal, but again such manipulation has not been previously used in conjunction with brain imaging recordings.

Decreased amygdala activity, combined with increased activity in emotion control regions, such as the medial PFC and the adjacent anterior cingulate cortex (ACC), might also be the result of a greater focus on emotion regulation goals. According to the Socioemotional Selectivity Theory (SST; Scheibe and Carstensen, 2010), older adults tend to prioritize social and emotional well-being goals over other goals, potentially as a result of shrinking time horizons. The increased salience of emotional goals may enhance older adults' motivation to regulate the emotions experienced in everyday life, either by selecting stimuli and situations that minimize negative emotions (Blanchard-Fields et al., 2004) or by using emotion regulation strategies (Gross et al., 1997). The "cognitive-control model" extension of the SST (Mather and Knight, 2005; Kryla-Lighthall and Mather, 2009) posits that such negativity avoidance is the result of older adults' greater chronic focus on emotion regulation goals. Consistent with the cognitive control model, a number of studies reported increased activity in the medial PFC/ACC to negative compared to neutral stimuli in older compared to young adults (Gunning-Dixon et al., 2003; Williams et al., 2006; Leclerc and Kensinger, 2008; Roalf et al., 2011). Moreover, studies also showed that the increased activity in medial PFC/ACC was accompanied by decreased activity in the amygdala in older, but not in young adults, during the anticipation of monetary loss (Larkin et al., 2007) and during evaluation of negative stimuli (St. Jacques et al., 2010). Notably, functional connectivity between these regions was greater in older compared to young adults, thus suggesting that medial PFC and ACC might be involved more generally in subcortical emotion regulation.

This interpretation is consistent with studies showing interactions between similar medial PFC/ACC regions and the amygdala, when older adults voluntarily decreased emotional responses to negative stimuli (Urry et al., 2006; Winecoff et al., 2011). Given that medial PFC shows stronger activity when adults (a) are told to up-regulate positive emotion and down-regulate negative emotion (Ochsner et al., 2004) and (b) spontaneously regulate their emotions (e.g., Drabant et al., 2009), the increased medial PFC/ACC activity seen in older adults while processing emotional stimuli might reflect their spontaneous engagement of emotion regulation operations. Moreover, negative correlations between the ventral ACC and amygdala when evaluating negative pictures (according to IAPS standardized norms) as neutral (negative-to-neutral shift; St. Jacques et al., 2010) suggest that the spontaneous emotion regulation in older adults might be limited to low arousing stimuli.

The present event-related fMRI study used a broader range of negative emotional stimuli (low, medium, and high arousing) to test the hypothesis that emotional functioning in aging is modulated by the level of arousal, and to identify the associated neural correlates. The focus was on the ACC/vmPFC and the amygdala. Participants were presented with negative and neutral pictures, which they rated for emotional content, while fMRI data were recorded. Based on the above review, we made the following four predictions. First, from the evidence showing a negative-to-neutral shift in older adults' ratings, we predicted lower ratings to the low arousing negative pictures in older adults. Second, we predicted that common engagement of the amygdala in young and older adults would be specific to high arousing pictures, reflecting preserved responses to high arousing stimuli in older adults. Third, we predicted that opposing patterns of response in the ACC/vmPFC (increased) vs. amygdala (decreased) would be specific to low arousing stimuli. Finally, consistent with a role of the vACC/vmPFC in spontaneous emotional regulation, we explored the possibility that increased activity in this region would be linked to reduced ratings for low arousing negative stimuli in older adults.

METHODS

PARTICIPANTS

The subject sample comprised 18 young adults between the ages of 18 and 32 years (10 females, mean age = 23.61, *SD* = 4.19) and 16 older adults between the ages of 59 and 84 years (11 females, mean age = 68.56, *SD* = 6.98). Participants were healthy, right-handed, native English speakers. As part of the initial screening, participants completed a number of questionnaires and cognitive measures. However, in the present study, these were used only for inclusion/exclusion purposes. Also as part of the initial screening, people with history of psychiatric and/or neurological conditions, uncontrolled hypertension, and subjects with history of alcohol or drug abuse were excluded from participation. It has been estimated that fMRI data from 18 subjects are needed to detect reasonable effect sizes with a power of 0.8 and an alpha of 0.05 (Huettel and McCarthy, 2001; Desmond and Glover, 2002). We collected data from more participants, but due to data attrition (e.g., ratings not recorded, response box problems, participants feeling uncomfortable in the scanner) only data from 18 young and 16 older participants are used for analyses. The age groups were matched on demographic variables, including education (see **Table 1**). All participants provided written informed consent under a protocol approved by the Institutional Ethics Review Board.

MATERIALS

Stimuli presented during the scanning session consisted of 180 pictures (90 negative and 90 neutral) selected from the IAPS (Lang et al., 1997). Additional neutral pictures were selected from other sources (Yamasaki et al., 2002), to equate the emotional pictures for visual complexity and human content. The negative picture set was further divided into equal numbers of low, medium, and high arousing negative pictures, based on their normative scores. Valence has not been held constant across the three levels of arousal in the negative pictures. Information about the pictures could be received from the corresponding author.

Table 1 | Summary of demographic characteristics for young and older groups.

	Younger	Older	*p*
n	18	16	
Male/Female	8/10	5/11	
Age range	18–32	59–84	
Mean age (*SD*)	23.61 (4.19)	68.56 (6.98)	<0.001
Years of education (*SD*)	14.11 (2.22)	14.19 (2.97)	0.99

SD, standard deviation.

The focus on negative emotional pictures in the present study was justified by the following reasons. First, previous evidence shows that the influence of arousal on age differences is more pronounced for negative than for positive stimuli (Kensinger, 2008). Second, previous behavioral results show that positive stimuli are generally more difficult to interpret, due to the lack of consistency of subjective ratings for positive pictures with the normative ratings in the older participants (St. Jacques et al., 2010). Such inconsistencies are even more evident when considering arousal, as older adults tend to rate low-arousing pleasant pictures as more pleasant than high-arousing pleasant pictures (Streubel and Kunzmann, 2011). Thus, it would be difficult to meaningfully interpret the fMRI data based on the behavioral results. Third, to match the level of arousal in negative stimuli, the positive stimuli should have included a large number of pictures with radical sport and erotic content, which are processed differently in older adults (see Backs et al., 2005).

PROCEDURE

The pool of 180 pictures was divided into sets of 30 pictures (15 negative and 15 neutral pictures in each set), which were randomly assigned to six study blocks. The block orders were randomly assigned to the participants. To avoid mood induction, pictures were pseudo-randomized so that no more than three pictures of the same valence were consecutively presented. Functional MR images were recorded while participants viewed and rated negative and neutral images. Each picture was presented on the screen for 4 s, and then was removed to minimize confounding effects of eye movements associated with prolonged scanning of images. Participants were asked to watch the pictures and rate their subjective emotional experience triggered by the pictures on an 8-point scale (1 = neutral, 8 = extremely negative). The rating scale was presented at the bottom of each picture. The screen containing the picture and rating scale was followed by a fixation cross, presented on the screen for 12 s. Participants were instructed to rate the pictures only after they were aware of the content of the picture and of their emotional response to the picture. Participants were encouraged to try and rate the pictures while they were on the screen. However, participants were also told to respond during the fixation screen if they needed more time to rate the picture. Participants first completed a run in which they were instructed to experience any feelings or thoughts the pictures might trigger. The first run was intended to collect data on participants' spontaneous processing and evaluation of negative information with varying degrees of arousal. The following runs were intended to collect data on participants' responses following the induction of the goal to regulate emotion (Dolcos et al., 2011). Given the present focus on spontaneous processing of emotional information in young and older adults, the results reported here resulted from analyses performed on the data collected during the first run, before the induction of the goal to regulate emotions. The results of the emotion regulation manipulation are the focus of a different report.

SCANNING

fMRI data were recorded using a 1.5 Tesla Siemens Sonata scanner. The anatomical images were 3D MPRAGE anatomical series (repetition time, $TR = 1600$ ms; echo time $TE = 3.82$ ms; field of view, FOV = 256 × 256 mm; number of slices = 112; voxel size = 1 × 1 × 1 mm), and the functional images consisted of series of images acquired axially using an echoplanar sequence ($TR = 2000$ ms; $TE = 40$ ms; FOV = 256 × 256 mm; number of slices = 28; voxel size = 4 × 4 × 4 mm; flip angle = 90°; T2*-weighted images), thus allowing for full-brain coverage. Stimuli were projected on a screen directly behind the participant's head within the scanner, which participants viewed through a mirror. Responses were recorded using a 4-button response box placed under the participant's right hand; ratings 5–8 were indicated by the participants with double-clicks on buttons 1–4, respectively. Double-clicking to rate the higher-arousing negative pictures (to indicate a rating of 5–8) might lead to higher activation in motor areas, compared to the lower-arousing pictures, which required only one button click (ratings of 1–4). However, analyses looking at this issue showed no significant differences in the motor areas between the high and low arousing pictures in the two groups.

fMRI DATA ANALYSIS

Standard pre-processing steps included quality assurance, TR alignment, motion correction, co-registration, normalization and smoothing (8 mm full-width half maximum isotropic kernel). Motion parameters calculated during the realignment were included as parameters of no interest to control for movement artifacts. For individual analyses, each event was modeled by the canonical hemodynamic response function (hrf) and its temporal derivative. The hemodynamic response can potentially show age-related differences (for review, see Dennis and Cabeza, 2008), but in the present study these differences were not problematic because we examined the effects of relative activity between task conditions (Buckner et al., 2000; Huettel et al., 2001; St. Jacques et al., 2010). The general linear model, as implemented in SPM2, was used to model the effects of interest and other confounding effects (e.g., magnetic field drift). Individual analyses produced whole-brain activation maps for the contrasts of interest. These individual contrasts were then entered into group-level random-effects analyses, which allowed investigation of the common and dissociating effects of negative and neutral pictures on brain activity engaged by young and older adults.

The main goal of the study was to investigate age-related differences in the neural correlates of evaluating emotional information with different levels of arousal. The focus was on the role of regions involved in basic emotion processing (amygdala) and emotion control (ACC/vmPFC). To accomplish this goal, analyses were performed to identify the common set of brain regions engaged by both young and older adults, through conjunction analyses. To examine our a priori hypothesis regarding the amygdala, we used anatomical ROI masks derived from the Wake Forest University Pick Atlas toolbox (Dolcos et al., 2004). For the amygdala, an intensity threshold of $p < 0.05$ uncorrected and an extent threshold of five contiguous voxels were used. The conjunction map for the amygdala was defined as $[(\text{Negative}_{\text{Old}} > \text{Neutral}_{\text{Old}}) \cap (\text{Negative}_{\text{Young}} > \text{Neutral}_{\text{Young}})]$, and calculated using the ImCalc feature in SPM. Thus, the conjoint probability of the conjunction map for the amygdala was 0.0025 (Fisher, 1950). In this context, we would like to emphasize the advantages of using the conjunction procedures. The conjunction procedure was performed using the Minimum Statistic compared to the Conjunction Null (MS/CN; Nichols et al., 2005), where a voxel/cluster only survives if it is significant in each independent map included in the conjunction analysis. While corrections for multiple comparisons, such as false discovery rate (FDR) and family-wise error rate (FWER), offer conservative approaches to controlling for Type I errors, they are (especially FWER) prone to Type II errors (Lieberman and Cunningham, 2009). Therefore, when used in conjunction, the statistical and extent thresholds used for the current analyses offer the best balance between Type I and II errors and result in a statistical value that is within the acceptable criterion for publication (Forman et al., 1995; Lieberman and Cunningham, 2009).

Further analyses were performed to identify dissociable sets of brain regions showing greater sensitivity to negative than to neutral pictures across groups, using ANOVAs and two-sample t-tests. Analyses were also performed separately for the low, medium and high arousing negative stimuli. Finally, to further elucidate the role of the brain regions showing age-related differences in response to negative and neutral stimuli, brain-behavior relations were investigated by examining co-variations of their neural responses with behavioral ratings. Behavioral measures were correlated with mean statistics after identifying clusters of activation at the group level. For all analyses, an intensity threshold of $p < 0.005$ uncorrected and an extent threshold of 10 contiguous voxels were used, except for the amygdala where an intensity threshold of $p < 0.05$ and an extent threshold of five contiguous voxels were used. An intensity threshold of $p < 0.005$ uncorrected coupled with an extent threshold of 10 voxels is typically considered a good trade-off between Type I and Type II errors (Lieberman and Cunningham, 2009). We also corrected for multiple comparisons in two ways. We applied two levels of FDR corrections: one corresponding to a p-value of 0.05 for each anatomical ROI (see **Table 3**), and the other corresponding to a p-value of 0.05 for each functional cluster.

RESULTS

BEHAVIORAL RESULTS

Reduced ratings to low arousing negative pictures in older adults

First, a Valence (Negative and Neutral) × Age Group (Young and Older) repeated-measures ANOVA with Valence as a within-subject factor and Age Group as a between-subjects factor revealed a main effect of Valence [$F_{(1, 32)} = 247.38$, $p < 0.001$]. The Valence × Age Group [$F_{(1, 32)} = 1.66$, $p = 0.21$] interaction was not significant. Second, separate analyses showed the expected effect of valence, with the negative pictures being rated as more negative than the neutral pictures, both by the young ($t = 17.28$, $p < 0.001$) and the older ($t = 7.97$, $p < 0.001$) adults. Third, an Arousal (Negative Low, Medium, and High) × Age Group (Young and Older) repeated-measures ANOVA with Arousal as a within-subject factor and Age Group as a between-subjects factor revealed a main effect of Arousal [$F_{(1, 32)} = 46.86$, $p < 0.001$]. The Arousal × Age Group [$F_{(1, 32)} = 0.77$, $p = 0.47$] interaction was not significant. Fourth, planned comparisons revealed a trend in the age-related comparison of low-arousing negative pictures, consistent with our first prediction that the ratings for low-arousing negative pictures will be lower in the older ($M = 3.88$, $SD = 1.19$) than in the young ($M = 4.62$, $SD = 1.29$) adults ($t = 1.72$, $p = 0.096$; one-tailed $p = 0.048$). There were no age-related differences in the ratings for the high and medium arousing negative pictures, nor in the ratings for the neutral pictures (see **Table 2**). Analyses also showed no age-related differences in the ratings for Negative High vs. Negative Low, and Negative Medium vs. Negative Low.

fMRI RESULTS

Common engagement of the amygdala in young and older groups driven by high arousing stimuli

Conjunction analyses of brain activity associated with the evaluation of negative and neutral pictures identified an area in the right amygdala that was commonly engaged by both age groups (see **Table 3**; **Figure 1**). Consistent with previous evidence showing common engagement of the amygdala to negative compared to neutral stimuli by both age-groups (St. Jacques et al., 2010), we did not find significant differences in this region in an ANOVA examining Valence (Negative and Neutral) × Age Group (Young and Older) interaction. Analyses looking at the effect of arousal revealed that the common engagement of the right amygdala in the two age-groups was driven by the high arousing negative stimuli, which also activated left amygdala in both groups. Further analyses identified amygdala activation to low, medium, and high arousing negative stimuli in younger adults, but only to high and medium arousing negative stimuli in older adults. However, there were no overlapping areas in the brain regions engaged by the low and medium arousing pictures. The Arousal (NegLo vs. NeuAll, NegMed vs. NeuAll, and NegHi vs. NeuAll) × Age Group (Young and Older) interaction was not significant in the amygdala region commonly engaged by young and older adults in response to negative compared to neutral pictures, but it was significant ($F = 4.55$, $p < 0.05$) for the peak voxel showing decreased amygdala activity to low-arousing stimuli in the older compared to young adults (discussed below). Although the interaction was not significant in the amygdala region commonly

Table 2 | Behavioral ratings for young and older groups.

	Age group		t	p
	Young ($n = 18$)	Older ($n = 16$)		
NegHi	6.55 (1.08)	5.68 (1.82)	1.68	0.106
NegMed	5.58 (1.38)	5.18 (1.59)	0.80	0.425
NegLo	4.62 (1.29)	3.89 (1.19)	1.72	0.096
NegAll	*5.59 (1.11)*	*4.91 (1.39)*	1.56	0.128
NeuAll	*1.88 (0.55)*	*1.77 (0.60)*	0.55	0.584

Values before parentheses indicate the means. Values in parentheses indicate standard deviations. Reported p-values are two-tailed.

Table 3 | Common amygdala activity for negative vs. neutral stimuli.

Brain region	H	Voxels	Talairach coordinates			t
			x	y	z	
YOUNG ∩ OLDER (NegAll vs. NeuAll)						
Amygdala	R	6	28	−1	−20	**3.86**
YOUNG ∩ OLDER (NegHi vs. NeuAll)						
Amygdala	L	6	−20	−5	−17	**3.98**
Amygdala	R	22	16	−5	−17	**3.11***
			28	−1	−20	**2.86***

*H, Hemisphere. t-values represent the multiplied score from the conjunction analysis of young and older groups. Bolded t-values indicate the voxels surviving a voxel-level threshold of p < 0.05 (FDR-corrected). *Denotes significant difference at a cluster-level threshold of p < 0.05 (FDR-corrected).*

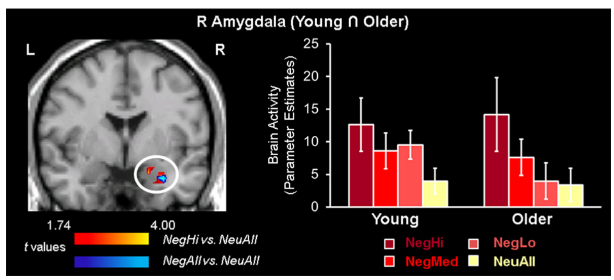

FIGURE 1 | Common amygdala activation for high arousing stimuli in young and older adults. Common engagement of the right amygdala by young and older groups was identified using conjunction analysis based on a region of interest approach, where both young and older groups showed common activity for negative vs. neutral (blue area) and high arousing negative vs. neutral (red area) stimuli ($p = 0.0025$). The bar graph illustrates the parameter estimates corresponding to the peak voxel in the area of R AMY commonly activated by young and older adults for NegAll vs. NeuAll contrast. L, left; R, right; NegHi, Negative High Arousal; NegMed, Negative Medium Arousal; NegLo, Negative Low Arousal; NegAll, Negative All; NeuAll, Neutral All.

engaged by young and older adults in response to negative compared to neutral pictures, our findings are still consistent with the idea that the overlap is more likely to occur in high-arousing stimuli, and with our prediction that amygdala activity will be associated with minimal age-related differences for high arousing negative stimuli, but will show age-related differences for the low-arousing negative stimuli. This differential impact is also reflected in the results of the follow-up pairwise comparisons showing age-related differences in the amygdala to low, but not to medium and high arousing negative pictures. *T*-tests comparing amygdala activation to high arousing negative stimuli revealed reduced activity to the high arousing negative pictures in temporal, occipital, parietal, and cingulate areas, and to the medium arousing pictures in occipital areas (see **Table 4**) in older compared to the young adults. In addition to the right amygdala, high arousing stimuli also engaged a common area in the extra striate cortex (Talairach coordinates: $x = 48$, $y = -74$, $z = 7$), in both young and older adults. As described below, low arousing pictures were associated with different patterns of activity in young and older adults.

Opposing spontaneous responses in rostral/ventral ACC and amygdala activity in older adults driven by low-arousing pictures

Confirming our third prediction, targeted two-sample *t*-tests revealed an age-related increase to low arousing stimuli in the rostral/ventral ACC (**Tables 4**, **5**). In older adults this region showed activation, whereas in young adults it showed deactivation. Deactivation in this area is not surprising, as a variety of previous fMRI studies have shown that deactivation in medial frontal areas is rather common during tasks that entail goal-directed behavior (Frankenstein et al., 2003). Deactivations in this region typically occur when resources are allocated to other brain regions, possibly to facilitate task-relevant processing (Frankenstein et al., 2003). Importantly, this region partially overlapped with the ACC region showing a significant Arousal × Age Group interaction ($F = 12.70$, $p < 0.005$). Targeted two-sample *t*-tests also revealed an age-related decrease in the bilateral amygdala activity, for the low arousing pictures (see **Figure 2**). Moreover, the peak voxel showing decreased amygdala activity to low arousing stimuli in older compared to the young adults also survived the Arousal × Age Group interaction ($F = 4.55$, $p < 0.05$). As illustrated in **Figure 2**, rostral/ventral ACC activation was significant only for the older group, whereas the amygdala activation was significant only for the young group. In addition, young adults showed increased activity in frontal, temporal, and occipital areas (see **Table 4**).

Age-related increased activity in ventral ACC/ventromedial PFC was linked to lower ratings for low arousing negative stimuli

Co-variations of activity in the vACC/vmPFC with the behavioral ratings further elucidated the role played by this region in the evaluation of low arousing stimuli in older adults (see **Figure 3**). As illustrated in the figure, the vACC/vmPFC (Talairach coordinates: $x = 0$, $y = 38$, $z = -9$) activity was negatively correlated with the ratings for low arousing negative pictures in the older adults ($r = -0.72$, $p < 0.005$). That is, older participants who engaged this region when processing low arousing negative pictures also rated those pictures as less negative. Of note, portions of the vACC/vmPFC showing the negative co-variation with ratings for low arousing pictures in older adults partially overlapped with the vACC/vmPFC area showing stronger response to low arousing negative stimuli in older, compared to the young adults. The correlation between vACC/vmPFC and ratings was specific to ratings for low arousing negative pictures in older adults, as indicated by the significant difference between this correlation and the similar correlation for the young group (using the *r* to *z* transformation, $z = -4.06$, $p < 0.0001$). There were no other significant correlations between the vACC/vmPFC and ratings. The significant co-variations between other brain areas and behavioral ratings are presented in **Table 6**.

DISCUSSION

Despite substantial evidence supporting the idea of enhanced affective well-being and emotional stability in healthy aging, relatively little is known about the role of emotional arousal in this effect and the underlying brain mechanisms. The current study addressees this gap in the emotional aging literature by investigating the effect of emotional arousal on behavioral and neural responses in young and older adults. There were three main novel findings regarding the neural correlates. First, we showed that the common engagement of the right amygdala in young and older adults was driven by high arousing stimuli. Second, we showed that the opposing spontaneous pattern of increased activity in the rostral/ventral ACC and decreased activity in the right amygdala is specific to low arousing stimuli. Third, we linked the increased spontaneous activity in the vACC/vmPFC to older adults' reduced ratings for low arousing stimuli. These findings are discussed below.

COMMON ENGAGEMENT OF THE AMYGDALA IN YOUNG AND OLDER GROUPS DRIVEN BY HIGH AROUSING STIMULI

The present study revealed that right amygdala activation in older adults had overlapping areas with that from younger adults, thus showing that both groups involve the same amygdala regions to process negative stimuli. Moreover, the present study advances previous findings (St. Jacques et al., 2010) by showing that the common engagement of the right amygdala is driven by high arousing stimuli. Decreased amygdala activity to low arousing stimuli in older adults might be attributed to a potential deterioration of this brain structure with age. However, our finding showing similar amygdala engagement by high arousing stimuli in both age groups provides evidence against such a hypothesis and confirms previous evidence showing that amygdala activity is preserved with age. Increased amygdala activation by high arousing negative emotional stimuli is consistent with previous behavioral findings suggesting that emotion processing is not impaired in aging (Mather and Knight, 2006), and with brain imaging evidence showing that aging is associated with robust functional activation of the amygdala (Wright et al., 2006; St. Jacques et al., 2010). Increased amygdala activation in response to high arousing stimuli is also consistent with previous behavioral evidence (Kensinger, 2008) showing minimal age-differences for high arousing stimuli (but identifying age-related differences for low arousing stimuli).

Table 4 | Dissociable brain activity for negative vs. neutral stimuli by arousal levels in young and older adults.

Contrast	Brain region	BA	*H*	Voxels	Talairach coordinates *x*	*y*	*z*	*t*
YOUNG > OLDER								
High arousal (NegHi vs. NeuAll)								
	Cuneus	18	R	26	12	−85	19	4.26
					8	−92	19	3.71
	Precuneus	19	R	12	28	−60	36	3.94
	Middle temporal gyrus	19	R	21	48	−61	14	3.85
	Cingulate gyrus	32	L	17	−4	17	32	3.69
	Postcentral gyrus	2	R	10	51	−21	42	3.66
	Middle temporal gyrus	19	L	18	−44	−61	14	3.60
	Middle temporal gyrus	37			−51	−62	3	2.83
Medium arousal (NegMed vs. NeuAll)								
	Middle occipital gyrus	18	L	21	−32	−89	4	3.47
					−24	−89	15	3.38
Low arousal (NegLo vs. NeuAll)								
	Amygdala	34	L	11	−20	−1	−10	2.49*
					−32	−5	−17	2.10*
	Amygdala	28	R	18	16	−4	−10	2.44*
		34			28	3	−14	1.96*
	Inferior frontal gyrus	47	R	34	44	11	−4	4.81
	Superior temporal gyrus	41	R	13	40	−35	9	4.02
					48	−31	5	3.17
					40	−38	16	2.82
	Middle temporal gyrus	39	R	23	48	−61	21	3.85
					44	−54	14	3.31
					48	−62	10	2.99
	Superior frontal gyrus	9	R	26	40	40	31	3.79
					16	52	38	3.78
					4	56	38	3.67
	Superior frontal gyrus	9	L	22	−28	52	34	3.77
					−12	52	38	3.62
	Middle occipital gyrus	19	L	14	−28	−77	11	3.75
					−32	−85	8	3.43
					−24	−89	15	3.09
	Inferior frontal gyrus	47	L	20	−48	42	−9	3.75
					−51	30	−5	2.94
					−55	35	2	2.86
	Middle frontal gyrus	8	R	32	36	22	47	3.68
					48	21	39	3.67
					32	6	58	3.25
	Superior temporal gyrus	38	L	40	−44	11	−14	3.64
					−40	23	−11	3.47
					−51	7	−7	3.32
OLDER > YOUNG								
Low arousal (NegLo vs. NeuAll)								
	Anterior cingulate gyrus	32	L	39	−16	36	13	**4.22**
					−12	43	−2	2.42
		32	R	8	8	40	16	1.88

*BA, Brodmann's area; H, Hemisphere. A threshold of $p < 0.005$ (uncorrected) was used. Bolded t-values indicate the voxels surviving a cluster-level threshold of $p < 0.05$ (FDR-corrected). *Denotes significant difference at $p < 0.05$ (uncorrected).*

Table 5 | Mean parameter estimates for peak voxel activity in anterior cingulate cortex (ACC) and amygdala (AMY) for young and older groups.

Brain region		Age group	
		Young (n = 18)	Older (n = 16)
ACC	NegHi	1.35 (1.42)	−4.93 (2.27)
	NegMed	−4.91 (2.08)	−3.08 (1.98)
	NegLo	−4.29 (1.48)	2.39 (1.35)
	NeuAll	−1.78 (1.83)	−4.68 (1.60)
AMY	NegHi	22.93 (7.18)	12.88 (4.92)
	NegMed	15.18 (5.07)	2.34 (4.34)
	NegLo	15.83 (4.44)	−0.93 (3.96)
	NeuAll	6.74 (2.29)	4.12 (3.20)

Values before parentheses indicate the means. Values in parentheses indicate the standard errors of the means. The mean parameter estimates were extracted in each of the four conditions against the baseline activity for each age group at the coordinates corresponding to the peak voxels for each of the ACC and AMY regions showing overlapping activity between (1) the Arousal × Age Group interaction and (2) the two-sample t-test targeting low arousing stimuli.

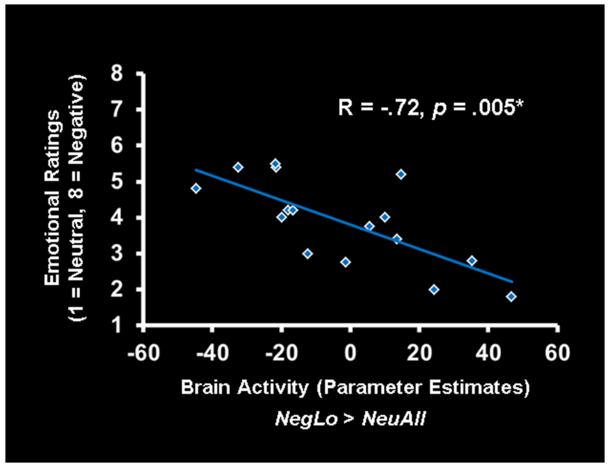

FIGURE 3 | Activity in the ACC was linked to reduced ratings for low-arousing stimuli in older adults. In older adults, increased activity in the ventral anterior cingulate cortex (vACC)/ventro-medial prefrontal cortex (vmPFC) correlated negatively with the ratings for low arousing negative stimuli. The scatterplot is based on the parameter estimates corresponding to the peak voxel in the area of vACC/vmPFC showing negative correlation with the behavioral ratings. NegLo, Negative Low Arousal; NeuAll, Neutral All.

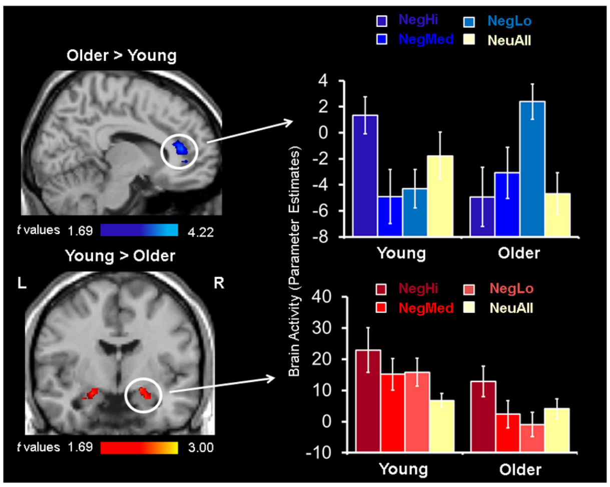

FIGURE 2 | Opposing patterns of response in rostral/ventral ACC and AMY for low arousing stimuli. Increased activity in rostral/ventral ACC (top sagittal image), and decreased activity in the amygdala (bottom coronal image) in older compared to young adults was identified using two-sample *t*-tests between activation maps for NegLo vs. NeuAll contrast in the two groups. The bar graphs on the right illustrate the parameter estimates corresponding to the peak voxels in the area of ACC and AMY showing increased activity to low arousing negative stimuli in the young and older groups. L, left; R, right; NegHi, Negative Hi Arousal; NegMed, Negative Medium Arousal; NegLo, Negative Low Arousal; NeuAll, Neutral All.

The present results are also in line with more recent theories of emotional aging (cognitive control model: Mather and Carstensen, 2005), which suggest that the relatively preserved emotional well-being in older adults is the result of age-related differences in the controlled processing of emotional information, and that processing of high arousing stimuli is less dependent on controlled processing compared to low arousing stimuli (Kensinger, 2008). Therefore, if the emotional well-being is caused by age-related declines in the controlled processing of emotional information, evaluation of low arousing stimuli, which relies more on controlled processes, would be more affected than the evaluation of the high arousing stimuli, which relies more on automatic processes. Given that (a) amygdala is involved in processing stimulus relevance for the goals and motivations of the perceiver (Cunningham and Brosch, 2012) and (b) right amygdala is involved in the initial, rapid, possibly automatic detection of an emotional stimulus (Gläscher and Adolphs, 2003), then (c) our results showing bilateral amygdala engagement in the evaluation of high arousing stimuli by both age groups suggest that this type of stimuli are automatically detected by both groups because of their increased personal relevance. The present findings showing dissociable responses in the commonly activated amygdala based on the level of arousal suggest that the age-related differences identified in previous studies may not be caused by an overall decline in the amygdala functioning, but rather by age-related changes in the intensity of the emotional stimuli to which amygdala is more receptive.

OPPOSING SPONTANEOUS RESPONSES IN ROSTRAL/VENTRAL ACC AND AMYGDALA ACTIVITY IN OLDER ADULTS SPECIFIC TO LOW-AROUSING PICTURES

The present study also advances previous findings by showing that the age-related differences in the engagement of amygdala and rostral/ventral ACC are specific to low arousing negative stimuli. Older adults' reduced amygdala activation to low arousing negative pictures can be the consequence of many factors,

Table 6 | Co-variations between brain activity and the ratings of negative pictures by young and older adults.

(Contrast) × Ratings	*r* value	Brain region	BA	*H*	Voxels	Talairach coordinates			*t*
						x	*y*	*z*	
YOUNG									
(NegHi vs. NeuAll) × NegHi	−0.668	Inferior frontal gyrus	47	L	10	−20	31	−5	3.59
(NegLo vs. NeuAll) × NegLo	−0.726	Parahippocampal gyrus	35	L	14	−20	−35	−5	4.22
OLDER									
(NegHi vs. NeuAll) × NegHi	+0.803	Precuneus	7	L	56	−4	−53	43	5.04
	+0.770					0	−45	28	4.52
	+0.705		7	R		12	−52	43	3.72
	+0.778	Precentral gyrus	9	L	12	−36	21	39	4.64
	+0.769	Superior parietal lobule	7	R	16	28	−68	44	4.50
	+0.746	Precuneus	7	L	10	−12	−59	55	4.19
	+0.722					−12	−68	51	3.90
	+0.707	Medial frontal gyrus	8		12	0	45	38	3.74
	+0.707					0	56	30	3.74
	+0.669	Medial frontal gyrus	9	L		−4	40	31	3.37
	+0.690	Superior frontal gyrus	9	L	14	−8	60	26	3.57
	+0.679			R		8	63	15	3.45
(NegMed vs. NeuAll) × NegMed	−0.819	Inferior parietal lobule	40	L	11	−40	−29	42	5.34
	−0.686					−28	−37	42	3.52
	−0.797	Precentral gyrus	6	R	10	32	−9	56	4.94
	−0.783	Precentral gyrus	6	L	26	−24	−10	52	4.70
	−0.699					−16	−1	55	3.65
	−0.699					−24	−1	48	3.65
	−0.777	Precentral gyrus	6	L	13	−55	−2	41	4.62
	−0.774	Precuneus	7	R	26	8	−59	62	4.58
	−0.668					4	−56	51	3.35
	−0.751	Precuneus	7	L	11	−28	−71	55	4.25
	−0.749	Caudate nucleus		R	20	4	8	0	4.23
	−0.711			L		−4	4	−4	3.79
	−0.739	Lentiform nucleus		R	19	20	−4	8	4.11
	−0.712	Inferior parietal lobule	40	L	21	−44	−36	57	3.79
	−0.700					−40	−47	61	2.67
	−0.710	Superior temporal gyrus	22	R	10	60	−7	8	3.77
	−0.708					51	4	7	3.75
	−0.675					48	5	15	3.43
(NegLo vs. NeuAll) × NegLo	+0.750	Insula	13	R	12	28	−26	23	4.24
	+0.743					36	−45	28	4.22
	+0.767					32	−34	24	4.04
	+0.711	Supramarginal gyrus	40	L	11	−44	−45	32	4.16
	+0.653	Superior frontal gyrus	8	R	10	4	37	46	3.53
(NegLo vs. NeuAll) × NegLo	−0.577	Anterior cingulate	32	R	7	0	38	−9	4.11

BA, Brodmann's area; H, Hemisphere. A threshold of $p < 0.005$ (uncorrected) was used.

including an age-related atrophy in neural systems important for processing negative stimuli, age-related decreases in psychophysiological responses to arousing stimuli (Tsai et al., 2000), or an age-related decline in the amygdala, which selectively diminishes emotional arousal in response to negative stimuli and decreases the experienced negative affect (the aging brain model; Cacioppo et al., 2011). However, in the present study, the decreased bilateral amygdala activity was accompanied by increased activity in the rostral/ventral ACC in older compared to the young adults. This opposing pattern of brain activity is consistent with previous findings showing decreased amygdala activity coupled with increased activity in cortical control regions during the perception and evaluation of negative stimuli (anterior ventral insula; Fischer et al., 2005; ventral and medial PFC; Tessitore et al., 2005), and with greater functional connectivity between the right amygdala and ACC in older compared to young adults (St. Jacques et al., 2010). Moreover, a similar region has shown a negative correlation with right amygdala on trials in which older adults subjectively experienced negative pictures (according to the IAPS standardized norms) as neutral, but not for negative pictures subjectively rated as negative (St. Jacques et al., 2010). This suggests a role of this region in reducing amygdala activity when regulation is successful. This evidence, together with our findings, indicate that older adults' reduced amygdala activation to low arousing pictures may be the result of their successful emotion regulation of this type of stimuli.

Taken together, our findings show enhanced activity in an emotional control region, the rostral/ventral ACC, coupled with decreased bilateral amygdala activity to low arousing negative stimuli, in a task in which participants were not explicitly instructed to down-regulate their emotional responses. This may reflect older adults' spontaneous engagement of emotion control regions to down-regulate low arousing negative emotions. Moreover, the negative association between vACC/vmPFC and behavioral ratings for low arousing stimuli, discussed below, reflects their success in regulating low arousing negative emotions. These results support the idea that older adults may have emotion regulation chronically activated (Mather and Carstensen, 2005; Nashiro et al., 2012), and that this effect is specific to low arousing negative emotions.

AGE-RELATED INCREASED ACTIVITY IN VENTRAL ACC/VENTROMEDIAL PFC LINKED TO LOWER RATINGS FOR LOW AROUSING STIMULI

Ventromedial PFC and the ACC play an important role in processing emotional information, and are particularly involved in the automatic regulation of emotional responses (for reviews see Bush et al., 2000; Phillips et al., 2003) during incidental emotion regulation paradigms, such as affect labeling and self-distraction from a fear-conditioning stimulus (Lieberman et al., 2007). Unlike other frontal regions, which thin dramatically with aging (Fjell et al., 2009), vmPFC/ACC maintain their cortical thickness in normal aging, which suggests that some of the neural circuitry critical for emotion regulation is well preserved in older adults. In the present study, evaluation of low arousing negative stimuli was associated with increased vACC/vmPFC activity in older compared to the young adults. Moreover, activity in these areas was negatively associated with the behavioral ratings for low arousing stimuli in older adults, further supporting a role of this region in effective spontaneous regulation of this type of emotions.

Although our study contributes important novel information, it also has some limitations. One limitation concerns the size of our subject sample in the older group, which although allowed identification of robust findings, was slightly smaller than the optimal fMRI sample size of 18 suggested for investigations of brain-behavior relations (Lieberman et al., 2009). However, the size of our samples was comparable to that involved in other investigations of age-related differences (e.g., St. Jacques et al., 2010). Although we took measures to minimize multiple comparisons, we recognize the importance of replicating the findings in a larger sample. There were also different age-spans in the young (14 years) and the older (25 years) groups, which potentially could have led to greater variance in the older adults group. Finally, involving only negative stimuli and manipulating only the level of arousal limits the generalizability of our results to negative stimuli with different degrees of arousal. Future studies should investigate whether the effects identified in the present study are confirmed for positive stimuli and in investigations that manipulate independently emotional valence and arousal.

CONCLUSION

In the present study, we examined the effect of arousal as a potential factor influencing the enhanced affective well-being and emotional stability commonly associated with healthy aging. There were three novel findings regarding the neural correlates of emotion processing: (a) right amygdala was commonly engaged by young and older adults only during the evaluation of high arousing stimuli, (b) amygdala and rostral/ventral ACC showed an opposing pattern of activity for low arousing stimuli in older compared to young adults, and (c) the engagement of the ventral ACC/vmPFC in older adults reflected successful regulation of low arousing negative stimuli. These findings highlight the important effect of arousal on age-related emotional processing, suggesting that aging is associated with preserved emotional processing of high arousing negative information, and with altered processing of low arousing negative information. By showing that older adults engage more automatic processes when evaluating high arousing negative information, and more controlled, resource-demanding processes in response to low arousing negative information, the present study advances our understanding of the neural correlates underlying the enhanced emotional well-being in healthy aging. Moreover, by linking the spontaneous engagement of the emotion control regions in older adults to reduced subjective experiencing of low arousing negative information, the present study provides further evidence supporting the idea that emotion regulation is chronically activated in healthy aging, and clarifies that this effect is specific to low arousing negative information. This new evidence highlights the need of adopting a comprehensive approach that takes into consideration both the valence and arousal in examining emotional aging.

ACKNOWLEDGMENTS

This research was supported by funds from the Brain & Behavior Research Foundation (formerly NARSAD), Healthy Minds Canada (formerly CPRF), and the University of Alberta. The authors were supported by NIH R01 grant AG008235 from the National Institutes of Health (National Institute on Aging) (Roger A. Dixon and Sanda Dolcos), the Canada Research Chairs program (Roger A. Dixon), the University of Alberta (Sanda Dolcos and Roger A. Dixon), and the University of Illinois (Sanda Dolcos). The authors wish to thank Keen Sung, Trisha Chakrabarty, and Kristina Suen for assistance with data collection and analysis, and to Florin Dolcos for feedback on an earlier version of the manuscript.

REFERENCES

Allen, J. S., Bruss, J., Brown, C. K., and Damasio, H. (2005). Normal neuroanatomical variation due to age: the major lobes and a parcellation of the temporal region. *Neurobiol. Aging* 26, 1245–1260. doi: 10.1016/j.neurobiolaging.2005.05.023

Anderson, A. K., and Phelps, E. A. (1998). Intact recognition of vocal expressions of fear following bilateral lesions of the human amygdala. *Neuroreport* 9, 3607–3613.

Backs, R. W., da Silva, S. P., and Han, K. (2005). A comparison of younger and older adults' self-assessment manikin ratings of affective pictures. *Exp. Aging Res.* 31, 421–440. doi: 10.1080/03610730500206808

Blanchard-Fields, F., Stein, R., and Watson, T. L. (2004). Age differences in emotion-regulation strategies in handling everyday problems. *J. Gerontol. B Psychol. Sci. Soc. Sci.* 59, 261–269. doi: 10.1093/geronb/59.6.P261

Brabec, J., Rulseh, A., Hoyt, B., Vizek, M., Horinek, D., Hort, J., et al. (2010). Volumetry of the human amygdala—an anatomical study. *Psychiatry Res.* 182, 67–72. doi: 10.1016/j.pscychresns.2009.11.005

Bradley, M. M., and Lang, P. J. (2000). "Measuring emotion: behavior, feeling, and physiology," in *Cognitive Neuroscience of Emotion*, eds R. D. Lane and L. Nadel (New York, NY: Oxford University Press), 242–276.

Bradley, M. M., and Lang, P. J. (2007). "Emotion and motivation," in *Handbook of Psychophysiology*, 3rd Edn., eds J. T. Cacioppo, L. G. Tassinary, and G. Berntson (New York, NY: Cambridge University Press), 581–607.

Buckner, R. L., Snyder, A. Z., Sanders, A. L., Raichle, M. E., and Morris, J. C. (2000). Functional brain imaging of young, nondemented, and demented older adults. *J. Cogn. Neurosci.* 12, 24–34. doi: 10.1162/089892900564046

Bush, G., Luu, P., and Posner, M. I. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends Cogn. Sci.* 4, 215–222. doi: 10.1016/S1364-6613(00)01483-2

Cacioppo, J. T., Berntson, G. G., Bechara, A., Tranel, D., and Hawkley, L. C. (2011). "Could an aging brain contribute to subjective well-being? The value added by a social neuroscience perspective," in *Social Neuroscience: Toward Understanding the Underpinnings of the Social Mind*, eds A. Todorov, S. Fiske, and D. Prentice (New York, NY: Oxford University Press), 249–262.

Charles, S. T., Mather, M., and Carstensen, L. L. (2003). Aging and emotional memory: the forgettable nature of negative images for older adults. *J. Exp. Psychol. Gen.* 132, 310–324. doi: 10.1037/0096-3445.132.2.310

Cunningham, W. A., and Brosch, T. (2012). Motivational salience: amygdala tuning from traits, needs, values, and goals. *Curr. Dir. Psychol. Sci.* 21, 54–59. doi: 10.1177/0963721411430832

Dennis, N. A., and Cabeza, R. (2008). "Neuroimaging of healthy cognitive aging," in *The Handbook of Aging and Cognition*, 3rd Edn., eds F. I. M. Craik and T. A. Salthouse (Mahwah, NJ: Lawrence Erlbaum Associates), 1–54.

Desmond, J. E., and Glover, G. H. (2002). Estimating sample size in functional MRI (fMRI) neuroimaging studies: statistical power analyses. *J. Neurosci. Methods* 118, 115–128. doi: 10.1016/S0165-0270(02)00121-8

Dolan, R. J. (2002). Emotion, cognition, and behavior. *Science* 298, 1191–1194. doi: 10.1126/science.1076358

Dolan, R. J., and Vuilleumier, P. (2003). Amygdala automaticity in emotional processing. *Ann. N.Y. Acad. Sci.* 985, 348–355. doi: 10.1111/j.1749-6632.2003.tb07093.x

Dolcos, F., LaBar, K. S., and Cabeza, R. (2004). Interaction between the amygdala and the medial temporal lobe memory system predicts better memory for emotional events. *Neuron* 42, 855–863. doi: 10.1016/S0896-6273(04)00289-2

Dolcos, S., Sung, K., Denkova, E., Dixon, R. A., and Dolcos, F. (2011). Brain imaging investigation of the neural correlates of emotion regulation. *J. Vis. Exp.* 54:2430. doi: 10.3791/2430

Drabant, E. M., McRae, K., Manuck, S. B., Hariri, A. R., and Gross, J. J. (2009). Individual differences in typical reappraisal use predict amygdala and prefrontal responses. *Biol. Psychiatry* 65, 367–373. doi: 10.1016/j.biopsych.2008.09.007

Erk, S., Walter, H., and Abler, B. (2008). Age-related physiological responses to emotion anticipation and exposure. *Neuroreport* 19, 447–452. doi: 10.1097/WNR.0b013e3282f5d92f

Fischer, H., Sandblom, J., Gavazzeni, J., Fransson, P., Wright, C. I., and Backman, L. (2005). Age-differential patterns of brain activation during perception of angry faces. *Neurosci. Lett.* 386, 99–104. doi: 10.1016/j.neulet.2005.06.002

Fisher, R. A. (1950). *Statistical Methods for Research Workers*. London: Oliver and Boyd.

Fjell, A. M., Westlye, L. T., Amlien, I., Espeseth, T., Reinvang, I., Raz, N., et al. (2009). High consistency of regional cortical thinning in aging acrossmultiple samples. *Cereb. Cortex* 19, 2001–2012. doi: 10.1093/cercor/bhn232

Forman, S. D., Cohen, J. D., Fitzgerald, M., Eddy, W. F., Mintun, M. A., and Noll, D. C. (1995). Improved assessment of significant activation in functional magnetic resonance imaging (fMRI): use of a cluster-size threshold. *Magn. Reson. Med.* 33, 636–647. doi: 10.1002/mrm.1910330508

Frankenstein, U., Wennerberg, A., Richter, W., Bernstein, C., Morden, D., Rémy, F., et al. (2003). Activation and deactivation in blood oxygenation level dependent functional magnetic resonance imaging. *Concept. Magnetic Res. Educ. J.* 16A, 63–70. doi: 10.1002/cmr.a.10054

Gläscher, J., and Adolphs, R. (2003). Processing of the arousal of subliminal and supraliminal emotional stimuli by the human amygdala. *J. Neurosci.* 23, 10274–10282. Available online at: http://www.jneurosci.org/content/23/32/10274.full

Gross, J. J., Carstensen, L. L., Pasupathi, M., Tsai, J., Skorpen, C. G., and Hsu, A. Y. C. (1997). Emotion and aging: experience, expression, and control. *Psychol. Aging* 12, 590–599. doi: 10.1037/0882-7974.12.4.590

Gruhn, D., Scheibe, S., and Baltes, P. B. (2007). Reduced negativity effect in older adults' memory for emotional pictures: the heterogeneity-homogeneity list paradigm. *Psychol. Aging* 22, 644–649. doi: 10.1037/0882-7974.22.3.644

Gunning-Dixon, F. M., Gur, R. C., Perkins, A. C., Schroeder, L., Turner, T., Turetsky, B. I., et al. (2003). Age-related differences in brain activation during emotional face processing. *Neurobiol. Aging* 24, 285–295. doi: 10.1016/S0197-4580(02)00099-4

Huettel, S. A., and McCarthy, G. (2001). The effects of single-trial averaging upon the spatial extent of fMRI activation. *Neuroreport* 12, 2411–2416. doi: 10.1097/00001756-200108080-00025

Huettel, S. A., Singerman, J. D., and McCarthy, G. (2001). The effects of aging upon the hemodynamic response measured by functional MRI. *Neuroimage* 13, 161–175. doi: 10.1006/nimg.2000.0675

Iidaka, T., Okada, T., Murata, T., Omori, M., Kosaka, K., Sadato, N., et al. (2002). Age-related differences in the medial temporal lobe responses to emotional faces as revealed by fMRI. *Hippocampus* 12, 352–362. doi: 10.1002/hipo.1113

Isaacowitz, D. M., Wadlinger, H. A., Goren, D., and Wilson, H. R. (2006). Selective preference in visual fixation away from negative images in old age? An eye-tracking study. *Psychol. Aging* 21, 40–48. doi: 10.1037/0882-7974.21.1.40

Ito, T. A., Cacioppo, J. T., and Lang, P. J. (1998). Eliciting affect using the international affective picture system: trajectories through evaluative space. *Pers. Soc. Psychol. Bull.* 24, 855–879. doi: 10.1177/0146167298248006

Keil, A., and Freund, A. M. (2009). Changes in the sensitivity to appetitive and aversive arousal across adulthood. *Psychol. Aging* 24, 668–680. doi: 10.1037/a0016969

Kensinger, E. A. (2008). Age differences in memory for arousing and nonarousing emotional words. *J. Gerontol. Psychol. Sci.* 63, P13–P18. doi: 10.1093/geronb/63.1.P13

Kensinger, E. A., and Corkin, S. (2004). Two routes to emotional memory: distinct neural processes for valence and arousal. *Proc. Natl. Acad. Sci. U.S.A.* 101, 3310–3115. doi: 10.1073/pnas.0306408101

Kryla-Lighthall, N., and Mather, M. (2009). "The role of cognitive control in older adults' emotional well-being," in *Handbook of Theories of Aging*, eds V. Berngtson, D. Gans, N. Putney, and M. Silverstein (New York, NY: Springer Publishing), 323–344.

Lang, P. J. (1995). The emotion probe: studies of motivation and attention. *Am. Psychol.* 50, 372. doi: 10.1037/0003-066X.50.5.372

Lang, P. J., Bradley, M. M., and Cuthbert, B. N. (1992). A motivational analysis of emotion: reflex-cortex connections. *Psychol. Sci.* 3, 44–49. doi: 10.1111/j.1467-9280.1992.tb00255.x

Lang, P. J., Bradley, M. M., and Cuthbert, B. N. (1997). *International Affective Picture System (IAPS): Technical Manual and Affective Ratings*. Gainesville, FL: NIMH, The center for the study of emotion and attention, University of Florida.

Lang, P. J., Bradley, M. M., and Cuthbert, B. N. (1998). Emotion, motivation, and anxiety: brain mechanisms and psychophysiology. *Biol. Psychiatry* 44, 1248–1263. doi: 10.1016/S0006-3223(98)00275-3

Larkin, G. R., Gibbs, S. E., Khanna, K., Nielsen, L., Carstensen, L. L., and Knutson, B. (2007). Anticipation of monetary gain but not loss in healthy older adults. *Nat. Neurosci.* 10, 787–791. doi: 10.1038/nn1894

Leclerc, C. M., and Kensinger, E. A. (2008). Age-related differences in medial prefrontal activation in response to emotional images. *Cogn. Affect. Behav. Neurosci.* 8, 153–164. doi: 10.3758/CABN.8.2.153

Libkuman, T. M., Otani, H., Kern, R., Viger, S. G., and Novak, N. (2007). Multidimensional normative ratings for the international affective picture system. *Behav. Res. Methods* 39, 326–334. doi: 10.3758/BF03193164

Lieberman, M. D., Berkman, E. T., and Wager, T. D. (2009). Correlations in social neuroscience aren't voodoo: a reply to Vul, et al. *Perspect. Psychol. Sci.* 4, 299–307. doi: 10.1111/j.1745-6924.2009.01128.x

Lieberman, M. D., and Cunningham, W. A. (2009). Type I and Type II error concerns in fMRI research: re-balancing the scale. *Soc. Cogn. Affect. Neurosci.* 4, 423–428. doi: 10.1093/scan/nsp052

Lieberman, M. D., Eisenberger, N. I., Crockett, M. J., Tom, S. M., Pfeifer, J. H., and Way, B. M. (2007). Putting feelings into words: affect labeling disrupts amygdala activity to affective stimuli. *Psychol. Sci.* 18, 421–428. doi: 10.1111/j.1467-9280.2007.01916.x

Mather, M., Canli, T., English, T., Whitfield, S., Wais, P., Ochsner, K., et al. (2004). Amygdala responses to emotionally valenced stimuli in older and younger adults. *Psychol. Sci.* 15, 259–263. doi: 10.1111/j.0956-7976.2004.00662.x

Mather, M., and Carstensen, L. L. (2003). Aging and attentional biases for emotional faces. *Psychol. Sci.* 14, 409–415. doi: 10.1111/1467-9280.01455

Mather, M., and Carstensen, L. L. (2005). Aging and motivated cognition: the positivity effect in attention and memory. *Trends Cogn. Sci.* 9, 496–502. doi: 10.1016/j.tics.2005.08.005

Mather, M., and Knight, M. (2005). Goal-directed memory: the role of cognitive control in older adults' emotional memory. *Psychol. Aging* 20, 554–570. doi: 10.1037/0882-7974.20.4.554

Mather, M., and Knight, M. R. (2006). Angry faces get noticed quickly: threat detection is not impaired among older adults. *J. Gerontol. B Psychol. Sci. Soc. Sci.* 61, P54–P57. doi: 10.1093/geronb/61.1.P54

Moriguchi, Y., Negreira, A., Weierich, M., Dautoff, R., Dickerson, B. C., Wright, C. I., et al. (2011). Differential hemodynamic response in affective circuitry with aging: an FMRI study of novelty, valence, and arousal. *J. Cogn. Neurosci.* 23, 1027–1041. doi: 10.1162/jocn.2010.21527

Nashiro, K., Sakaki, M., and Mather, M. (2012). Age differences in brain activity during emotion processing: Reflections of age-related decline or increased emotion regulation? *Gerontology* 58, 156–163. doi: 10.1159/000328465

Nichols, T., Brett, M., Andersson, J., Wager, T., and Poline, J. B. (2005). Valid conjunction inference with the minimum statistic. *Neuroimage* 25, 653–660. doi: 10.1016/j.neuroimage.2004.12.005

Ochsner, K. N., Ray, R. D., Cooper, J. C., Robertson, E. R., Chopra, S., Gabrieli, J. D., et al. (2004). For better or for worse: neural systems supporting the cognitive down- and up-regulation of negative emotion. *Neuroimage* 23, 483–499. doi: 10.1016/j.neuroimage.2004.06.030

Phillips, M. L., Drevets, W. C., Rauch, S. L., and Lane, R. (2003). Neurobiology of emotion perception I: the neural basis of normal emotion perception. *Biol. Psychiatry* 54, 504–514. doi: 10.1016/S0006-3223(03)00168-9

Ribeiro, R. L., Teixeira-Silva, F., Pompéia, S., and Bueno, O. F. A. (2007). IAPS includes photographs that elicit low-arousal physiological responses in healthy volunteers. *Physiol. Behav.* 91, 671–675. doi: 10.1016/j.physbeh.2007.03.031

Roalf, D. R., Pruis, T. A., Stevens, A. A., and Janowsky, J. S. (2011). More is less: emotion induced prefrontal cortex activity habituates in aging. *Neurobiol. Aging* 32, 1634–1650. doi: 10.1016/j.neurobiolaging.2009.10.007

Russell, J. A. (1980). A circumplex model of affect. *J. Pers. Soc. Psychol.* 39, 1161. doi: 10.1037/h0077714

Scheibe, S., and Carstensen, L. L. (2010). Emotional aging: recent findings and future trends. *J. Gerontol. Psychol. Sci.* 65, 135–144. doi: 10.1093/geronb/gbp132

St. Jacques, P., Dolcos, F., and Cabeza, R. (2010). Effects of aging on functional connectivity of the amygdala during negative evaluation: a network analysis of fMRI data. *Neurobiol. Aging* 31, 315–331. doi: 10.1016/j.neurobiolaging.2008.03.012

Streubel, B., and Kunzmann, U. (2011). Age differences in emotional reactions: arousal and age-relevance count. *Psychol. Aging* 26, 966–978. doi: 10.1037/a0023424

Tessitore, A., Hariri, A. R., Fera, F., Smith, W. G., Das, S., Weinberger, D. R., et al. (2005). Functional changes in the activity of brain regions underlying emotion processing in the elderly. *Psychiatry Res.* 139, 9–18. doi: 10.1016/j.pscychresns.2005.02.009

Tsai, J. L., Levenson, R. W., and Carstensen, L. L. (2000). Autonomic, subjective, and expressive responses to emotional films in older and younger Chinese Americans and European Americans. *Psychol. Aging* 15, 684–693. doi: 10.1037/0882-7974.15.4.684

Urry, H. L., van Reekum, C. M., Johnstone, T., Kalin, N. H., Thurow, M. E., Schaefer, H. S., et al. (2006). Amygdala and ventromedial prefrontal cortex are inversely coupled during regulation of negative affect and predict the diurnal pattern of cortisol secretion among older adults. *J. Neurosci.* 26, 4415–4425. doi: 10.1523/JNEUROSCI.3215-05.2006

Williams, L. M., Brown, K. J., Palmer, D., Liddell, B. J., Kemp, A. H., Olivieri, G., et al. (2006). The mellow years? Neural basis of improving emotional stability over age. *J. Neurosci.* 26, 6422–6430. doi: 10.1523/JNEUROSCI.0022-06.2006

Winecoff, A., Labar, K. S., Madden, D. J., Cabeza, R., and Huettel, S. A. (2011). Cognitive and neural contributors to emotion regulation in aging. *Soc. Cogn. Affect. Neurosci.* 6, 165–176. doi: 10.1093/scan/nsq030

Wood, S., and Kisley, M. A. (2006). The negativity bias is eliminated in older adults: age-related reduction in event-related brain potentials associated with evaluative categorization. *Psychol. Aging* 21, 815–820. doi: 10.1037/0882-7974.21.4.815

Wright, C. I., Wedig, M. M., Williams, D., Rauch, S. L., and Albert, M. S. (2006). Novel fearful faces activate the amygdala in healthy young and elderly adults. *Neurobiol. Aging* 27, 361–374. doi: 10.1016/j.neurobiolaging.2005.01.014

Yamasaki, H., LaBar, K. S., and McCarthy, G. (2002). Dissociable prefrontal brain systems for attention and emotion. *Proc. Natl. Acad. Sci. U.S.A.* 99, 11447–11451. doi: 10.1073/pnas.182176499

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 05 January 2014; accepted: 12 June 2014; published online: 28 July 2014.

Citation: Dolcos S, Katsumi Y and Dixon RA (2014) The role of arousal in the spontaneous regulation of emotions in healthy aging: a fMRI investigation. Front. Psychol. ***5****:681. doi: 10.3389/fpsyg.2014.00681*

This article was submitted to Emotion Science, a section of the journal Frontiers in Psychology.

frontiers in PSYCHOLOGY

ORIGINAL RESEARCH ARTICLE
published: 17 June 2014
doi: 10.3389/fpsyg.2014.00609

Fluid cognitive ability is a resource for successful emotion regulation in older and younger adults

Philipp C. Opitz[1†], Ihno A. Lee[2], James J. Gross[2] and Heather L. Urry[1*]

[1] Department of Psychology, Tufts University, Medford, MA, USA
[2] Department of Psychology, Stanford University, Stanford, CA, USA

Edited by:
Natalie Ebner, University of Florida, USA

Reviewed by:
Hakan Fischer, Stockholm University, Sweden
Sanda Dolcos, University of Illinois at Urbana-Champaign, USA
Susanne Scheibe, University of Groningen, Netherlands

***Correspondence:**
Heather L. Urry, Department of Psychology, Tufts University, 490 Boston Avenue, Medford, MA 02155, USA
e-mail: heather.urry@tufts.edu

†Present address:
Philipp C. Opitz, Department of Gerontology, University of Southern California, Los angeles, CA, USA

The Selection, Optimization, and Compensation with Emotion Regulation (SOC-ER) framework suggests that (1) emotion regulation (ER) strategies require resources and that (2) higher levels of relevant resources may increase ER success. In the current experiment, we tested the specific hypothesis that individual differences in one internal class of resources, namely cognitive ability, would contribute to greater success using cognitive reappraisal (CR), a form of ER in which one reinterprets the meaning of emotion-eliciting situations. To test this hypothesis, 60 participants (30 younger and 30 older adults) completed standardized neuropsychological tests that assess fluid and crystallized cognitive ability, as well as a CR task in which participants reinterpreted the meaning of sad pictures in order to alter (increase or decrease) their emotions. In a control condition, they viewed the pictures without trying to change how they felt. Throughout the task, we indexed subjective emotional experience (self-reported ratings of emotional intensity), expressive behavior (corrugator muscle activity), and autonomic physiology (heart rate and electrodermal activity) as measures of emotional responding. Multilevel models were constructed to explain within-subjects variation in emotional responding as a function of ER contrasts comparing increase or decrease conditions with the view control condition and between-subjects variation as a function of cognitive ability and/or age group (older, younger). As predicted, higher fluid cognitive ability—indexed by perceptual reasoning, processing speed, and working memory—was associated with greater success using reappraisal to alter emotional responding. Reappraisal success did not vary as a function of crystallized cognitive ability or age group. Collectively, our results provide support for a key tenet of the SOC-ER framework that higher levels of relevant resources may confer greater success at emotion regulation.

Keywords: emotion regulation, cognitive reappraisal, working memory, cognitive ability, SOC-ER, older adults

INTRODUCTION

Emotions are frequently helpful in achieving adaptive goals. However, our emotions can at times be either the wrong intensity or duration, thereby impeding rather than facilitating goal achievement. When this happens, it is useful to regulate our emotions. Gross' (1998) process model of emotion regulation (ER) describes five families of ER strategies, namely, situation selection, situation modification, attentional deployment, cognitive change, and response modulation. Research has shown that people differ with regard to the strategies they habitually choose to regulate their emotions (Gross and John, 2003) and there are individual differences in success at implementing specific ER strategies as well (for example, as a function of older vs. younger age; Shiota and Levenson, 2009; Opitz et al., 2012a).

Although ER has been linked to important adaptive outcomes (Appleton et al., 2013; Gross, 2014), we know very little about the factors that explain these individual differences. The Selection, Optimization, and Compensation with Emotion Regulation (SOC-ER) framework (Urry and Gross, 2010; Opitz et al., 2012b) offers a set of factors that may help explain individual differences in ER.

According to the SOC-ER framework, successful ER depends on three factors: (1) choosing ER strategies for which resources are available at sufficient levels (Selection), (2) devoting time, practice, and effort to using these strategies successfully (Optimization), and (3) choosing alternate ER strategies when the ER strategy one chose initially is unsuccessful, perhaps as a result of insufficient resources (Compensation) (Urry and Gross, 2010; Opitz et al., 2012b). The cornerstone of this framework is the notion that successful ER requires resources—internal abilities and/or environmental affordances that promote the use of a given ER strategy. From this perspective, as resource levels vary within individuals (i.e., from one situation to the next, or from one phase of the life span to the next) or across individuals (i.e., from one person to another), ER success should vary accordingly. In the present study, we test this cornerstone SOC-ER idea with respect to individual differences in one class of resources—cognitive ability—and one ER strategy, cognitive reappraisal (CR).

CR refers to altering one's emotional response by reinterpreting the emotion-eliciting situation or one's response to it. Neuroimaging studies have shown that successful CR recruits brain areas involved in working memory, suggesting that successful CR may depend on the ability to hold information in mind (Ochsner et al., 2002, 2004; McRae et al., 2010). Additionally, CR has been shown to be most effective when initiated early in the emotion-generative cycle (Sheppes and Meiran, 2007), signifying that the ability to process information quickly may be beneficial, too. These observations hint at two cognitive abilities—working memory capacity (WMC) and processing speed (PS)—that may be resources for CR and thus contribute to CR success. Providing partial support for this idea, cross-sectional research suggests that older adults (OA), who exhibit deficits in WMC and PS (e.g., Salthouse et al., 2003; Hedden and Gabrieli, 2004), are less successful using some forms of CR compared to younger adults (YA), like detached reappraisals aimed at decreasing negative emotions (Shiota and Levenson, 2009). Of course, the observation of an age difference provides only indirect support for the role of cognitive ability as a resource for CR. To clarify our understanding of the relationship between these putative resources and CR, research directly assessing relations between cognitive abilities and CR success is needed.

Schmeichel et al. (2008) presented the first direct assessment of the role of cognitive ability as a resource for successful CR in a between-subjects design. These authors demonstrated that higher levels of WMC were correlated with reduced experience of unpleasant emotion in a group of participants who were assigned to adopt neutral, nonemotional appraisals of disgusting film clips. In another between-subjects design, Malooly et al. (2013) assessed relations between affective and nonaffective cognitive flexibility and successful CR. In both cases, cognitive flexibility was operationalized as reaction time costs of switching between rules regarding how to process different features of target stimuli. In the nonaffective flexibility task, neither the rules nor the target stimuli were emotional; in the affective flexibility task, both were emotional. Results of this study suggested that higher levels of affective cognitive flexibility were associated with reduced experience of sad emotion in a group of participants who were assigned to reappraise sad film clips by adopting a neutral, analytic, objective mindset. Finally, McRae et al. (2012) examined the relationship between CR and WMC, as well as other components of cognitive ability, in a within-subjects context. Results indicated moderate positive correlations between the ability to use CR to decrease unpleasant emotions and WMC and set-shifting costs; a similar trend was observed for perceptual reasoning. By contrast, verbal fluency and response inhibition were uncorrelated with reappraisal ability.

Together, these findings from Schmeichel et al. (2008); McRae et al. (2012); Malooly et al. (2013) and provide convergent, direct support for the role of cognitive ability—particularly, WMC and cognitive flexibility—as a resource for successful CR. These studies further suggest that not all cognitive abilities are resources for CR, pointing to a certain degree of specificity regarding the role of cognitive resources in CR. Still, with only these three studies in hand, important questions remain.

In the present paper, our primary goal is to address the following questions: First, are as-of-yet unexamined cognitive abilities resources for successful CR? Here, we examine PS, an index of cognitive ability that also has promise as a resource for CR. We also examine working memory, verbal ability, and perceptual reasoning to conceptually replicate previous findings. Second, are associations between cognitive ability and CR success dependent on whether one's CR goal is to decrease or increase one's emotional response? The two previous studies found that some aspects of cognitive ability were associated with the ability to use CR to *decrease* unpleasant emotional experience. Here we examine the ability to *increase* unpleasant emotion too. This is important methodologically because it provides an active, effortful comparison. In addition, this is important conceptually since ER efforts are sometimes directed in pursuit of contrahedonic feeling states (Ford and Tamir, 2012; Tamir and Ford, 2012; Tamir et al., 2013).

To achieve our primary goal, we recruited both younger and OA. In light of aforementioned age differences in cognitive abilities of interest, recruiting younger and OA allowed us to maximize meaningful variation in cognitive abilities in our sample. This also allowed us to address a secondary goal, which was to assess whether older age—normatively associated with decrements in cognitive resources including WM and PS—impacts CR success. Previous research has demonstrated mixed results, with some indicating age-related decrements for reappraisals aimed at decreasing unpleasant emotions (Opitz et al., 2012a) and detached reappraisals (Shiota and Levenson, 2009), and others indicating age-related sparing for reappraisals aimed at increasing unpleasant emotions (Opitz et al., 2012a) and positive reappraisals (Shiota and Levenson, 2009; Lohani and Isaacowitz, 2013). However, these mixed results may reflect variation across studies in emotional load and task demands. OA may perform less well only when CR tasks include highly potent negative images and require excessive shifting from one condition to the next. Here we examine CR success in a task that keeps emotional load and task demands to a minimum.

In pursuit of our primary and secondary goals, our younger and older participants completed well-validated, standardized neuropsychological measures of fluid and crystallized cognitive ability and a CR task. In the CR task, participants used CR to increase or decrease their emotional response to sad pictures. We chose sad stimuli specifically as previous research suggests sadness to be among the most frequently regulated emotions (Gross et al., 2006), thus maximizing the likelihood that participants would want to regulate emotions elicited by the pictures and have some experience doing so. These two conditions were compared to a view control condition in which participants responded naturally to the pictures without trying to change how they felt. We used a gaze-directed variant of the CR task validated in previous studies (Urry, 2010; Opitz et al., 2012a). The gaze direction manipulation enabled us to maximize the extent to which deployment of attention to arousing and non-arousing information was equivalent across the increase, view, and decrease CR instructions. This may be particularly important when studying OA because OA are more apt to deploy greater attention to positive than negative emotional information in some contexts (Isaacowitz et al., 2008, 2009).

During the CR task, we recorded subjective emotional experience (self-reported ratings of intensity), expressive behavior (corrugator muscle activity), and autonomic physiology [heart rate (HR) and electrodermal activity (EDA)] as measures of emotional responding. Multilevel models were constructed to explain within-subjects variation in emotional responding as a function of the CR manipulations and between-subjects variation as a function of cognitive ability or age. Our comprehensive approach offers several benefits. First, we are capturing trial-by-trial variation in emotional responding in three components of emotion. Past studies suggest that components of emotional responding cohere to some degree (Mauss et al., 2005), but this coherence is imperfect. This means one cannot measure just one component and make strong inferences about other, unmeasured components. This also means some components of emotional responding may show predicted effects while others may not. Second, our measures of expressive behavior and autonomic physiology are less subject to demand characteristics than self-report evaluations of emotional experience. Thus, were we to find predicted effects for expressive behavior and/or autonomic physiology, this would bolster the interpretation that differences between the CR conditions of interest reflect emotion regulatory success and not just demand characteristics of the experiment. Third, the continuous nature of our peripheral physiological measures provided a moment-to-moment index of responses during the task, allowing us to separately model pre-instruction and post-instruction activity. This allowed us to account for initial emotion reactivity (for which there often are age differences).

With these design features in place, we tested the hypothesis that higher levels of fluid (perceptual reasoning, PS, and working memory) and perhaps crystallized (verbal ability) cognitive abilities would predict greater CR success.

Table 1 | Characteristics of the sample.

Measure	Younger	Older	Significant age difference?
Mean (*SD*) age in years	19.45 (1.18)	61.90 (5.14)	$t_{(30.96)} = -42.44$, $p < 0.001$
Total *N*	30	30	
Men	10 (33%)	13 (43%)	$\chi^2(1) = 0.648$, $p = 0.421$
Women	19 (67%)	16 (57%)	
HIGHEST LEVEL OF EDUCATION			
High school diploma	11 (36%)	1 (3%)	$\chi^2(3) = 30.21$, $p < 0.001$
Some college	16 (53%)	6 (20%)	
College diploma	2 (6%)	10 (33%)	
Graduate degree	0	12 (40%)	
MARITAL STATUS			
Never married	29 (97%)	3 (10%)	$\chi^2(4) = 47.13$, $p < 0.001$
Married	0	12 (40%)	
Separated	0	1 (3%)	
Divorced	0	11 (36%)	
Widowed	0	2 (6%)	

Demographic data for two participants (one younger) were not collected, and are therefore not included (except in total N).

METHODS

PARTICIPANTS

Thirty younger (20 female, 18–22 years, $M = 19.5$, $SD = 1.18$) and 30 older (17 female, 55–71 years, $M = 61.9$, $SD = 5.14$) adults were recruited via internet (e.g., http://www.craigslist.com), local newspaper, and community e-mailing list advertisements. Participants endorsed the following non-exclusive racial categories: Asian: 11 (18.3%); White: 46 (76.7%); Declined to respond: 3 (5%). Two participants (3.4%) endorsed being of Hispanic origin, and two participants declined to report ethnicity. See **Table 1** for additional participant characteristics.

No participants reported any history of psychiatric or neurological disorders, or current use of any psychoactive medications. Before completing the experiment, participants completed a hearing test (WWW Hearing Test, Digital Recordings, Halifax, NS, Canada) and two vision tests (Arditi, 2005; Dougherty et al., 2005) to ensure they could hear and see the stimuli. All procedures were approved by the Social, Behavioral, and Educational Research Institutional Review Board at Tufts University. Participants provided written informed consent prior to participating.

MATERIALS

Cognitive ability

To assess cognitive ability, participants completed four subtests of the Wechsler Adult Intelligence Scale IV (WAIS IV, Pearson, San Antonio, TX).

We assessed working memory using the Digit Span (DS) task, in which participants hear and verbally reproduce an increasing number of digit strings (two trials per digit string length) in forward order (DS Forward), backward order (DS Backward), or in ascending order (Sequencing). The task continues until both trials of a given digit string length are incorrect or until the last item of the task is reached.

We assessed verbal ability using the Vocabulary (VC) task, in which participants provide definitions for increasingly difficult words presented orally. For instance, on an early (easy) trial, participants defined "APPLE," whereas on a later (hard) trial, participants defined "PALLIATE." For the purposes of this paper, we report scores based on one half of the VC task. The other difficulty-matched half was subject to a manipulation of no relevance to this paper.

We assessed perceptual reasoning using the Block Design (BD) task, in which participants are given a set of nine red-and/or-white cubes, which they have to assemble to reproduce two-dimensional patterns of increasing difficulty. The task continues until two consecutive trials are incorrect or until the last item of the task is reached.

Lastly, we assessed PS using the Coding (CD) task, in which participants are given a sheet of paper containing a "key" that links numbers one through nine with simple non-alphanumeric symbols. Participants are asked to draw the correct symbol (according to the key) below each of multiple rows of numbers on the sheet below until 2 min has elapsed or until the last item of the task is reached. Data for one older participant were not available for CD due to participant misunderstanding of instructions.

OA tend to perform less well than YA on the DS, BD, and CD subtests, which are indicators of fluid cognitive ability; OA perform similarly or better than YA on the VC subtest, an indicator of crystallized cognitive ability (Salthouse et al., 2003; Hedden and Gabrieli, 2004).

Picture stimuli

In the CR task, which is described below, participants viewed a set of 120 digital color pictures (800 × 600 pixels). Most were selected from the International Affective Picture System (IAPS; Lang et al., 2008) using normative valence ratings provided by Mikels et al. (2005). Specifically, we used those images that Mikels et al. (2005) categorized as sad on a scale from 1 to 7, where 1 corresponded to *not at all* sad, and 7 corresponded to *very sad*; our set was moderately sad on average ($M = 4.09$, $SD = 0.85$). To have enough sad pictures to avoid repetition, we supplemented the IAPS pictures with pictures selected from stock photo libraries (Shutterstock and the Wellcome Image Collection). These pictures, for which no normative ratings exist, were selected for content similar to those selected from the IAPS. The final set of 120 sad pictures mostly depicted withdrawn, lonely, or sad older and YA and/or injured, solitary, or apparently sad animals. We purposefully sought content that is relevant to participants in both age groups.

Cognitive reappraisal task

The pictures were presented in the context of a gaze-directed CR task, a variant of the task validated by Urry (2010) and also used with both younger and OA by Lang et al. (2008); Opitz et al. (2012b). This task comprised 120 trials described by crossing two within-subjects factors, CR condition (increase, view, decrease, no CR) and gaze direction condition (arousing, free/no gaze direction, non-arousing). Prior to completing the CR task, participants received in-depth training to ensure that they understood the CR and gaze direction manipulations (described below) as well as how to rate the intensity of their emotional response on each trial.

For the CR manipulation, participants were trained to increase or decrease their emotional response to the pictures by considering the personal relevance of the depicted situation (self-focused reappraisal) or imagining alternative outcomes (situation-focused reappraisal). Cues to begin using CR were presented via single-word audio recording, "increase" or "decrease" 3 s after picture onset. As part of their training, participants saw a picture of a man lying in a hospital bed, seemingly in pain. For the "increase" instruction, participants were told they could imagine that "you yourself or a loved one are the person in this picture, or that you are present and are witnessing the man's pain and struggle." Conversely, for the "decrease" instruction, participants were told that they could imagine that "you are simply observing the man objectively, or that he will get better soon." A third audio recording, "view," served as a cue to respond naturally without trying to change how they felt. A fourth CR condition, "no CR," entailed viewing the picture with no instruction, which enabled us to determine whether the simple instruction to "view" would alter emotional responding. For all four conditions, participants were instructed not to think of the pictures as fake or unreal.

For the gaze direction manipulation, participant gaze was directed to an emotionally arousing or non-arousing (neutral) area of the picture beginning 4 s after picture onset, or participant gaze was not directed, i.e., allowed to vary freely. This gaze direction manipulation enabled us to control the ways in which participants deployed their visual attention to the emotional information in the pictures during the 8-s regulation period of interest (c.f., Isaacowitz et al., 2008, 2009). As validated in prior work (Urry, 2010), eye tracking data (not shown) confirmed that the present sample of participants followed the gaze direction instruction equally across the CR conditions, increasing looking time in the designated areas of interest following the manipulation onset. These data also suggested that older and YA did not differ in their gaze behavior.

The CR task was programmed using E-Prime version 1.2.1.8 (Psychology Software Tools, Inc., Sharpsburg, PA) in 10 blocks of 12 trials each. Pictures were presented on a TFT display (1280 × 1204 maximum resolution) while auditory instructions were delivered via speakers in a sound- and RF-shielded experiment booth. Half of the blocks included the "increase," "view," and "no CR" conditions, while the other half included the "decrease," "view," and "no CR" conditions. We blocked increase and decrease CR trials in this manner to reduce the mental set shifting demands of the experiment. CR conditions, gaze directions, and pictures were otherwise randomly assigned to each trial. The gaze-directed CR task trial structure is depicted in **Figure 1**.

DEPENDENT VARIABLES

Three measures of emotional responding were recorded during the CR task. Self-report ratings of emotional intensity were collected at the end of each trial. Expressive behavior (corrugator muscle activity via facial electromyography) and autonomic physiology (HR and EDA) were collected continuously using an MP150 system (Biopac, Goleta, CA) and processed offline using ANSLAB (Wilhelm and Peyk, 2005).

Self-report ratings of intensity

Self-report ratings of emotional intensity ranging from 1 (not very intense) to 9 (very intense) were collected at the end of each trial. This 9-point numeric scale was illustrated with five figures based on the arousal scale of the Self-Assessment Manikin (Lang et al., 2008). Figures ranged from a relaxed, sleepy figure at the left (not at all intense) to an excited, wide-eyed figure at the right (very intense; see **Figure 1**).

Corrugator electromyography (EMG)

Corrugator activity has been shown to be sensitive to stimulus valence, with greater activity being associated with higher levels of stimulus unpleasantness (Bradley and Lang, 2007). Two 4-mm Ag/AgCl electrodes were placed in bipolar configuration over the right eye per Fridlund and Cacioppo (1986). One ground was placed on the forehead. The data were sampled at 1000 Hz and

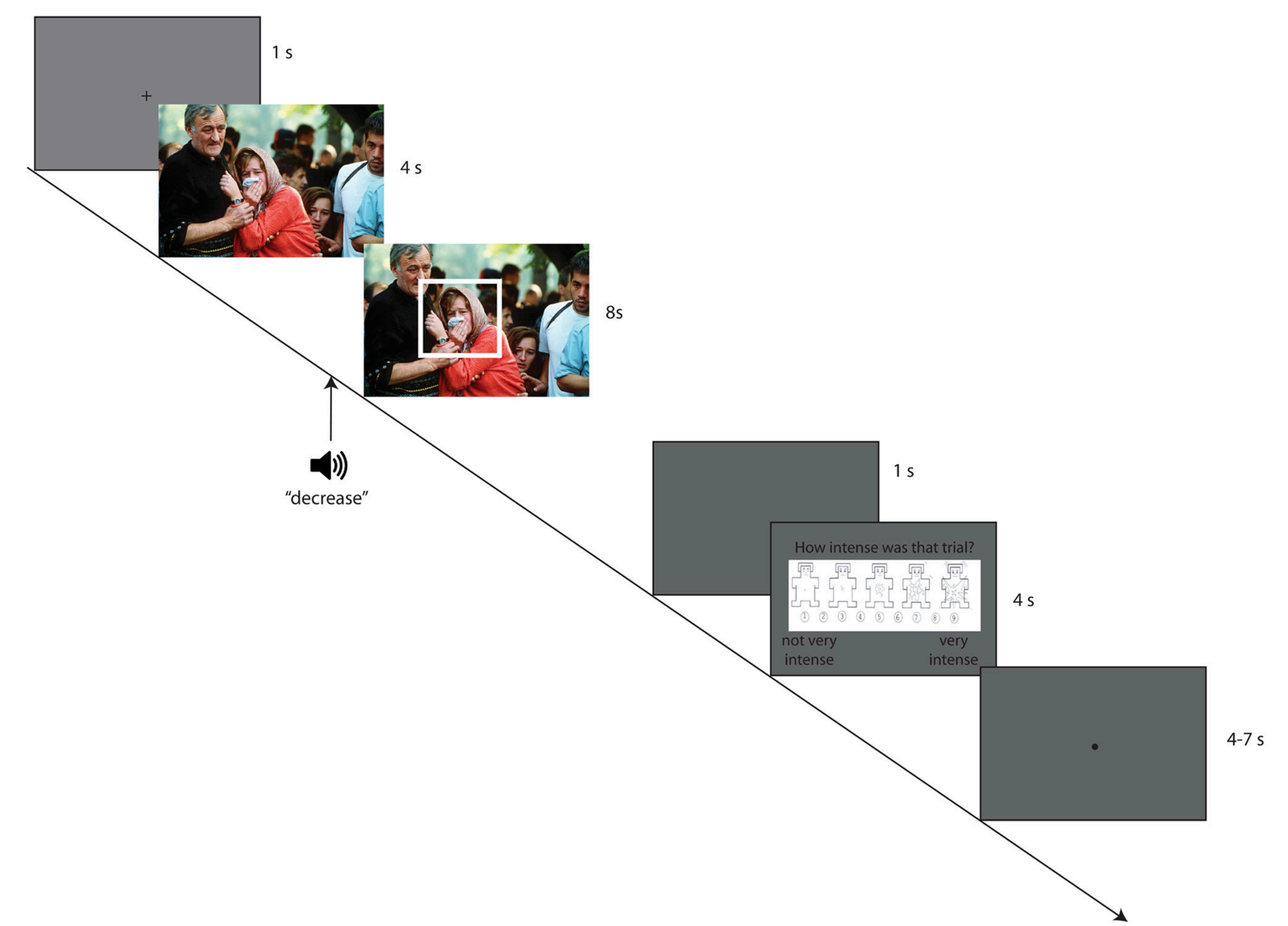

FIGURE 1 | Trial structure. Participants first saw a fixation cross for 1 s, followed by a picture for a total of 12 s. Three seconds after picture onset, participants heard the cognitive reappraisal (CR) instruction for that trial, if applicable (in this case, "decrease"). One second thereafter, a box directed them to look in an arousing or nonarousing area of the picture, if applicable (in this case, the box is directing gaze to an arousing area). After the 8-s regulatory period during which they followed the CR and gaze direction instructions, participants briefly saw a gray screen (1 s). This was followed by a 9-point intensity rating screen which was available for up to 4 s. After the rating screen, a gray screen with a black dot signaled a break between trials, which varied from 4 to 7 s. Photo of mourning family from Evstafiev (1992). Used with permission of the photographer.

bandpass filtered online (5 Hz to 3 kHz; 60-Hz notch filter on). Offline, data were resampled to 400 Hz, rectified, filtered (16 Hz low-pass), decimated to 4 Hz, and smoothed (1-s prior moving average).

Electrocardiography

Electrocardiography was used to measure HR, which is dually innervated by the sympathetic and parasympathetic branches of the autonomic nervous system. In event-related paradigms involving passive viewing of negative pictures, HR is sensitive to stimulus valence and often exhibits an initial, parasympathetically mediated deceleration (Bradley and Lang, 2007). Two disposable Ag/AgCl electrodes pregelled with 7% chloride gel (1 cm circular contact area) were placed under the left and right collarbones on the chest after swabbing with an alcohol or an electrode prep pad. ECG was acquired continuously at 1000 Hz. Offline, the ECG signal was downsampled to 400 Hz and bandpass-filtered from 0.5 to 40 Hz.

Interbeat interval series were created by identifying R-spikes using automated ANSLAB algorithms. R-spikes that were not detected automatically, thus leading to an erroneously long period between successive R-spikes, were marked for inclusion by hand. Similarly, R-spikes that were identified incorrectly, thus leading to an erroneously short period between successive R-spikes, were removed by hand. Following such artifact correction, the interbeat interval series was converted to HR in beats per minute. HR data were decimated to 10 Hz and then smoothed with a 1-s prior moving average filter.

Electrodermal activity

EDA was selected as a pure measure of sympathetic activation of the autonomic nervous system. Two disposable Ag/AgCl electrodes pregelled with 0.5% chloride isotonic gel (1 cm circular contact area) were attached to the distal phalanges of the index and middle fingers on the left hand. EDA level was recorded with DC coupling and constant voltage electrode excitation at 31.25 Hz (sensitivity = 0.7 nS). Offline, EDA was smoothed with a 1-Hz, low-pass filter, decimated to 10 Hz, and linearly detrended on a trial-by-trial basis. One ground electrode for all physiological channels was placed on the forehead.

PROCEDURES

After providing informed consent, participants completed the BD, CD, DS, and VC subtests of the WAIS-IV in the order described above. Participants were then prepared for physiological recording and completed the training procedure for the CR task. Immediately following this training, participants completed the CR task. At various points in the session, participants completed additional questionnaires and a second set of WAIS-IV subtests. These additional procedures were not the focus of this report and some were subject to an unrelated manipulation thus the data are not reported here[1].

DATA REDUCTION, RETENTION, AND ANALYSIS

For the continuous peripheral physiological measures, we summarized raw activity for two periods of interest in each trial, pre-instruction activity (reactivity period; mean of activity occurring 4 s after picture onset) and post-instruction activity (regulation period; mean of activity occurring 8 s after both ER manipulations). To prevent leveraging of condition estimates by outlying values in the dependent variables, trials for which the estimate of Mahalanobis Distance within each measure was too large ($p < 0.001$) were set to missing (see Fidell and Tabachnick, 2003). An average of 95.4% ($SD = 0.789$; minimum = 94.2%, maximum = 96.0%) of all observations were available for analysis.

Multilevel analyses with two levels, some incorporating latent variables (see Hox, 2002; Kline, 2010), were conducted using Mplus v. 7.11 (Muthén and Muthén, 1998–2013). Continuous predictors were grand-mean centered. Estimates were generated (and missing values handled) using full information maximum likelihood estimation with robust standard errors. Although multilevel analyses are reported less often than traditional repeated measures analyses, they have three key advantages. First, this approach allows us to model emotional responding as a latent construct with experiential (self-reported intensity), expressive (corrugator activity), and autonomic physiological (HR, EDA) components. Traditional analyses compel one to analyze each measure as if they were independent. Second, this approach allows us to model trial-related variation in the dependent variable within each condition. Traditional analyses compel one to average across trials within each condition with the perhaps unfounded assumption that there is no trial-related variation. Third, this approach provides estimates using all available data. Traditional analyses compel listwise deletion of cases with missing observations.

RESULTS

Results are presented below in four sections. We first present preliminary analyses undertaken to determine (1) whether there are individual differences in pre-instruction emotion reactivity, and (2) whether there are main and/or interactive effects of our CR and gaze direction manipulations. Then, in pursuit of our primary goal, we present analyses germane to determining whether cognitive ability predicts successful CR. Next, in pursuit of our secondary goal, we present analyses germane to determining whether there are age differences in CR success. Finally, we report supplemental analyses that provide estimates of emotional responding as a function of age group, CR, and gaze direction during the regulation period on a measure-by-measure basis.

PRELIMINARY ANALYSES

Individual differences in pre-instruction emotion reactivity

Using a two-level structural equation model, we examined whether there were individual differences in pre-instruction reactivity to the stimuli as a function of between-subjects variables of primary and secondary interest in this research (fluid cognitive ability, crystallized cognitive ability, age group). We also examined education level and marital status, both of which varied as a function of age group and thus represent control variables of interest.

On the first (within-subjects) level, activity during the reactivity period was regressed on baseline activity (mean of activity occurring 1 s prior to picture onset) for each of the three physiological measures.

On the second (between-subjects) level, activity during the reactivity period for each measure (self-reported intensity corrugator activity, HR, and EDA) was regressed on five between-subjects predictors as follows: fluid cognitive ability, crystallized cognitive ability, age group (older = 1, younger = 0), ever married (1 = yes, 0 = no), and education level. Fluid cognitive ability was modeled as a latent predictor variable with three manifest indicators, BD, CD, DS; variance was constrained at 1. Crystallized cognitive ability was modeled as the stand-alone manifest indicator, VC.

Participants exhibited significant, nonzero values for all four criterion variables (self-reported intensity $B = 4.26$, $SE = 0.353$; corrugator activity $B = 7.15$, $SE = 0.459$; HR $B = 72.1$ $SE = 0.876$; and EDA $B = 11.57$, $SE = 0.014$, all $ps < 0.001$). Factor loadings for the fluid cognitive ability latent predictor variable were positive and significant ($p = 0.001$ for BD and CD; $p = 0.002$ for DS). Finally, there were some significant individual differences in the criterion variables as follows: Higher fluid cognitive ability and lower crystallized cognitive ability were associated with lower EDA ($B = -0.02$, $SE = 0.009$, $p = 0.031$ and $B = 0.002$, $SE = 0.001$, $p = 0.031$, respectively) but not self-reported intensity, corrugator activity, or HR (all $ps > 0.20$). Older age was associated with lower corrugator activity ($B = -1.63$, $SE = 0.782$, $p = 0.037$) but not self-reported

[1]Before and after the WAIS-IV subtests reported here, participants completed items assessing appraisals of threat and challenge and current emotional state. Immediately after the CR task, participants provided open-ended reports of strategies used, and items assessing satisfaction with life, state and trait anxiety, ER, perceived stress, health, quality of life, and socioeconomic status. Participants then received information related to a between-subjects stereotype threat manipulation and completed the second set of WAIS-IV subtests (matrix reasoning, letter-number sequencing, symbol search, and the second, difficulty-matched VC subtest). Before and after the second set of WAIS-IV subtests, participants again completed items assessing appraisals of threat and challenge and current emotional state. At the end of the session, participants completed items assessing test anxiety, beliefs about the malleability of intelligence and emotions, age-related stereotypes of cognitive performance, and thoughts about what the experiment was about.

intensity, HR, or EDA (all $ps > 0.70$). Ever having been married was associated with higher corrugator activity ($B = 1.37$, $SE = 0.451$, $p = 0.002$), lower HR ($B = -3.28$, $SE = 1.557$, $p = 0.035$), and lower EDA ($B = -0.06$, $SE = 0.027$, $p = 0.026$) but not self-reported intensity ($p = 0.763$). Education level was not associated with any of the criterion variables (all $ps > 0.17$). We do not consider these isolated and non-predicted findings further.

Main and interactive effects of CR and gaze direction

In a second two-level structural equation model, we tested the main and interactive effects of the CR and gaze direction manipulations on within-subjects (trial-by-trial) variation in emotional responding. The first column of **Table 2** summarizes the criterion and predictor variables in this preliminary analysis.

On the first level, activity during the regulation period was regressed on activity during the reactivity period for each physiological measure in order to isolate CR- and gaze direction-related variation in emotional responding. Emotional responding was then modeled as one latent dependent variable with variance constrained at 1. Emotional responding had four manifest indicators, namely self-reported emotional intensity and corrugator activity, HR, and EDA during the regulation period.

The emotional responding latent dependent variable was regressed on three CR condition contrasts [increase (1) vs. view (−1), decrease (1) vs. view (−1), and no CR (1) vs. view (−1)] to estimate the effects of CR, and two gaze direction condition contrasts [arousing (1) vs. not directed (−1) and non-arousing (1) vs. not directed (−1)] to estimate the effects of gaze direction. The latent variable was also regressed on six contrasts reflecting the products of each of the CR condition contrasts with each of the gaze direction condition contrasts to estimate the interaction between CR and gaze direction.

On the second level, random slopes were estimated for the decrease and increase CR predictors and the arousing and non-arousing gaze direction predictors from the first level. Random slopes were not estimated for the no CR predictor, which was a covariate of no interest, or for the six interaction contrasts by convention (Hoffman and Rovine, 2007).

As shown in the second column of **Table 2**, this analysis revealed that two of four manifest indicators, self-reported intensity and corrugator activity, loaded positively and significantly on the latent emotional response dependent variable on the first level (both $p = 0.001$); a third, skin conductance, exhibited a trend in the same direction ($p = 0.083$). In addition, the CR manipulation impacted emotional responding as expected. Participants responded with greater emotion in the increase condition vs. the view condition ($B = 1.00$, $p < 0.001$), lower emotion in the decrease condition vs. the view condition ($B = -0.64$, $p < 0.001$), and lower emotion in the no CR condition vs. the view condition ($B = -0.18$, $p = 0.006$).

The gaze direction manipulation also impacted emotional responding. Participants responded with greater emotion when gaze was directed to an arousing area vs. when gaze was not directed ($B = 0.07$, $p = 0.086$, a nonsignificant trend), and lower emotion when gaze was directed to a non-arousing area vs. when gaze was not directed ($B = -0.17$, $p = 0.016$). Importantly, gaze direction moderated the decrease CR effect, significantly for the non-arousing gaze direction contrast ($B = 0.20$, $p = 0.013$) but not significantly for the arousing gaze direction contrast ($B = -0.11$, $p = 0.108$). Neither gaze direction contrast moderated the increase CR effect (both $p > 0.40$).

In light of the significant interaction above, we conducted a set of follow-up analyses in which we estimated the three CR effects separately for each of the three gaze direction conditions. In these analyses, a random slope was estimated at the between-subjects level for the decrease CR contrast. When gaze was not directed, participants responded with lower emotion in the decrease condition vs. the view condition ($B = -0.42$, $p = 0.009$). When gaze was directed to an arousing area, this decrease CR effect was even stronger ($B = -0.98$, $p < 0.001$). However, when gaze was directed to a non-arousing area, the decrease CR effect narrowly reached significance in the opposite direction ($B = 0.35$, $p = 0.048$).

These results suggest that CR generally impacts emotional responding in expected ways. However, using CR to decrease emotional responding was effective only when participants were directing attention to emotional information in the pictures, either on their own or as cued by us. Because gaze direction moderated some CR effects, subsequent hypothesis testing analyses retained gaze direction contrasts and their interaction terms as fixed effects within subjects.

Table 2 | Parameter estimates from preliminary analysis examining cognitive reappraisal and gaze direction effects on emotional responding.

Emotion response latent criterion variable	B (SE)
Indicators	**Factor loadings**
Self-reported intensity	0.961 (0.279)*
Corrugator activity	0.508 (0.085)**
Heart rate	0.077 (0.1)
Skin conductance	0.003 (0.001)+
Within-subjects predictors	**B (SE)**
CR CONTRASTS	
Decrease—view[a]	−0.637 (0.171)**
Increase—view[a]	0.997 (0.237)**
No CR—view	−0.176 (0.063)*
GAZE DIRECTION CONTRASTS	
Arousing—not directed[a]	0.07 (0.04)+
Non-arousing—not directed[a]	−0.166 (0.069)*
CR × GAZE DIRECTION INTERACTION CONTRASTS	
(Decrease—view) × (Arousing—not directed)	−0.112 (0.07)
(Increase—view) × (Arousing—not directed)	0.051 (0.066)
(No CR—view) × (Arousing—not directed)	−0.021 (0.062)
(Decrease—view) × (Non-arousing—not directed)	0.197 (0.079)*
(Increase—view) × (Non-arousing—not directed)	−0.045 (0.061)
(No CR—view) × (Non-arousing—not directed)	−0.037 (0.06)

CR, cognitive reappraisal. Pre-instruction activity was a positive, significant predictor of post-instruction activity for all three physiological measures; these estimates are not reported for the sake of brevity.

[a] Slope was estimated as a random effect.

$^{**}p < 0.001$, $^{*}p < 0.05$, $^{+}p < 0.10$.

PRIMARY ANALYSES

To test our hypothesis that higher cognitive ability would predict more successful CR, we evaluated a two-level structural equation model (referred to as the Cognitive Ability Model in **Table 3**).

On the first level, the predictor and criterion variables were the same as noted for the preliminary analysis that tested the main and interactive effects of CR and gaze direction[2].

On the second level, the slopes estimated from the decrease and increase CR predictors on the first level were treated as criterion variables that were regressed on two between-subjects predictors, fluid cognitive ability and crystallized cognitive ability. Fluid cognitive ability was modeled as a latent predictor variable with three manifest indicators, BD, CD, DS; variance was constrained at 1. Crystallized cognitive ability was modeled as the stand-alone manifest indicator, VC.

As shown in **Table 3**, factor loadings for the fluid cognitive ability latent predictor variable were positive and significant or nearly so ($p = 0.001$ for BD and CD; $p = 0.070$ for DS). Note that negative estimates of the association between cognitive ability and CR success are expected for the decrease effect since the contrast was calculated as decrease minus view. Positive estimates are expected for the increase effect since the contrast was calculated as increase minus view. Consistent with our hypothesis, this analysis revealed that higher fluid cognitive ability was associated with greater success at decreasing (B = -0.37, $p < 0.001$) and increasing ($B = 0.42$, $p = 0.001$) emotional responding. Crystallized cognitive ability as indexed by VC was not associated with the decrease or increase CR effect (both $p > 0.30$).

[2]The no CR vs. view contrast is retained in all models. We focus in text on comparisons between the increase and decrease conditions vs. the view condition. We do so because the view condition is a better control than the no CR condition because the view, increase, and decrease conditions all include an auditory instruction on each trial whereas the no CR condition does not.

In follow-up analyses, we repeated the analyses above, but this time specified the fluid cognitive ability latent predictor variable with just one indicator, setting its residual variance and the slopes for the remaining two indicators to 0. In these analyses, higher levels of CD on its own were associated with greater success at decreasing ($B = -0.19$, $p = 0.023$) and increasing ($B = 0.24$, $p = 0.058$, a trend) emotional responding. Similarly, higher levels of BD on its own were associated with greater success at decreasing ($B = -0.80$, $p = 0.081$, a trend) and increasing ($B = 0.07$, $p = 0.033$) emotional responding. Neither of these associations was significant when considering DS on its own (both $ps > 0.10$). In another follow-up analysis, we dropped the latent fluid cognitive ability predictor variable and instead estimated a random effect for each of the four indicators of cognitive ability simultaneously. In this analysis, none of the four indicators was uniquely associated with CR success. Together, these results suggest that it is variance shared primarily between perceptual reasoning (BD) and PS (CD)—putatively fluid cognitive ability—that predicts successful CR.

SECONDARY ANALYSES

In pursuit of our secondary goal, we next present analyses that examine whether there are age differences in cognitive ability and CR success.

Age differences in cognitive ability

To examine whether the older and YA in this sample exhibited differences in fluid and/or crystallized cognitive ability as in previous studies, we conducted a between-subjects structural equation model. Fluid cognitive ability was estimated as a latent variable with BD, CD, and DS as manifest indicators; crystallized cognitive ability was estimated as the manifest indicator, VC. Both were regressed on age group (1 = older, 0 = younger). This structural equation model fit the data well, $\chi^2(4, N = 60) = 1.40$,

Table 3 | Parameter estimates from hypothesis tests examining cognitive ability or age group as predictors of cognitive reappraisal success.

Fluid cognitive ability latent variable	**Cognitive ability model**		**Age group model**		**Expanded model**	
	***B* (*SE*)**		***B* (*SE*)**		***B* (*SE*)**	
Indicators	Factor loadings				Factor loadings	
BD	7.811 (2.305)*		–		10.607 (1.274)**	
CD	11.039 (3.317)*		–		12.688 (2.22)**	
DS	1.63 (0.899)$^+$		–		2.31 (0.767)*	
Between-subjects predictors	**Decrease—view criterion**	**Decrease—view criterion**	**Decrease—view criterion**	**Increase—view criterion**	**Decrease—view criterion**	**Increase—view criterion**
Fluid cognitive ability	−0.367 (0.08)**	0.431 (0.128)*	–	–	−0.423 (0.107)**	0.479 (0.152)*
Crystallized cognitive ability (VC)	0.007 (0.007)	−0.004 (0.01)	–	–	0.006 (0.008)	−0.002 (0.011)
Age group (older = 1, younger = 0)	–	–	0.207 (0.13)	−0.226 (0.18)	0.102 (0.197)	−0.388 (0.239)
Ever married (yes = 1, 0 = no)	–	–	–	–	−0.558 (0.159)**	0.909 (0.217)**
Education level (higher values = more educated)	–	–	–	–	−0.012 (0.079)	0.062 (0.096)

Within-subjects effects recapitulate effects reported in ***Table 2*** *and thus are not reported here. BD, Block Design; CD, Coding; DS, Digit Span.*
$^{**}p < 0.001$, $^{*}p < 0.05$, $^{+}p < 0.10$.

$p = 0.844$, RMSEA = 0.00, 90% CI [0.00, 0.10], CFI = 1.00, SRMR = 0.019.

Results confirmed significant positive factor loadings for all three manifest indicators of the fluid cognitive ability latent variable (all $p < 0.01$). In addition, higher fluid cognitive ability was associated with higher crystallized cognitive ability ($\beta = 0.51$, $p = 0.002$). Importantly, although older age was not significantly associated with crystallized cognitive ability ($\beta = -0.08$, $p = 0.525$), older age was significantly associated with lower fluid cognitive ability ($\beta = -0.89$, $p < 0.001$).

Age differences in CR success

In light of the preceding analysis indicating a high degree of shared variance between age group and fluid cognitive ability, we first treated older age as the sole between-subjects predictor of emotional responding in a two-level model (referred to as the Age Group Model in **Table 3**).

On the first level, the predictor and criterion variables were the same as noted for the preliminary analysis that tested the main and interactive effects of CR and gaze direction.

On the second level, the slopes estimated from the decrease and increase CR predictors on the first level were treated as criterion variables that were regressed on one between-subjects predictor, age group (older = 1, younger = 0).

Relative to the moderating effect of fluid cognitive ability, the moderating effect of age group on using CR to decrease ($B = 0.21$, $p = 0.112$) and increase ($B = -0.23$, $p = 0.209$) emotional responding relative to the view condition were modest in magnitude—roughly half the magnitude of the effects reported for fluid cognitive ability. The directions of these effects are consistent with older age predicting reduced CR success (see **Figure 2**) but they were not statistically significant. Follow-up analyses assessing the age difference within each gaze direction condition revealed effects that also were not statistically significant (results not shown; all $ps > 0.10$).

Age differences in CR success: expanded model

It was possible that age differences in CR success were being obscured by individual differences in variables that covaried with age group (fluid cognitive ability, marital status, and education level). Thus, next we examined several simultaneous between-subjects predictors of emotional responding in a two-level structural equation model (referred to as the Expanded Model in **Table 3**)[3].

On the first level, the predictor and criterion variables were the same as noted previously.

On the second level, the slopes estimated from the decrease and increase CR predictors on the first level were treated as criterion variables. This time, they were regressed on five between-subjects predictors as follows: fluid cognitive ability, crystallized cognitive ability, age group (older = 1, younger = 0), ever married (1 = yes, 0 = no), and education level.

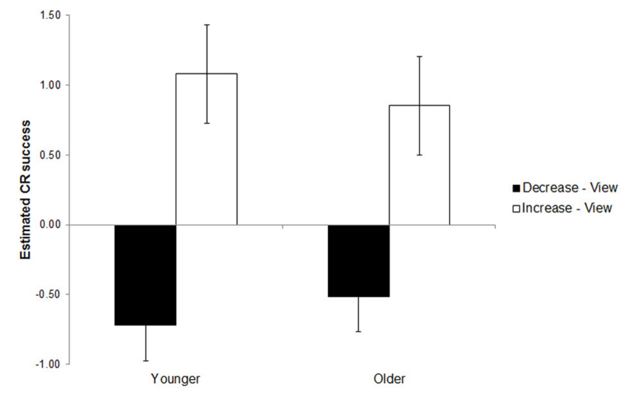

FIGURE 2 | This figure depicts success using cognitive reappraisal to decrease (black bars) and increase (white bars) emotional responding as a function of age group in the Age Group Model (see Table 3). Note that larger negative parameter estimates signal greater success for decrease vs. view whereas larger positive parameter estimates signal greater success for increase vs. view. Success scores were modestly lower in magnitude for older adults (right) than younger adults (left) but neither age difference was statistically significant. Error bars reflect the 95% confidence interval around the estimate of the age difference in cognitive reappraisal (CR) success.

In this analysis, higher fluid cognitive ability continued to be associated with greater success at decreasing ($B = -0.42$, $p < 0.001$) and increasing ($B = 0.48$, $p = 0.002$) emotional responding. There remained no significant effect of age group on using CR to decrease ($B = 0.10$, $p = 0.606$) or increase ($B = -0.39$, $p = 0.105$) emotional responding relative to the view condition. Notably, relative to when age group was modeled on its own, the magnitude of the effect of age group on using CR to decrease emotional responding was smaller by about one-half; the magnitude of the effect of age group on using CR to increase emotional responding was bigger by about one-half (and just barely approached marginal significance). Interestingly, ever having been married was associated with greater success using CR to decrease ($B = -0.56$, $p < 0.001$) and increase ($B = 0.91$, $p < 0.001$) emotional responding. Neither crystallized cognitive ability nor education level predicted success at decreasing or increasing emotional responding (see **Table 3**).

Estimates of emotional responding during the regulation period on a measure-by-measure basis

The primary and secondary analyses reported above focused on variation in emotional responding during the regulation period modeled as a latent variable with four indicators. Some readers may be interested to examine estimates for each indicator individually as a function of age group, CR instruction, and gaze direction. To produce these estimates, we computed a series of 24 two-level models.

On the first level, there were four criterion variables (self-reported emotional intensity, corrugator activity, HR, EDA during the regulation period). These criterion variables were regressed on three within-subjects, dummy-coded CR instruction predictors. The physiological criterion variables were each additionally regressed on activity during the reactivity period.

[3]Because of shared variance between predictors, estimates of the association between each predictor and the criterion variables should be interpreted with caution. In addition, although we attempted to test the interaction between age group and cognitive ability, this model would not converge, even when orthogonalizing cognitive ability with respect to age group.

On the second level, there were no explicit between-subjects predictors.

In **Table 4**, we report the B and SE for the intercept, which represents the mean value for the one CR instruction that was not included as a predictor in each model.

DISCUSSION

The SOC-ER framework suggests that people might be most successful regulating their emotions when they use strategies for which they have the prerequisite resources in a given situation (Urry and Gross, 2010; Opitz et al., 2012b). In this study, we assessed the role of one class of resources, cognitive ability, in the success of one ER process, CR. Specifically, we examined whether higher levels of cognitive ability would predict greater CR success.

Three important observations emerged from this effort. First, higher levels of fluid cognitive ability predicted greater success at using CR to regulate emotional responses to sad stimuli. Second, fluid cognitive ability predicted greater success at using CR irrespective of whether the regulatory goal was to increase or decrease the emotional response. Finally, despite age differences in cognitive ability in this sample, older age was not associated with variation in success at using CR. We discuss these results in turn below. We then consider broader implications of this work, limitations, and future directions.

COGNITIVE ABILITY PREDICTS SUCCESSFUL CR

Based on existing neuroimaging studies (see Buhle et al., 2013, for a meta-analysis) and the recent work of Schmeichel et al. (2008), McRae et al. (2012), and Malooly et al. (2013), we tested the prediction that cognitive abilities would predict CR success. Although correlational data preclude causal inference, the present findings are consistent with the idea that fluid cognitive abilities are resources for successful CR. Our results thus support a key tenet of the SOC-ER framework, namely that ER strategies draw on resources—internal abilities and/or environmental affordances that promote the use of a given ER strategy.

Not all previous studies have supported the idea that cognitive abilities should be associated with ER. For example, Farrelly and Austin (2007) failed to observe associations between cognitive ability and "managing emotions" as measured by the Mayer-Salovey-Caruso Emotional Intelligence Test (MSCEIT), the subscale most closely aligned with ER as conceptualized herein. In addition, Gross and John (2003) did not observe correlations between typical use of CR, as measured using the self-report Emotion Regulation Questionnaire (ERQ) and tests of scholastic performance and intelligence. Why, then, did we observe associations between fluid cognitive ability and CR success in this study?

One explanation pertains to the conceptualization and measurement of ER. While the MSCEIT and ERQ tap important aspects of ER, neither assesses success in modulating evoked emotional responses in accord with the emotion-regulatory goal. This is important because generally knowing the best emotion-regulating action to use in a particular context (which is assessed by the MSCEIT) or typically choosing to use CR (which is assessed by the ERQ) may be independent of how well one actually changes their emotional response in the midst of an emotion-triggering situation. Fluid cognitive abilities may be particularly relevant to how well one actually changes one's emotional response in accordance with the regulatory goal in an emotion-triggering situation, particularly in the face of a time limit and complex visual information to appreciate as was the case in this study.

Table 4 | Estimates of emotional responding for each measure as a function of Cognitive Reappraisal (CR) instruction, gaze direction, and age group.

	Younger adults				Older adults			
	Decrease	View	Increase	No CR	Decrease	View	Increase	No CR
CORRUGATOR ACTIVITY								
Arousing	1.267 (0.462)	1.809 (0.517)	2.047 (0.504)	1.956 (0.598)	1.736 (0.47)	2.431 (0.636)	2.984 (0.612)	2.054 (0.453)
Not directed	1.479 (0.539)	2.247 (0.613)	2.37 (0.594)	2.362 (0.667)	1.199 (0.479)	1.8 (0.755)	1.839 (0.542)	1.603 (0.554)
Non-arousing	1.11 (0.34)	1.339 (0.334)	2.018 (0.478)	1.536 (0.37)	1.188 (0.543)	1.404 (0.558)	1.245 (0.457)	1.344 (0.486)
HEART RATE								
Arousing	35.424 (3.181)	35.467 (3.048)	35.992 (3.139)	35.636 (3.171)	29.447 (3.494)	29.534 (3.442)	29.62 (3.443)	29.471 (3.449)
Not directed	33.499 (3.807)	33.685 (3.886)	33.728 (3.794)	33.476 (3.847)	32.764 (3.079)	32.866 (3.026)	32.908 (3.001)	32.849 (3.021)
Non-arousing	36.299 (2.659)	36.512 (2.666)	37.335 (2.576)	36.46 (2.541)	29.457 (3.497)	29.482 (3.475)	29.506 (3.469)	29.485 (3.48)
ELECTRODERMAL ACTIVITY								
Arousing	−0.015 (0.012)	−0.026 (0.018)	0.002 (0.01)	−0.003 (0.012)	0.004 (0.007)	0.003 (0.006)	−0.003 (0.005)	0 (0.003)
Not directed	−0.007 (0.011)	−0.015 (0.009)	0.002 (0.015)	0.007 (0.012)	0.007 (0.003)	0.007 (0.005)	0.007 (0.003)	0.004 (0.003)
Non-arousing	0.018 (0.01)	−0.001 (0.007)	0.019 (0.011)	0.015 (0.01)	0.001 (0.005)	−0.004 (0.004)	0.003 (0.004)	−0.002 (0.004)
INTENSITY RATING								
Arousing	3.658 (0.204)	4.293 (0.238)	5.412 (0.243)	3.967 (0.249)	4.111 (0.28)	4.6 (0.246)	5.771 (0.296)	4.753 (0.282)
Not directed	3.481 (0.203)	4.104 (0.271)	5.491 (0.226)	4.208 (0.236)	4.359 (0.277)	4.655 (0.274)	5.701 (0.273)	4.646 (0.249)
Non-arousing	3.562 (0.206)	3.728 (0.224)	5.136 (0.261)	3.745 (0.235)	4.343 (0.244)	4.371 (0.268)	5.548 (0.3)	4.523 (0.272)

Estimates were determined via a series of two-level multilevel models, one for each age group, gaze direction, and CR instruction as described in text. Reported here is the intercept B(SE) from each model, which represents the mean value for the one CR instruction in each model that was not included as a predictor.

COGNITIVE ABILITY PREDICTS SUCCESSFUL CR, NO MATTER THE GOAL

Much ER research has focused on the down-regulation of negative emotions. This approach is motivated by the idea that prohedonic regulatory goals (e.g., "decrease negative") are commonly pursued in daily life (Gross et al., 2006; Riediger et al., 2011), and may have important clinical implications (Goldin et al., 2012; Gross, 2013). However, research focusing on the up-regulation of negative emotions is also warranted for two reasons. First, people also pursue contrahedonic regulatory (e.g., "increase negative") goals (Riediger et al., 2009, 2011; Tamir et al., 2013). Second, manipulating both pro- and contrahedonic ER in the same study helps to disambiguate the cognitive effort required to reappraise from changes in emotional arousal (see, e.g., Urry et al., 2009).

Examining both pro- and contra-hedonic goals in the present study gave us the opportunity to determine whether success in achieving these two ER goals is differentially predicted by cognitive ability. The existing literature provides mixed suggestions about these potentially differential relationships. On the one hand, prior work suggested that prohedonic ER goals may be more difficult to achieve than contrahedonic ER goals (Ochsner et al., 2004). This implies that fluid cognitive ability should be more useful when decreasing negative emotion than when increasing negative emotion. On the other hand, evidence also suggests that the association between working memory—one cognitive resource—and preferences for contrahedonic emotions is stronger than the association between working memory and preferences for prohedonic emotions (Riediger et al., 2011). This implies that fluid cognitive ability should be *less* useful when decreasing negative emotion than when increasing negative emotion.

Contrary to both possibilities, we found no difference in the extent to which higher levels of fluid cognitive ability predicted successful CR in pursuit of contrahedonic vs. prohedonic goals. Of course, it is possible that features of our design facilitated this outcome. For example, the use of mildly intense sad stimuli and a pseudo-block design may have reduced the typical disparity in difficulty. Future studies will be needed to understand the conditions that moderate how resources like fluid cognitive ability contribute to differential success of ER strategies as a function of contrahedonic or prohedonic aims.

AGE DIFFERENCES IN COGNITIVE ABILITY BUT NOT CR SUCCESS

Theoretical models suggest that we might expect age differences in emotion and/or its regulation, at least in some contexts (e.g., Socioemotional Selectivity Theory Carstensen et al., 1999, Strength and Vulnerability Integration Charles, 2010). Indeed, consistent with that expectation, Opitz et al. (2012a) previously demonstrated that OA were less successful than YA at using CR to decrease negative emotions, but more successful at using CR to increase negative emotions. OA in that study also exhibited reduced CR-related activation in brain regions implicated in cognitive control processes like information selection and conflict monitoring compared to YA. The authors concluded that OA may lack the cognitive resources to reduce negative emotion using the particular form of CR that was studied. However, it is important to acknowledge that some of the stimuli used in that study may have been less relevant to OA. Moreover, participants had to frequently switch between ER goals and the regulation period was very brief. That particular design may therefore have put OA at a disadvantage in applying CR.

In the current study, we used only sad, moderately intense pictures which had face-valid relevance to both younger and OA. Additionally, participants had more time to use CR and only had to switch between one active CR condition and the view and no CR control conditions within each block. These changes likely reduced the degree to which OA would be at a disadvantage relative to YA in being able to successfully apply CR. With these changes in place, we observed significant associations between fluid cognitive ability and CR success but not between age group and CR success. Of course, this may in part be because of insufficient power to detect small effects in the present study. However, alternatively or in addition, the age differences in CR success observed by Opitz et al. (2012a) based on fewer participants may have been due to age-related variation in cognitive ability as well as age-related inequality in opportunity for success. Together, these two studies are consistent with the idea that age differences in affective responding are apt to be observed only in "highly resource-demanding situations that overtax OA capacities" (Wrzus et al., 2013, p. 386).

It is important to note that our ability to examine age differences in CR success in this study was hampered for at least two reasons. For one, the age range in the older and younger samples differed (16-year span vs. 4-year span, respectively). The larger age range in the older adult group may introduce greater within-group variation, thus reducing sensitivity to between-group differences. In addition, the two age groups differed not just in terms of age but also in terms of education, marital status, and fluid cognitive ability; OA had more education, were more likely to have been married, and had lower fluid cognitive ability than YA. Thus, even if we had identified age differences in CR success, it would ultimately be unclear whether age itself or one or more of these other variables represents the source of those differences. Importantly, when we modeled all of these as simultaneous predictors in one model, we did not observe any statistically significant effects of age group; instead, ever having been married was associated with greater CR success. Although intriguing, we are reluctant to make inferences about these marital status effects (and the absence of age effects) because none of the YA had ever been married and only three of the OA had never been married; as such, marital status is confounded with older age in this sample. It remains for future research to determine whether ever having been married really does relate to greater CR success, as potentially suggested by our results.

We did not have *a priori* predictions about age differences in the relation between cognitive ability and CR success. Even if we did, as noted above, age was significantly associated with fluid cognitive ability, marital status, and education level in the present sample, which hampers our ability to isolate unique effects. Thus, we suggest that fluid cognitive ability was perhaps a resource for successful CR across the whole sample. We also speculate that the inclusion of older and YA in our sample increased the range of meaningful variation in fluid cognitive ability; this may have enhanced sensitivity to the association between fluid cognitive ability and CR success.

LIMITATIONS AND DIRECTIONS FOR FUTURE RESEARCH

While this study had numerous strengths, including the multimethod approach to measuring emotional responding, inclusion of both younger and older adult participants, and use of multilevel structural equation modeling to test our hypothesis, we acknowledge that this study has some important limitations to be addressed in future research. First, we concentrated on CR, which is just one of five families of ER processes. While individual differences in fluid cognitive ability predict the success of CR, this should not be taken to indicate that fluid cognitive ability would similarly predict the success of other ER strategies. This should also not be taken to indicate that fluid cognitive ability, as indexed by perceptual reasoning, PS, and working memory, are the only resources for CR. By the same token, the present study used only sad picture stimuli. It is unclear whether the current results will generalize to other specific emotions, like fear, disgust, or anger, or to positive emotions like happiness. It will be important in future studies to determine whether the cognitive abilities studied here serve as resources for other families of ER, to identify other resources that support successful CR, and to determine whether these resources play similar roles in the regulation of emotions other than sadness.

Second, cognitive ability is largely internal to an individual. Other resources that might be involved in CR might include resources that are largely *external*. Previous work has proposed, for example, that having access to people who help one generate new meanings for emotion-triggering situations may be a resource for CR (Urry and Gross, 2010). The elegant work of Coan et al. (2006) has demonstrated that stress-sensitive brain regions responded less in women who held someone's hand while undergoing threat of shock compared to women who did not hold someone's hand. While that example is not specific to CR, it suggests that social support in the form of hand-holding may be an external resource that facilitates ER. Assessing external resources for ER is an important direction for future research.

Third, our sample was mostly Caucasian and there were not enough participants to assess potential gender differences in the relations we have reported. In addition, these are cross-sectional, correlational data, which preclude drawing inferences about the putative causal direction on which we have focused here—namely that resources contribute to regulatory success. In order to determine the generalizability of these findings, it will be important to introduce heterogeneity with respect to the types of participants who are recruited for future studies. In addition, to facilitate causal inference, it will be important to (1) measure resources and regulatory success at multiple time points to examine whether a change in resources precedes a change in regulatory success and/or (2) manipulate the resources to see whether a change in resources effects a change in regulatory success.

CONCLUSION

In this paper, we provide evidence that higher levels of fluid cognitive ability predict greater success at using CR to increase and decrease sad emotion. This finding supports a basic tenet of the SOC-ER framework (Urry and Gross, 2010), which proposes that higher levels of relevant resources contribute to greater ER success. Importantly, the relation between cognitive ability and successful CR was invariant with respect to whether the goal of CR was contrahedonic or prohedonic. This paper sets the stage for research that seeks to understand variation in successful ER in the context of fluctuating resources. Of key interest from the perspective of SOC-ER is determining the ways in which we compensate for lost resources by (a) selecting different strategies that do not require lost resources and/or (b) optimizing our skill at using strategies for which resources have been compromised. We believe this is an important set of steps to take to further our basic understanding of emotion and its regulation and to further applied goals vis-à-vis augmenting well-being.

AUTHOR CONTRIBUTIONS

Philipp C. Opitz and Heather L. Urry conceived and designed the study, with significant input from James J. Gross. Philipp C. Opitz collected most of the data. Philipp C. Opitz, Ihno A. Lee, and Heather L. Urry analyzed the data. Philipp C. Opitz, Ihno A. Lee, James J. Gross, and Heather L. Urry wrote the manuscript.

ACKNOWLEDGMENTS

We are grateful to Tufts University for their assistance in funding this work via a Graduate Student Research Award to Philipp C. Opitz. We also thank the following individuals: E. Brown and D. Millstein for assistance with data collection and processing, J. L. Birk, S. R. Cavanagh, and J. A. DiCorcia for many valuable discussions, and F. Wilhelm and P. Peyk for making ANSLAB, a suite of open source Matlab routines used to process physiological data, available as freeware in the Society for Psychophysiological Research Software Repository (http://www.sprweb.org/repository).

REFERENCES

Appleton, A. A., Buka, S. L., Loucks, E. B., Gilman, S. E., and Kubzansky, L. D. (2013). Divergent associations of adaptive and maladaptive emotion regulation strategies with inflammation. *Health Psychol.* 32, 748–756. doi: 10.1037/a0030068

Arditi, A. (2005). Improving the design of the letter contrast sensitivity test. *Invest. Ophthalmol. Vis. Sci.* 46, 2225–2229. doi: 10.1167/iovs.04-1198

Bradley, M. M., and Lang, P. J. (2007). "Emotion and motivation," in *Handbook of Psychophysiology.* 3rd Edn., eds J. T. Cacioppo, L. G. Tassinary, and G. G. Berntson (Cambridge: Cambridge University Press), 581–607.

Buhle, J. T., Silvers, J. A., Wager, T. D., Lopez, R., Onyemekwu, C., Kober, H., et al. (2013). Cognitive reappraisal of emotion: A meta-analysis of human neuroimaging studies. *Cereb. Cortex.* doi: 10.1093/cercor/bht154. [Epub ahead of print].

Carstensen, L. L., Isaacowitz, D. M., and Charles, S. T. (1999). Taking time seriously: a theory of socioemotional selectivity. *Am. Psychol.* 54, 165.

Charles, S. T. (2010). Strength and vulnerability integration: a model of emotional well-being across adulthood. *Psychol. Bull.* 136, 1068. doi: 10.1037/a0021232

Coan, J. A., Schaefer, H. S., and Davidson, R. J. (2006). Lending a hand: social regulation of the neural response to threat. *Psychol. Sci.* 17, 1032–1039. doi: 10.1111/j.1467-9280.2006.01832.x

Dougherty, B., Flom, R., and Bullimore, M. (2005). An evaluation of the mars letter contrast sensitivity test. *Optom. Vis. Sci.* 82, 970–975. doi: 10.1097/01.opx.0000187844.27025.ea

Evstafiev, M. (1992). *A Family Mourns During a Funeral at the Lion's Cemetery in Sarajevo, 1992 [Photo]*. Available online at: http://commons.wikimedia.org/wiki/File:Evstafiev-bosnia-sarajevo-funeral-reaction.jpg

Farrelly, D., and Austin, E. J. (2007). Ability EI as an intelligence? Associations of the MSCEIT with performance on emotion processing and social tasks and with cognitive ability. *Cogn. Emot.* 21, 1043–1063. doi: 10.1080/02699930601069404

Fidell, L. S., Tabachnick, B. G. (2003). "Research methods in psychology," in *Handbook of Psychology*. Vol. 2., eds J. A. Schinka, and W. F. Velicer (Hoboken, NJ: John Wiley & Sons Inc. xxiii, 115–141, 711.

Ford, B. Q., and Tamir, M. (2012). When getting angry is smart: emotional preferences and emotional intelligence. *Emotion* 12, 685–689. doi: 10.1037/a0027149

Fridlund, A., and Cacioppo, J. (1986). Guidelines for human electromyographic research. *Psychophysiology* 23, 567–589.

Goldin, P. R., Ziv, M., Jazaieri, H., Werner, K., Kraemer, H., Heimberg, R. G., et al. (2012). Cognitive reappraisal self-efficacy mediates the effects of individual cognitive-behavioral therapy for social anxiety disorder. *J. Consul. Clin. Psychol.* 80, 1034–1040. doi: 10.1037/a0028555

Gross, J. J. (2013). Emotion regulation: taking stock and moving forward. *Emotion* 13, 359–365. doi: 10.1037/a0032135

Gross, J. J. (ed.). (2014). *Handbook of Emotion Regulation.* 2nd Edn. New York, NY: Guilford.

Gross, J. J. (1998). The emerging field of emotion regulation: an integrative review. *Rev. Gen. Psychol.* 2, 271–299.

Gross, J. J., Richards, J. M., and John, O. P. (2006). "Emotion regulation in everyday life," in *Emotion Regulation in Couples and Families: Pathways to Dysfunction and Health,* eds D. K. Snyder, J. A. Simpson, and J. N. Hughes (Washington, DC: American Psychological Association), 13–35.

Gross, J. J., and John, O. P. (2003). Individual differences in two emotion regulation processes: implications for affect, relationships, and well-being. *J. Pers. Soc. Psychol.* 85, 348–362. doi: 10.1037/0022-3514.85.2.348

Hedden, T., and Gabrieli, J. D. E. (2004). Insights into the ageing mind: a view from cognitive neuroscience. *Nat. Rev. Neurosci.* 5, 87–96. doi: 10.1038/nrn1323

Hoffman, L., and Rovine, M. J. (2007). Multilevel models for the experimental psychologist: foundations and illustrative examples. *Behav. Res. Methods* 39, 101–117. doi: 10.3758/BF03192848

Hox, J. (2002). *Multilevel Analysis: Techniques and Applications.* Manwah, NJ: Lawrence Erlbaum.

Isaacowitz, D. M., Toner, K., Goren, D., and Wilson, H. R. (2008). Looking while unhappy: mood-congruent gaze in young adults, positive gaze in older adults. *Psychol. Sci.* 19, 848–853. doi: 10.1111/j.1467-9280.2008.02167.x

Isaacowitz, D. M., Toner, K., and Neupert, S. D. (2009). Use of gaze for real-time mood regulation: effects of age and attentional functioning. *Psychol. Aging* 24, 989–994. doi: 10.1037/a0017706

Kline, R. B. (2010). *Principles and Practice of Structural Equation Modeling.* 3rd Edn. New York, NY: Guildford.

Lang, P. J., Bradley, M. M., and Cuthbert, B. N. (2008). "International affective picture system (IAPS): affective ratings of pictures and instruction manual," in *Technical Report A-8,* (Gainesville, FL: University of Florida).

Lohani, M., and Isaacowitz, D. M. (2013). Age differences in managing response to sadness elicitors using attentional deployment, positive reappraisal and suppression. *Cogn. Emot.* 28, 678–697. doi: 10.1080/02699931.2013.853648

Malooly, A. M., Genet, J., and Siemer, M. (2013). Individual differences in reappraisal effectiveness: the role of affective flexibility. *Emotion* 13, 302–313. doi: 10.1037/a0029980

Mauss, I. B., Levenson, R. W., Mccarter, L., Wilhelm, F. H., and Gross, J. J. (2005). The tie that binds? Coherence among emotion experience, behavior, and physiology. *Emotion* 5, 175–190. doi: 10.1037/1528-3542.5.2.175

McRae, K., Hughes, B., Chopra, S., Gabrieli, J. D. E., Gross, J. J. and Ochsner, K. N. (2010). The neural bases of distraction and reappraisal. *J. Cogn. Neurosci.* 22, 248–262. doi: 10.1162/jocn.2009.21243

McRae, K., Jacobs, S. E., Ray, R. D., John, O. P., and Gross, J. J. (2012). Individual differences in reappraisal ability: Links to reappraisal frequency, well-being, and cognitive control. *J. Res. Pers.* 46, 2–7. doi: 10.1016/j.jrp.2011.10.003

Mikels, J., Fredrickson, B., Larkin, G., Lindberg, C., Maglio, S., and Reuter-Lorenz, P. (2005). Emotional category data on images from the International affective picture system. *Behav. Res. Methods* 37, 626–630. doi: 10.3758/BF03192732

Muthén, L. K., and Muthén, B. O. (1998–2013). *Mplus User's Guide.* 7th Edn. Los Angeles, CA: Muthén & Muthén.

Ochsner, K. N., Bunge, S. A., Gross, J. J., and Gabrieli, J. D. E. (2002). Rethinking feelings: an FMRI study of the cognitive regulation of emotion. *J. Cogn. Neurosci.* 14, 1215–1229. doi: 10.1162/089892902760807212

Ochsner, K. N., Day, R. D., Cooper, J. C., Robertson, E. R., Chopra, S., Gabrieli, J. D. E., et al. (2004). For better or for worse: neural systems supporting the cognitive down- and up-regulation of negative emotion. *Neuroimage* 23, 483–499. doi: 10.1016/j.neuroimage.2004.06.030

Opitz, P. C., Gross, J. J., and Urry, H. L. (2012b). Selection, optimization, and compensation in the domain of emotion regulation: applications to adolescence, older age, and major depressive disorder. *Soc. Pers. Psychol. Compass* 6, 142–155. doi: 10.1111/j.1751-9004.2011.00413.x

Opitz, P. C., Rauch, L. C., Terry, D. P., and Urry, H. L. (2012a). Prefrontal mediation of age differences in cognitive reappraisal. *Neurobiol. Aging*, 33, 645–655. doi: 10.1016/j.neurobiolaging.2010.06.004

Riediger, M., Schmiedek, F., Wagner, G. G., and Lindenberger, U. (2009). Seeking pleasure and seeking pain: differences in prohedonic and contra-hedonic motivation from adolescence to old age. *Psychol. Sci.* 20, 1529–1535. doi: 10.1111/j.1467-9280.2009.02473.x

Riediger, M., Wrzus, C., Schmiedek, F., Wagner, G. G., and Lindenberger, U. (2011). Is seeking bad mood cognitively demanding? Contra-hedonic orientation and working-memory capacity in everyday life. *Emotion* 11, 656–665. doi: 10.1037/a0022756

Salthouse, T. A., Atkinson, T. M., and Berish, D. E. (2003). Executive functioning as a potential mediator of age-related cognitive decline in normal adults. *J. Exp. Psychol.* 132, 566–594. doi: 10.1037/0096-3445.132.4.566

Sheppes, G., and Meiran, N. (2007). Better late than never? On the dynamics of online regulation of sadness using distraction and cognitive reappraisal. *Pers. Soc. Psychol. Bull.* 33, 1518–1532. doi: 10.1177/0146167207305537

Shiota, M. N., and Levenson, R. W. (2009). Effects of aging on experimentally instructed detached reappraisal, positive reappraisal, and emotional behavior suppression. *Psychol. Aging* 24, 890–900. doi: 10.1037/a0017896

Schmeichel, B. J., Volokhov, R. N., and Demaree, H. A. (2008). Working memory capacity and the self-regulation of emotional expression and experience. *J. Pers. Soc. Psychol.* 95, 1526–1540. doi: 10.1037/a0013345

Tamir, M., and Ford, B. Q. (2012). Should people pursue feelings that feel good or feelings that do good? Emotional preferences and well-being. *Emotion* 12, 1061–1070. doi: 10.1037/a0027223

Tamir, M., Ford, B. Q., and Gilliam, M. (2013). Evidence for utilitarian motives in emotion regulation. *Cogn. Emot.* 27, 483–491. doi: 10.1080/02699931.2012.715079

Urry, H. L. (2010). Seeing, thinking, and feeling: emotion-regulating effects of gaze-directed cognitive reappraisal. *Emotion* 10, 125. doi: 10.1037/a0017434

Urry, H. L., and Gross, J. J. (2010). Emotion regulation in older age. *Curr. Dir. Psychol. Sci.* 19, 352. doi: 10.1177/0963721410388395

Urry, H. L., van Reekum, C. M., Johnstone, T., and Davidson, R. J. (2009). Individual differences in some (but not all) medial prefrontal regions reflect cognitive demand while regulating unpleasant emotion. *Neuroimage* 47, 852–863. doi: 10.1016/j.neuroimage.2009.05.069

Wilhelm, F. H., and Peyk, P. (2005). *ANSLAB: Autonomic Nervous System Laboratory (Version 4.0).* Available online at the SPR Software Respository: http://www.sprweb.org

Wrzus, C., Müller, V., Wagner, G. G., Lindenberger, U., and Riediger, M. (2013). Affective and cardiovascular responding to unpleasant events from adolescence to old age: complexity of events matters. *Dev. Psychol.* 49, 384–397. doi: 10.1037/a0028325

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 15 January 2014; accepted: 29 May 2014; published online: 17 June 2014.
*Citation: Opitz PC, Lee IA, Gross JJ and Urry HL (2014) Fluid cognitive ability is a resource for successful emotion regulation in older and younger adults. Front. Psychol. **5**:609. doi: 10.3389/fpsyg.2014.00609*
This article was submitted to Emotion Science, a section of the journal Frontiers in Psychology.

frontiers in PSYCHOLOGY

ORIGINAL RESEARCH ARTICLE
published: 26 June 2014
doi: 10.3389/fpsyg.2014.00635

A note on age differences in mood-congruent vs. mood-incongruent emotion processing in faces

Manuel C. Voelkle[1]*, Natalie C. Ebner[2], Ulman Lindenberger[1] and Michaela Riediger[1]

[1] Center for Lifespan Psychology, Max Planck Institute for Human Development, Berlin, Germany
[2] Department of Psychology, University of Florida, Gainesville, FL, USA

Edited by:
Hakan Fischer, Stockholm University, Sweden

Reviewed by:
Hakan Fischer, Stockholm University, Sweden
Mara Fölster, Humboldt-Universität zu Berlin, Germany
Marie Hennecke, University of Zurich, Switzerland

***Correspondence:**
Manuel C. Voelkle, Center for Lifespan Psychology, Max Planck Institute for Human Development, Lentzeallee 94, Berlin 14195, Germany
e-mail: voelkle@mpib-berlin.mpg.de

This article addresses four interrelated research questions: (1) Does experienced mood affect emotion perception in faces and is this perception mood-congruent or mood-incongruent? (2) Are there age-group differences in the interplay between experienced mood and emotion perception? (3) Does emotion perception in faces change as a function of the temporal sequence of study sessions and stimuli presentation, and (4) does emotion perception in faces serve a mood-regulatory function? One hundred fifty-four adults of three different age groups (younger: 20–31 years; middle-aged: 44–55 years; older adults: 70–81 years) were asked to provide multidimensional emotion ratings of a total of 1026 face pictures of younger, middle-aged, and older men and women, each displaying six different prototypical (primary) emotional expressions. By analyzing the likelihood of ascribing an additional emotional expression to a face whose primary emotion had been correctly recognized, the multidimensional rating approach permits the study of emotion perception while controlling for emotion recognition. Following up on previous research on mood responses to recurring unpleasant situations using the same dataset (Voelkle et al., 2013), crossed random effects analyses supported a mood-congruent relationship between experienced mood and perceived emotions in faces. In particular older adults were more likely to perceive happiness in faces when being in a positive mood and less likely to do so when being in a negative mood. This did not apply to younger adults. Temporal sequence of study sessions and stimuli presentation had a strong effect on the likelihood of ascribing an additional emotional expression. In contrast to previous findings, however, there was neither evidence for a change from mood-congruent to mood-incongruent responses over time nor evidence for a mood-regulatory effect.

Keywords: emotion perception, mood-(in)congruent information processing, mood regulation, faces, crossed random effects analysis

INTRODUCTION

How does the way we feel influence the perception of the world around us, and how does this perception in turn affect our own feelings? As innocuous as it may seem, this question constitutes one of the most fundamental research objectives in psychology, ranging from basic research on attention and perception (e.g., Becker and Leinenger, 2011; Hunter et al., 2011) to research in clinical psychology and psychiatry (e.g., Elliott et al., 2002; Eizenman et al., 2003; Rinck et al., 2003; Stuhrmann et al., 2013). For example, cognitive theories of anxiety and depression suggest attentional and memory biases of patients suffering from anxiety or depression toward threatening, respectively dysphoric, stimuli, which in turn contributes to the maintenance or aggravation of the disorder (Clark et al., 1999; Beevers and Carver, 2003; Koster et al., 2010). In particular the question of mood-congruent vs. mood-incongruent information processing, its determinants and consequences, has sparked a lot of research. The present paper contributes to this literature by investigating the relationship between experienced mood and the perception of emotional expression in faces, which has been shown to be important for individuals' social interactions (e.g., Baron-Cohen et al., 2000; Adolphs, 2003). Special emphasis will be put on age-related differences in mood-(in)congruent information processing, the role of the temporal sequence of study sessions and stimuli presentation, and the question whether mood may not only affect emotion perception, but whether emotion perception may also serve a mood-regulatory function.

As will be outlined in the following, a number of different theoretical models have been proposed to explain the—in parts conflicting—empirical findings on mood-congruent vs. mood-incongruent information processing:

MOOD-CONGRUENT INFORMATION PROCESSING

There exists ample evidence that information is often processed in a *mood-congruent* manner. For example, people in a positive mood are more likely to recall positive memories (Bower, 1981, 1991; Mayer et al., 1995), and report to be more satisfied with their lives (Schwarz and Clore, 1983). Mood congruency effects were also observed for emotion perception in faces. The pattern of findings, however, is somewhat mixed. For example, Coupland et al. (2004) demonstrated that low positive affect (anhedonia) decreased the identification of happy expressions, while negative affect increased the identification of disgust. Contrary to expectations, however, there was no increase in anger identification related to negative affect. Furthermore, Suzuki et al. (2007) found partial support for a mood-congruency effect by observing a positive correlation between negative affect and recognition of sadness. However, this effect did not generalize to other negative emotions. In addition, age-related decrease in sadness recognition was linked to an age-related decrease in negative affect. For similar findings on the relation between age-related decline in the perceived intensity of emotions in faces and age-related decrease in anxiety and depression see Phillips and Allen (2004).

At a more general level, the mood-congruency effect has been explained in terms of Bower's (1981) *associative network theory.* This theory refers to the idea that emotions serve as memory units and that activation of such a unit not only "aids retrieval of events associated with it [but…] also primes emotional themata for use in free association, fantasies, and perceptual categorization" (Bower, 1981, p. 129). The effect has also been explained in terms of *mood as information* (Schwarz and Clore, 2003, p. 296), that is, the idea that mood may serve an informational function and may help in directing attention to possible sources of feelings (Wyer and Carlston, 1979; Schwarz and Clore, 1983, 2003). Although both approaches suggest mood-congruent information processing, the proposed mechanisms differ. According to the *associative network theory*, mood influences information processing *indirectly* by priming the encoding, retrieval, and use of information, for example by selectively attending to "activated" mood-congruent details in the environment, by selectively encoding information into a network of primed associations, or by selectively retrieving mood-congruent information. According to the *mood-as-information account*, mood influences information processing *directly*. By (implicitly) asking themselves "…how do I feel about this? […people…] misread their current feelings as a response to the object of judgment, resulting in more favorable evaluations under positive rather than negative moods, unless their informational value is discredited" (Schwarz and Clore, 2003, p. 299).

In an attempt to integrate these seemingly contradictory explanations, Forgas (1995) proposed the *affect infusion model (AIM),* which states the more general preconditions for mood-congruency effects in judgmental processes. According to the AIM, affect-priming, in the sense of Bower's (1981) associative network theory, is most likely to occur during *substantive processing*, that is, in situations with complex, atypical, and/or personally relevant targets. For example, when being in a happy mood, people evaluate others more favorably than when being in a sad mood, in particular when judging unusual, atypical, persons (Forgas, 1992).

In contrast, mood-as-information (Schwarz and Clore, 1983) is the major affect infusion mechanism during *heuristic processing*, that is, in situations involving typical targets of low personal relevance and/or in situations with limited processing capacity (e.g., due to time pressure or information overload; Forgas, 1995).

MOOD-INCONGRUENT INFORMATION PROCESSING AS A MOOD-REGULATORY FUNCTION

In addition to the various findings on mood-congruency effects, a number of studies suggested that information may also be processed in a *mood-incongruent* manner (Morris and Reilly, 1987; Matt et al., 1992; Erber and Erber, 1994; Sedikides, 1994; Forgas and Ciarrochi, 2002; Isaacowitz et al., 2008, 2009b). For example, in two recent articles Isaacowitz and colleagues (Isaacowitz et al., 2008, 2009b) showed that older adults gazed toward positively valenced facial stimuli when in a bad mood. In contrast, a mood-congruency effect was observed in younger adults, in that they were more likely to look at positively valenced faces when in a good mood and more likely to look at negatively valenced faces when in a bad mood. Based on the observed age-differential relationship between mood and gazing pattern, Isaacowitz et al. (2008) concluded that "in older adults, gaze does not reflect mood, but rather is used to regulate it" (2008; p. 848). This interpretation is in line with socioemotional selectivity theory, which postulates that older adults—because of a shrinking time horizon—shift their motivational priorities toward emotion regulation (Carstensen et al., 1999; Carstensen, 2006). Furthermore, given that most studies on mood-(in)congruent information processing used college-student populations, this finding cautions generalizations to other populations and underscores the importance of studying different age groups.

Building upon the *first, congruency; then, incongruency* hypothesis postulated by Sedikides (1994, p. 163), Forgas and Ciarrochi (2002) showed, in a series of three experiments, that after an initial mood-congruency effect, people in a sad mood were more likely to generate positive person descriptions, positive personality trait adjectives, as well as positive self-descriptions. These findings were interpreted in terms of a spontaneous, homeostatic, mood management mechanism "that limit[s] affect congruence and thus allow[s] people to control and calibrate their mood states by selectively accessing more affect-incongruent responses over time" (Forgas and Ciarrochi, 2002, p. 337). Thus, the temporal sequence of information processing seems to play a crucial role in the interplay between experienced mood and information processing. This may also apply to the processing of emotional expressions in faces as investigated in the present study.

What the studies by Isaacowitz and colleagues and Forgas and colleagues have in common is that differences in mood-congruent vs. mood-incongruent information processing are explained in terms of mood regulation. That is, by focusing on stimuli of a certain valence, people attempt to manage their mood (e.g., they up-regulate their mood when previously in a bad mood). In contrast to work on mood-congruent attentional and memory biases for negatively valenced material, the mechanisms underlying a mood-incongruent bias toward positively valenced stimuli have been less clearly spelled out. However, given the functional relevance of mood-congruent information processing for dysphoria and depression (e.g., Clark et al., 1999; Beevers and Carver, 2003; Koster et al., 2010), it seems reasonable to assume that focusing on positively valenced stimuli when in a bad mood may help to counteract this effect. The underlying mechanism may either constitute a rather spontaneous, homeostatic mood management (Forgas and Ciarrochi, 2002) or active mood regulation.

While Isaacowitz and colleagues explained the mood-congruency vs. mood-incongruency effect *in terms of age* ("mood-congruent gaze in younger adults, positive gaze in older adults", Isaacowitz et al., 2008, p. 848), Forgas and Ciarrochi explained the effect *in terms of elapsed processing time* ("initially mood-congruent responses tend to be automatically corrected and reversed over time," Forgas and Ciarrochi, 2002, p. 344; see also Sedikides, 1994). Such mood-incongruent information processing is also in line with the AIM, which postulates that mood-congruency effects will be eliminated, or reversed, if a person is influenced by a strong motivational component, such as to improve mood when being in a bad mood (i.e., motivated processing; Erber and Erber, 1994; Forgas, 1995). In the absence of a strong motivational component, the AIM proposes the *direct access strategy* as another type of a low affect infusion strategy, that is, an information processing strategy that is unlikely to result in a mood-congruency effect. "Direct access processing is most likely when the target is well known or familiar and has highly prototypical features that cue an already-stored and available judgment, the judge is not personally involved, and there are no strong cognitive, affective, motivational, or situational forces mandating more elaborate processing" (Forgas, 1995, p. 46). We will get back to this strategy in the discussion. For a more detailed description of the AIM, and the four alternative processing strategies related to low affect infusion (motivated processing and direct access strategy) and high affect infusion (heuristic and substantive processing), we refer the reader to Forgas (1995).

To summarize, current research has provided ample support for mood-congruent, but also mood-incongruent, information processing. The AIM provides a general framework that predicts the degree of mood-(in)congruency in information processing (Forgas, 1995). According to this model, mood-congruency effects are most likely under *substantive processing* or *heuristic processing* which is in line with Bower's (1981) associative network theory, and Schwarz and Clore's (1983) theory of mood-as-information, respectively. In contrast, mood-congruency is least likely in case of *motivated processing* or the *direct access* strategy. Especially when in a bad mood, people may be motivated to change this state. As suggested by Isaacowitz et al. (2008), this motivation may be particularly strong in older adults. Furthermore, Forgas and Ciarrochi (2002) observed a shift from mood-congruent to mood-incongruent information processing, pointing to the role of homeostatic cognitive strategies in affect regulation. However, when explaining mood-incongruent information processing in terms of mood regulation, the crucial—and often untested—question is how effective is it in changing peoples' mood? In a recent eye-tracking study, Isaacowitz et al. (2009a,b) showed that older adults with good cognitive functioning showed less mood decline throughout the study when gazing toward positively valenced faces. This provides initial support for the notion that in some people mood-incongruent information processing may serve a mood-regulatory function.

Overall, the research reviewed so far indicates that effects of experienced mood on information processing are by no means simple, but influenced by multiple factors. With few exceptions (e.g., Mayer et al., 1995), most studies on mood-(in)congruent information processing involved active mood induction. Little is known about the extent to which these findings generalize to naturally occurring mood. Moreover, in real-life situations the various mechanisms underlying mood-(in)congruent information processing may work simultaneously and are likely to influence each other. For example, being in a moderately gloomy mood may prime the associative network toward the perception of negatively valenced features in the environment. This in turn may be perceived as more negative because of one's gloomy mood (mood-as-information). At the same time, this may increase the motivation to improve one's mood by selectively attending to positively valenced features in the environment, possibly eliminating or even reversing a mood-congruency effect. At present it is unclear which of these processes will prevail under less extreme conditions of natural mood, rather than experimentally induced mood.

THIS STUDY

The purpose of the present study was to link naturally occurring fluctuations in mood to the perception of emotions in faces in order to provide new insights into mood-congruent vs. mood-incongruent information processing. To this end we (1) examined whether natural mood affects emotion perception in faces and to what extent this perception was mood-congruent or mood-incongruent. We (2) tested for age group differences in the interplay between emotion perception and experienced mood, and (3) investigated the role of temporal sequence in emotion processing. Finally, we (4) examined the extent to which emotion perception in faces may serve a mood-regulatory function.

Based on previous findings reviewed above, and independent of age, we expected mood-congruent processing of emotional expressions in faces—operationalized as a higher likelihood of perceiving a positively valenced emotional expression when in a good mood, and a negatively valenced emotional expression when in a bad mood (*Hypothesis 1*). In line with prior research, but competing with Hypothesis 1, we expected older adults to have a higher likelihood of perceiving positive emotions in facial expressions when in a bad mood (*Hypothesis 2*). In addition, we expected a shift from mood-congruent to mood-incongruent information processing as a function of processing time (*Hypothesis 3*). Based on prior research, we expected a positive relationship between the likelihood of perceiving positively valenced emotions in faces and subsequent improvements in mood (*Hypothesis 4*), supporting the notion of a mood-regulatory function of emotion perception.

To test these hypotheses, we asked young, middle-aged, and older adults to indicate the amount of happiness, sadness, fear, disgust, anger, and neutrality they perceived in photographs of faces displaying prototypical happy, sad, fearful, disgusted, angry, or neutral facial expressions. Of importance, using a multidimensional rating approach, participants had rated all six emotions for each prototypical facial expression. For example, although a face may have been correctly recognized as displaying anger (prototypical primary expression), participants could indicate that they also perceived some sadness, or any of the other emotion(s), in the same face. In terms of the AIM, recognizing a prototypical facial expression is likely the result of either a direct access or motivational processing strategy and thus unlikely to infuse affect

(Forgas, 1995). In addition, individuals differ in their ability to recognize prototypical facial expressions, with age as an important predictor of these differences (see Ruffman et al., 2008, for an overview)[1] . For these reasons we were *not* interested in emotion recognition, but in the likelihood of ascribing an *additional* emotional expression to a face, whose primary emotion had already been correctly recognized. This procedure controls[2] for differences in emotion recognition and maximizes the likelihood of affect infusion (i.e., a mood-congruency or mood-incongruency effect). Throughout the remainder of this paper, the term e*motion perception* thus refers to the perception of additional emotional expressions in a face (other than the primary expression), once its primary emotional expression had been correctly recognized (see Methods section for details).

The present article follows up on previous work with the same dataset in which we investigated anticipatory and reactive mood changes throughout the course of the study (Voelkle et al., 2013), age-of-perceiver and age-of-rater effects on multidimensional emotion perception (Riediger et al., 2011), and accuracy and bias in age estimation (Voelkle et al., 2012). Until now, however, we never linked participants' mood to the perception of emotion in others (faces), which is the primary aim of the present study.

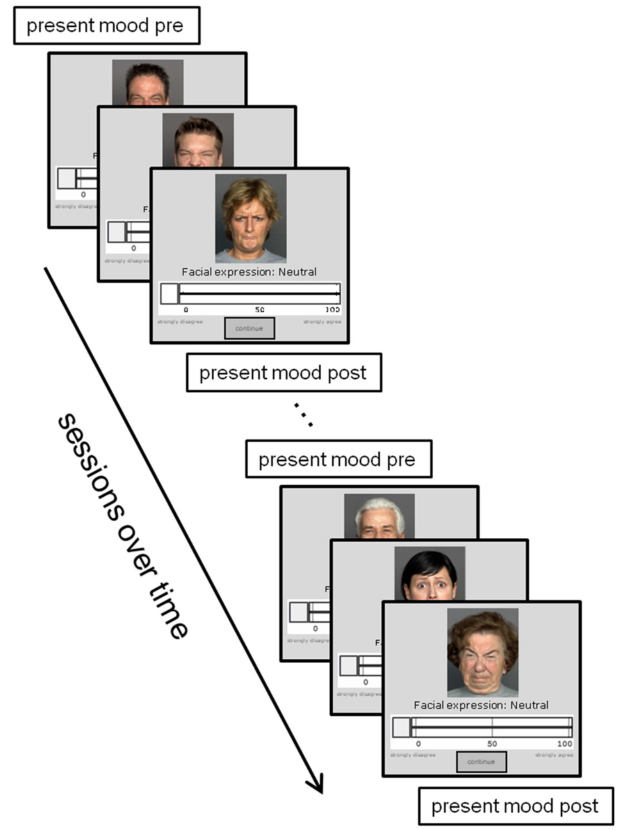

FIGURE 1 | Illustration of the study procedure. Present mood was assessed at the beginning and the end of each session. During each session, participants rated the emotional expression of different face pictures by adjusting a slider. In addition, the primary emotional expression (happiness, sadness, anger, disgust, fear, or neutrality) was assessed via categorical rating.

METHODS

PARTICIPANTS

One hundred fifty-four adults of three different age groups ($n = 52$ younger adults: 20–31 years; $n = 51$ middle-aged adults: 44–55 years; $n = 51$ older adults: 70–81 years) participated in the study. All of the 76 women and 78 men were Caucasian and German-speaking. Self-reported physical functioning was good, and visual-processing speed, as assessed by Wechsler's (1981) digit symbol substitution test, was comparable to typical performance levels in these age groups. For details about the demographic composition of the sample, see Ebner et al. (2010).

PROCEDURE

The study was approved by the MPI ethics review board. **Figure 1** provides a graphical illustration of the study procedure. After giving informed consent, participants were randomly assigned to one of two sets of parallel face pictures, which were presented one at a time on a 19-inch monitor. For each picture, participants indicated in a self-paced fashion the degree of happiness, sadness, fear, disgust, anger, or neutrality perceived in the face on a scale from 0 (*does not apply at all*) to 100 (*applies completely*). After these continuous ratings, participants indicated which of the six emotions was primarily displayed in the face (categorical rating). This was followed by additional face-specific questions that are not of relevance for the present paper. Due to the large number of face stimuli, participants had to complete the ratings in several sessions. Each session lasted for 100 min and there was only one session per day. Although it took up to 24 sessions for the slowest participant to complete all ratings, we restricted our analyses to the first 10 sessions to maintain comparability with previous research and to avoid increasing sparseness of the data. Participants' mood was assessed at the beginning and at the end of each session.

MEASURES

Positive and negative mood was assessed using Hampel's (1977) *Adjective Scales to Assess Mood*. For positive mood, participants

[1]For an analysis of age differences in emotional expression identification as a function of perceiver's and face model's age and facial expression with the present data, we refer the reader to Ebner et al. (2010).

[2]Although we disentangle the perception of additional emotional expressions from emotion recognition by analyzing only correctly recognized emotions, this does not preclude the possibility that people with higher recognition ability (and possible age differences therein) may be less likely to ascribe additional emotional expressions to a face after having identified the primary emotional expression. To control for this possibility, we repeated all analyses by including the person-specific recognition ability as an additional covariate. As a matter of fact, higher recognition ability decreased the likelihood of perceiving an additional emotional expression significantly (logit $= -10.750$; $p < 0.001$). In addition, the slightly lower (and non-significant at a 0.01 alpha level) likelihood of younger adults of perceiving an additional emotional expression disappeared after controlling for recognition ability. All other results, however, remained virtually unaffected by controlling for person-specific recognition ability. The additional analyses are provided as online Supplementary Materials A and B.

Table 1 | Results of a crossed random effects analysis predicting the likelihood of perceiving an (additional but the primary) emotional expression in a face by type of emotion, positive mood, session number, stimulus number, and age group.

Parameter	Estimate	*SE*	*t*-value	*p*-value
(A)				
Intercept (baseline: neutrality)	−1.9777	0.1230	−16.07	0.000
Happiness	−0.7191	0.018	−39.94	0.000
Anger	1.0122	0.0147	69.03	0.000
Disgust	0.7639	0.0147	51.88	0.000
Sadness	0.7937	0.0147	53.90	0.000
Fear	0.9049	0.0147	61.53	0.000
Session	−0.1340	0.0016	−83.71	0.000
Session squared	0.0173	0.0006	29.25	0.000
Younger adults (baseline: neutrality)	−0.3635	0.1727	−2.10	0.035
Older adults (baseline: neutrality)	0.1622	0.1736	0.93	0.350
Happiness × younger adults	−0.0446	0.025	−1.78	0.075
Happiness × older adults	−0.0179	0.0265	−0.68	0.499
Anger × younger adults	0.0717	0.0202	3.55	0.000
Anger × older adults	0.0619	0.0216	2.87	0.004
Disgust × younger adults	0.1361	0.0203	6.72	0.000
Disgust × older adults	0.0318	0.0217	1.47	0.142
Sadness × younger adults	0.1819	0.0203	8.98	0.000
Sadness × older adults	−0.0182	0.0217	−0.84	0.403
Fear × younger adults	0.0727	0.0203	3.59	0.000
Fear × older adults	0.1388	0.0216	6.41	0.000
(B) MOOD−CONGRUENT vs. MOOD−INCONGRUENT INFORMATION PROCESSING IN FACES				
Positive mood (baseline: neutrality)	0.0481	0.0155	3.11	0.002
Positive mood × happiness	0.1177	0.0207	5.69	0.000
Positive mood × anger	−0.0365	0.0167	−2.19	0.029
Positive mood × disgust	−0.0595	0.0167	−3.56	0.000
Positive mood × sadness	−0.0560	0.0167	−3.34	0.001
Positive mood × fear	−0.1086	0.0167	−6.50	0.000
(C) AGE GROUP DIFFERENCES IN MOOD−CONGRUENT vs. MOOD−INCONGRUENT INFORMATION PROCESSING				
Positive mood × younger adults (baseline: neutrality)	0.0305	0.0204	1.50	0.135
Positive mood × older adults (baseline: neutrality)	−0.1302	0.0236	−5.53	0.000
Positive mood × happiness × younger adults	−0.1567	0.0288	−5.44	0.000
Positive mood × happiness × older adults	0.1512	0.0305	4.96	0.000
Positive mood × anger × younger adults	−0.0128	0.0227	−0.56	0.573
Positive mood × anger × older adults	0.0056	0.0244	0.23	0.818
Positive mood × disgust × younger adults	−0.0580	0.0228	−2.55	0.011
Positive mood × disgust × older adults	0.0764	0.0245	3.12	0.002
Positive mood × sadness × younger adults	0.0344	0.0228	1.51	0.131
Positive mood × sadness × older adults	0.0810	0.0246	3.29	0.001
Positive mood × fear × younger adults	0.0149	0.0228	0.65	0.513
Positive mood × fear × older adults	−0.0291	0.0244	−1.19	0.234
(D) TEMPORAL SEQUENCE IN MOOD−CONGRUENT vs. MOOD−INCONGRUENT INFORMATION PROCESSING				
Stimulus number (baseline: neutrality)	−0.0004	0.0004	−1.05	0.295
Happiness × stimulus number	−0.0028	0.0006	−4.43	0.000
Anger × stimulus number	−0.0026	0.0005	−4.97	0.000
Disgust × stimulus number	−0.0029	0.0005	−5.63	0.000
Sadness × stimulus number	−0.0016	0.0005	−3.09	0.002
Fear × stimulus number	−0.0017	0.0005	−3.36	0.001
Positive mood × stimulus number (baseline: neutrality)	−0.0008	0.0005	−1.75	0.079
Positive mood × happiness × stimulus number	0.0011	0.0007	1.49	0.137
Positive mood × anger × stimulus number	0.0014	0.0006	2.36	0.018
Positive mood × disgust × stimulus number	0.0014	0.0006	2.44	0.015

(Continued)

Table 1 | Continued

Parameter	Estimate	*SE*	*t*-value	*p*-value
Positive mood × sadness × stimulus number	0.0006	0.0006	1.01	0.314
Positive mood × fear × stimulus number	0.0010	0.0006	1.63	0.102
Random intercept face	Variance = 0.016; *SD* = 0.127			
Random intercept participant	Variance = 2.289; *SD* = 1.513			
AIC	379620.8			
BIC	380192.4			
Log-likelihood	−189758.4			
Deviance	379516.8			

Type of emotion was dummy coded with perception of neutral emotional expression as baseline. Session = grand mean centered session number; Session squared = squared grand mean centered session number; Age group of participant (younger, middle-aged, older adults) was effect coded; Positive mood was group mean centered by subtracting the average positive mood at each study session; Stimulus number = individually centered position of stimulus in the sequence of stimuli within each session. Faces and participants were treated as two crossed random effects.

indicated on a scale from one to five the extent to which they currently felt happy, cheerful, elated, in high spirits, relaxed, mellow, and exuberant. Negative mood was assessed using the seven items insecure, sorrowful, disappointed, hopeless, melancholic, downhearted, and helpless. Corrected item-scale correlations for positive mood at the first measurement time point ranged between 0.51 and 0.79 (Cronbach's $\alpha = 0.89$) and between 0.41 and 0.63 (Cronbach's $\alpha = 0.81$) for negative mood (see Voelkle et al., 2013).

STIMULI

Face photographs of 58 younger (19–31 years), 56 middle-aged (39–55 years), and 57 older (69–80 years) adults were used as stimulus material. The photographs were taken from the FACES Lifespan Database of Facial Expressions (Ebner et al., 2010), which contains in two parallel sets a total of 2052 pictures, displaying each of the 171 target persons with a prototypical happy, angry, sad, disgusted, fearful, or neutral facial expression (i.e., the pictures were taken at the peak of the emotional expression, following a standardized production and selection procedure in line with the Affect Program Theory of facial expressions by Ekman, 1993). In line with the race and ethnicity of study participants and in order to reduce the design complexity (e.g., by avoiding possible race-biased in-group vs. out-group effects; cf. Meissner and Brigham, 2001) all face models were Caucasian. For details on the construction of the FACES database see Ebner et al. (2010).

ANALYSIS

For each of the 1026 photographs (171 individuals times six emotions), $N = 154$ participants were asked to provide continuous emotion ratings on six different emotions, resulting in a theoretical maximum of $1026 \times 6 \times 154 = 948{,}024$ ratings (plus the categorical emotion ratings and other ratings as mentioned above). Given that the face pictures displayed maximally prototypical emotional expressions, with about 80%[3], the average recognition rate of the primary emotional expression was fairly high. As noted before, we were not interested in emotion recognition, but in the likelihood of ascribing an additional emotional expression to a face, for which the primary emotion had already been correctly recognized. Therefore, we controlled for interindividual differences in accuracy of emotion recognition, by including only ratings of those stimuli of which the primary emotional expression had been correctly identified (as indicated by the categorical ratings). Furthermore, we decided to analyze the *likelihood* with which an additional emotional expression was perceived in a face rather than the *intensity* of this perception. The reasons for this decision were twofold: First, the ratings of the additional emotions attributed to a face followed a highly right-skewed distribution. Despite correctly recognizing the primary facial expressions, some individuals indicated additional emotions of 100 (highest intensity of emotion expression) on a scale from 0 to 100. In addition, some people seemed to have used the middle of the rating scale as a reference point for some of their ratings. As a consequence, we could not find a meaningful transformation (such as a log-transform) that would have resulted in homoscedastic and normally distributed residuals. Second, in about 74% of the ratings, no additional continuous emotion ratings were provided resulting in a preponderance of zeros. Although models have been developed to deal with the combination of a zero-inflated and continuous or count part (Hall, 2000; Olsen and Schafer, 2001), we are not aware of any readily available integration with crossed random effects analyses employed in the present paper. Future research in this direction will be desirable.

Differences in the likelihood to perceive an emotion in addition to the primary emotion were modeled as a function of the type of *emotion* (happiness, sadness, fear, disgust, anger, neutrality; dummy coded with neutrality as baseline), *mood* at the beginning of the session (group mean centered at the average mood level prior to each session), study *session* (1–10; grand mean centered at 5.5), *age group* of perceiver (younger, middle-aged, older; effects coded), *stimulus number* (i.e., the relative position of a face photograph in the sequence of photographs presented to an individual participant, centered at the average number of stimuli rated by each individual in each session), and interactions

[3]The average recognition rate of emotional expressions differed across emotions and age groups. For a more detailed analysis, see Ebner et al. (2010).

Table 2 | Results of a crossed random effects analysis predicting the likelihood of perceiving an (additional but the primary) emotional expression in a face by type of emotion, negative mood, session number, stimulus number, and age group.

Parameter	Estimate	*SE*	*t*-value	*p*-value
(A)				
Intercept (baseline: neutrality)	−1.9633	0.1228	−15.98	0.000
Happiness	−0.7409	0.0190	−39.06	0.000
Anger	0.9784	0.0151	64.99	0.000
Disgust	0.7296	0.0151	48.26	0.000
Sadness	0.7607	0.0151	50.32	0.000
Fear	0.8637	0.0151	57.13	0.000
Session	−0.1331	0.0016	−82.89	0.000
Session squared	0.0174	0.0006	29.29	0.000
Younger adults (baseline: neutrality)	−0.3565	0.1724	−2.07	0.039
Older adults (baseline: neutrality)	0.1484	0.1734	0.86	0.392
Happiness × younger adults	−0.0519	0.0266	−1.95	0.051
Happiness × older adults	−0.0735	0.0286	−2.56	0.010
Anger × younger adults	0.0529	0.021	2.52	0.012
Anger × older adults	0.0877	0.0221	3.96	0.000
Disgust × younger adults	0.0956	0.0211	4.53	0.000
Disgust × older adults	0.0631	0.0222	2.84	0.005
Sadness × younger adults	0.1713	0.0211	8.13	0.000
Sadness × older adults	0.0018	0.0223	0.08	0.936
Fear × younger adults	0.0169	0.0211	0.80	0.423
Fear × older adults	0.1773	0.0222	7.97	0.000
(B) MOOD−CONGRUENT vs. MOOD−INCONGRUENT INFORMATION PROCESSING IN FACES				
Negative mood (baseline: neutrality)	0.0132	0.0265	0.50	0.618
Negative mood × happiness	−0.2103	0.0396	−5.31	0.000
Negative mood × anger	−0.0520	0.0299	−1.74	0.081
Negative mood × disgust	0.0514	0.0298	1.72	0.085
Negative mood × sadness	−0.0500	0.0299	−1.67	0.094
Negative mood × fear	0.1490	0.0297	5.03	0.000
(C) AGE GROUP DIFFERENCES IN MOOD−CONGRUENT vs. MOOD−INCONGRUENT INFORMATION PROCESSING				
Negative mood × younger adults (baseline: neutrality)	−0.0585	0.0314	−1.86	0.063
Negative mood × older adults (baseline: neutrality)	0.0515	0.0422	1.22	0.222
Negative mood × happiness × younger adults	0.3286	0.0463	7.09	0.000
Negative mood × happiness × older adults	−0.5495	0.0654	−8.40	0.000
Negative mood × anger × younger adults	0.2393	0.0357	6.70	0.000
Negative mood × anger × older adults	0.0460	0.0459	1.00	0.316
Negative mood × disgust × younger adults	0.2511	0.0357	7.04	0.000
Negative mood × disgust × older adults	−0.0853	0.046	−1.86	0.063
Negative mood × sadness × younger adults	0.1920	0.0358	5.37	0.000
Negative mood × sadness × older adults	−0.0669	0.0461	−1.45	0.147
Negative mood × fear × younger adults	0.2346	0.0355	6.60	0.000
Negative mood × fear × older adults	−0.0040	0.0458	−0.09	0.931
(D) TEMPORAL SEQUENCE IN MOOD−CONGRUENT vs. MOOD−INCONGRUENT INFORMATION PROCESSING				
Stimulus number (baseline: neutrality)	−0.0005	0.0004	−1.38	0.167
Happiness × stimulus number	−0.0026	0.0006	−4.31	0.000
Anger × stimulus number	−0.0024	0.0005	−4.70	0.000
Disgust × stimulus number	−0.0028	0.0005	−5.51	0.000
Sadness × stimulus number	−0.0015	0.0005	−3.03	0.002
Fear × stimulus number	−0.0016	0.0005	−3.13	0.002
Negative mood × stimulus number (baseline: neutrality)	−0.0002	0.0007	−0.36	0.720
Negative mood × happiness × stimulus number	0.0011	0.0010	1.06	0.289
Negative mood × anger × stimulus number	0.0005	0.0008	0.64	0.525

(Continued)

Table 2 | Continued

Parameter	Estimate	*SE*	*t*-value	*p*-value
Negative mood × disgust × stimulus number	0.0013	0.0008	1.53	0.126
Negative mood × sadness × stimulus number	0.0009	0.0008	1.04	0.297
Negative mood × fear × stimulus number	0.0002	0.0008	0.29	0.769
Random intercept face	Variance = 0.016; *SD* = 0.127			
Random intercept participant	Variance = 2.280; *SD* = 1.510			
AIC	379195.9			
BIC	379767.5			
Log-likelihood	−189546.0			
Deviance	379091.9			

Type of emotion was dummy coded with perception of neutral emotional expression as baseline. Session = grand mean centered session number; Session squared = squared grand mean centered session number; Age group of participant (younger, middle-aged, older adults) was effect coded; Negative mood was group mean centered by subtracting the average negative mood at each study session; Stimulus number = individually centered position of the stimulus in the sequence of stimuli within each session. Faces and participants were treated as two crossed random effects.

between these factors[4]. Faces and participants were treated as two freely estimated crossed random effects in a generalized linear mixed effects model with a logit link function using the lme4 package 1.0.4 (Bates et al., 2013; see also Pinheiro and Bates, 2000) of R version 2.15.2 (R Core Team, 2012).

The possible role of emotion perception in faces as a mood-regulatory function was investigated by predicting the pre- to post-session *changes* in mood by how often a participant indicated perceiving a certain emotional expression out of the total number of ratings of this participant (i.e., the individual percentage of emotion perception in each session). In previous work we have demonstrated that changes in pre- to post-session mood decline significantly across the course of the entire study and that this change-in-change is almost perfectly captured by a logistic growth curve model (Voelkle et al., 2013). In order to control for this general trend we used the same model as in Voelkle et al. (2013) and added the interaction between age group and percentage of perceived emotional expression as time varying covariates with time varying effects[5]. To control for overall trends in emotion perception, session-mean centered scores were used.

RESULTS

The results section is organized as follows: **Table 1** contains all parameter estimates of a single crossed random effects model as described above. In the following, we report results on the relationship between *positive* mood and emotion perception in faces. The corresponding results regarding *negative* mood and emotion perception are presented in **Table 2**. We will begin with discussing differences between displayed emotions, changes in emotion perception across study sessions, and age group differences in the perception of different emotions (**Tables 1**, **2**, Part A). Next, we will turn to the question of *mood-congruent vs. mood-incongruent information processing in faces* by investigating the effect of present mood on the perception of different emotions in faces (*Hypothesis 1*; **Tables 1**, **2**, Part B), as well as *age group differences in mood-congruent vs. mood-incongruent information processing* (*Hypothesis 2*; **Tables 1**, **2**, Part C). After that we will focus on *the role of the temporal sequence in emotion processing* by analyzing the effect of stimulus position on emotion perception across the six different facial expressions along with a short discussion of possible three-way interactions of mood × stimulus position × emotion (*Hypothesis 3*; **Tables 1**, **2**, Part D). Finally, we will investigate the *effectiveness of emotion perception in faces as a mood-regulatory function* (*Hypothesis* 4; **Figure 4**).

After recognizing the primary emotional expression, the average probability to perceive an additional neutral expression in a randomly selected face picture, presented after half of the stimuli had been rated within a given study session, and after half of the sessions had been completed was $[100 \cdot (1/(1 + e^{1.978}))] = 12.16\%$ in a participant with an average within-session positive mood. However, there were large differences between the types of emotions: While the probability of perceiving an additional happy expression was significantly lower $[100 \cdot (1/(1 + e^{1.978+0.719}))] = 6.31\%$ (logit $= -0.719$; odds ratio $= 0.487$; $p < 0.001$), the probability of perceiving an additional angry expression was significantly higher (27.58%; logit $= 1.012$; odds ratio $= 2.751$; $p < 0.001$). The other emotions fell somewhere in between. Likewise, the likelihood of reporting an additional (neutral) emotional expression changed as a function of the number of sessions, with a significantly higher likelihood at the beginning of the study (20.82%) than after 10 sessions (6.79%). Note that the decline was not linear but leveled off toward the end of the study (i.e., a positive quadratic effect; $\text{logit}_{\text{Linear}} = -0.1340$, odds ratio $= 0.875$, $p < 0.001$; $\text{logit}_{\text{Quadratic}} = 0.017$, odds ratio $= 1.017$, $p < 0.001$). In contrast to the impact of session and type of emotion, age group differences in the perception of different emotions were smaller and somewhat mixed. As compared

[4] In a separate analysis, we included sex of participant as an additional predictor, which resulted in a non-significant improvement in model fit and did not change the pattern of results or any of the substantive conclusions ($2\text{Log-Likelihood}_{Diff} = 1.2$; $df_{Diff} = 1$). Because we had no prior expectations regarding sex effects, we report the analyses without sex.

[5] Missing values on the predictor variables due to study drop out were handled via Expectation Maximization (EM) imputation.

to the average age (age groups are effects coded[6]), the likelihood to perceive anger increased for both, younger ($logit_{Younger} = 0.072$, odds ratio = 1.07, $p < 0.001$) and older ($logit_{Older} = 0.062$, odds ratio = 1.06, $p < 0.001$) adults. The same applied to fear ($logit_{Younger} = 0.073$, odds ratio = 1.08, $p < 0.001$; $logit_{Older} = 0.139$, odds ratio = 1.15, $p < 0.001$). In addition, the likelihood of reporting disgust and sadness increased significantly in younger adults. However, with an odds ratio of $e^{0.182} = 1.20$ even the largest effect was rather small. See **Table 1**, Part A, for details.

MOOD-CONGRUENT VS. MOOD-INCONGRUENT INFORMATION PROCESSING IN FACES

Turning to *Hypothesis 1*, and putting age aside for the moment, there was clear evidence for a mood-congruency effect in emotion perception. The more positive participants' mood, the more likely they were to perceive happiness in the presented faces. For example, someone in a maximally positive mood would have a probability of $[100 \cdot (1/(1 + e^{1.978+0.719-0.048\cdot 2-0.118\cdot 2}))] = 8.58\%$ of perceiving an additional happy expression, but only a probability of $[100 \cdot (1/(1 + e^{1.978+0.719-0.048\cdot -2-0.118\cdot -2}))] = 4.61\%$ if scoring at the lower end of the mood scale (logit = 0.118; odds ratio = 1.125; $p < 0.001$). Being in a positive mood also slightly increased the probability of perceiving an additional neutral expression (logit = 0.048; odds ratio = 1.049; $p < 0.01$). However, being in a positive mood consistently reduced the probability of perceiving an additional expression for all negatively valenced emotions (i.e., anger, disgust, sadness, and fear; see **Table 1**). See **Table 1**, Part B.

As apparent from **Table 2**, a similar pattern held for increasing negative mood. That is, higher levels of negative mood led to a lower probability of perceiving an additional happy expression (logit = −0.210; odds ratio = 0.810; $p < 0.001$), but an increase in the likelihood to perceive an additional fearful expression (logit = 0.149; odds ratio = 1.161; $p < 0.001$). All other emotions fell somewhere in between (none of them were significant at a 0.05 alpha level).

AGE GROUP DIFFERENCES IN MOOD-CONGRUENT VS. MOOD-INCONGRUENT INFORMATION PROCESSING

Contradictory to *Hypothesis 2*, which predicted that older adults have a higher likelihood of perceiving positive emotions in facial expressions when being in a bad mood (i.e., mood-*in*congruency), a mood-congruency effect was primarily shown by older adults. Other than younger adults (logit = −0.157; odds ratio = 0.855; $p < 0.001$), older adults exhibited a significantly higher probability of perceiving happiness, when being in a good mood (logit = 0.151; odds ratio = 1.163; $p < 0.001$). **Figure 2** provides a graphical illustration of the model-predicted probabilities of perceiving an additional happy emotional expression in faces for younger and older adults with maximally high vs. low levels of positive mood. As compared to the baseline, higher levels

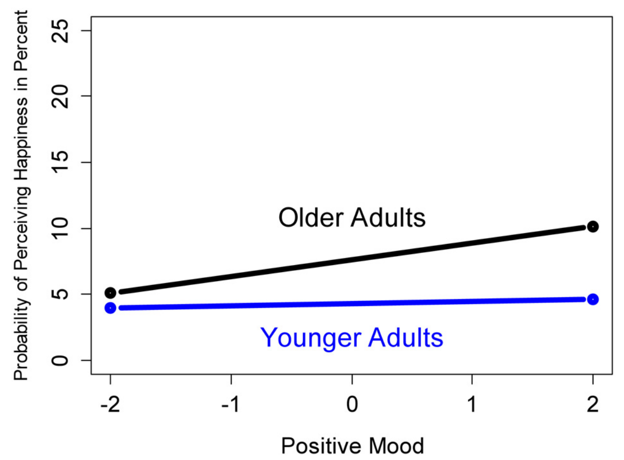

FIGURE 2 | Predicted probability of perceiving an additional happy emotional expression in faces for younger and older adults with maximally high (right) vs. maximally low (left) levels of positive mood.

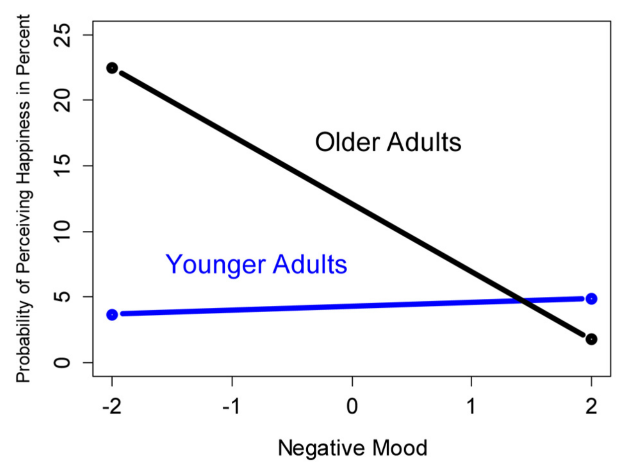

FIGURE 3 | Predicted probability of perceiving an additional happy emotional expression in faces for younger and older adults with maximally high (right) vs. maximally low (left) levels of negative mood.

of positive mood in older adults also increased the likelihood of perceiving disgust and sadness (logit = 0.076; odds ratio = 1.079; $p < 0.01$; logit = 0.081; odds ratio = 1.084; $p < 0.01$, respectively). In contrast, positive mood in older adults decreased the likelihood of perceiving neutrality (logit = −0.130; odds ratio = 0.878; $p < 0.001$). Although the results were somewhat mixed, the pronounced mood-congruency effect for older adults in the perception of happiness speaks against *Hypothesis 2*. See **Table 1**, Part C, for details. The effect for negative mood (**Table 2**) further bolstered the rejection of *Hypothesis 2*: Higher levels of negative mood in older adults *decreased* the probability of perceiving happiness (logit = −0.550; odds ratio = 0.578; $p < 0.001$), while no such decrease was found for younger adults (logit = 0.329; odds ratio = 1.390; $p < 0.001$). These results are illustrated in **Figure 3**.

[6] Middle-aged adults were chosen as the base group. As pointed out by Cohen et al. (2003), when using effects coding the base group is usually selected to be the group "for which comparisons to the mean are of *least* interest" (p. 322). This is because the analysis does not inform us *directly* about this group, but only indirectly. All information, however, is considered in the analysis. See Cohen et al. (2003) for more detailed information.

THE ROLE OF THE TEMPORAL SEQUENCE IN EMOTION PROCESSING

The probability of perceiving an additional emotional expression decreased not only across study sessions, but also within each study session (i.e., with stimulus number; see **Table 1**, Part D). While the decrease was somewhat lower and non-significant for the perception of neutrality (logit $= -0.0004$; odds ratio $= 0.999$; $p = 0.295$), it was significant for all other emotions ($p < 0.01$). At the descriptive level, the downward trend in the likelihood of reporting an emotional expression, other than neutrality, was slightly weakened for participants in a positive mood, but none of the effects was significant at a 0.01 alpha level. Likewise, there were no three-way interactions with negative mood (see **Table 2**). Given the non-significant interaction of positive mood with stimulus number and negative mood with stimulus number, respectively, along with the uniform downward trend in the likelihood of perceiving an additional emotional expression, there was little evidence for a shift from mood-congruent to mood-incongruent information processing as a function of elapsed processing time in the present study. Thus, *Hypothesis 3* was rejected.

EFFECTIVENESS OF EMOTION PERCEPTION IN FACES AS A MOOD-REGULATORY FUNCTION

In *Hypothesis* 4 we postulated a positive relationship between the likelihood of perceiving positively valenced emotions in faces and subsequent improvements in mood. This hypothesis was based on prior research suggesting that mood-incongruent information processing in older adults, or a shift from mood-congruent to mood-incongruent information processing as a function of processing time, may serve a mood-regulatory function—in particular if initial mood was bad. Given that we found no empirical support for Hypotheses 2 and 3 this seemed unlikely. To explicitly test the effect of emotion perception during a study session on mood changes from the beginning to the end of a session, we added the interaction between age group and percentage of perceived emotional expressions as time varying covariates to a logistic growth curve model of mood changes as described above. The results are presented in **Figure 4** which shows the standardized effects of emotion perception on pre- to post-session mood changes across the 10 study sessions, separated for younger, middle-aged, and older adults, and for all six emotional expressions. As apparent from the 95% confidence intervals, almost none of the effects were significant and there was no consistent pattern across time, across emotions, or across age groups. Rather, most effects varied around zero, providing no empirical support for *Hypothesis 4*.

DISCUSSION

We began this work by asking how the way we feel influences the perception of the world around us, and how this perception may affect our own feelings. We approached this question by studying the relationship between natural mood (as opposed to experimentally induced mood) and the attribution of emotions to faces for which the primary emotional expression had been correctly identified.

Consistent with our expectations in Hypothesis 1, more positive mood increased the likelihood of perceiving a happy facial expression. In particular older adults had a higher likelihood of reporting the perception of happiness in faces when being in a positive mood, and a lower likelihood when being in a negative mood. Likewise, older adults were increasingly less likely to perceive happiness in faces when in a more negative mood. Both findings did not apply to younger adults. This stands in contrast to Hypothesis 2 which predicted that older adults have a higher likelihood of perceiving positive emotions in facial expressions when in a bad mood. In contrast to previous reports in the literature (Forgas and Ciarrochi, 2002; Isaacowitz et al., 2008, 2009a), we found neither evidence for a change from mood-congruent to mood-incongruent responses over time (Hypothesis 3) nor for a mood-regulatory effect of emotion processing in faces (Hypothesis 4). In the remainder of the discussion we will offer interpretations for our central findings.

MOOD-CONGRUENT INFORMATION PROCESSING

Although partly in contrast to our expectations based on previous research using active mood induction in controlled laboratory settings, our results may be explained in terms of the AIM. The fact that older adults showed a mood-congruency effect in emotion perception suggests their use of a high affect infusion strategy such as heuristic or substantive processing. Unfortunately, the present study does not allow us to clearly disentangle the underlying mechanisms in terms of heuristic vs. substantive processing. Even though this remains an important topic to be addressed in future research, we believe that the observed mood-congruent information processing in older adults may even be due to a combination of the two processing strategies. On the one hand—and independent of present mood—older compared to younger adults were not only more likely to indicate the perception of an additional happy but also an additional neutral facial expression (see **Tables 1**, **2**). This may reflect their higher personal involvement in the task, which suggests the use of a substantive processing strategy. On the other hand, reducing cognitive resources may have let older adults rely stronger on other sources of information, such as their current mood, supporting the notion of a heuristic (mood-as-information) processing strategy.

For younger adults in contrast, the increase in the perception of happiness almost completely disappeared (see **Figure 2**), suggesting their use of a low affect infusion strategy such as motivated processing or the direct access strategy. The motivation to increase one's mood—in particular when in a bad mood—should not only eliminate a mood-congruency effect, but should result in mood-incongruent information processing (i.e., an increased likelihood of perceiving happiness). The fact that we did not observe such an effect, rather suggests the use of a direct access strategy in younger adults. As described in the introduction, this strategy is particularly likely when "the judge is not personally involved, and there are no strong cognitive, affective, motivational, or situational forces mandating more elaborate processing" (Forgas, 1995, p. 46).

MOOD-INCONGRUENT INFORMATION PROCESSING AS A MOOD-REGULATORY FUNCTION

As apparent from **Figure 4**, there was no empirical support that emotion perception in faces serves a mood-regulatory function

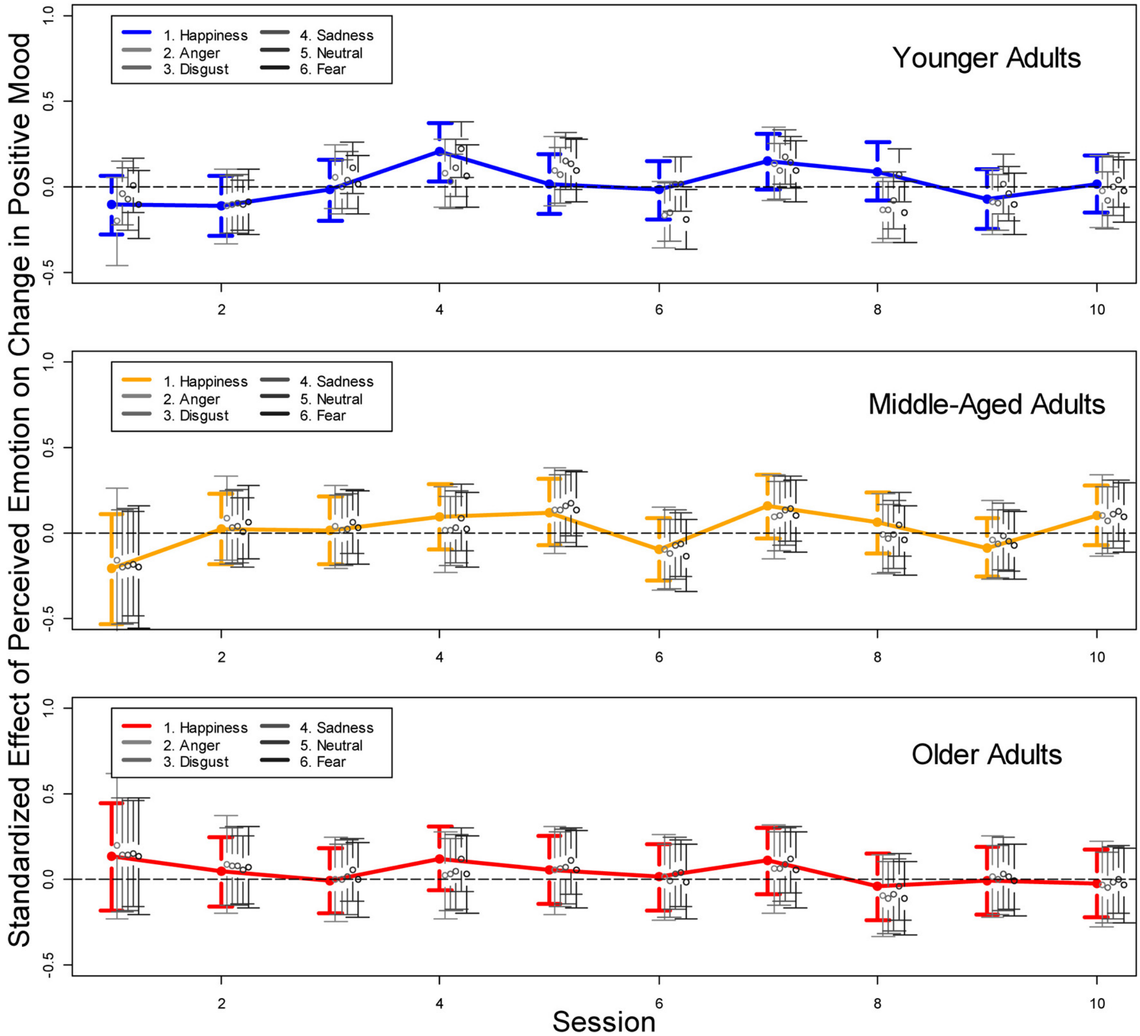

FIGURE 4 | Standardized effects of perceived happiness, anger, disgust, sadness, neutrality, and fear on changes between pre- to post-session mood for younger, middle-aged, and older participants. In six separate analyses (for the six emotions), the interaction between perceived emotional expression and age group was entered as a time-varying covariate with time-varying effects into a logistic growth curve model of changes in mood changes across the 10 study sessions (see Voelkle et al., 2013).

under conditions of natural occurring mood rather than actively induced mood. This stands in contrast to research using experimentally induced mood, which showed that the focus of older adults in a bad mood on positively valenced faces may help to regulate their mood. One reason for these different findings may be that the naturally occurring fluctuations in positive mood assessed in the present context were not sufficiently strong to reveal such an effect. Furthermore, ascribing an additional emotional expression to a face whose primary emotion had been correctly recognized is, of course, a much more subtle measure of mood-(in)congruent emotion processing as compared, for example, to gaze patterns toward prototypically positively or negatively valenced facial expressions as used in the study by Isaacowitz et al. (2008). In addition, the anticipatory (down)adjustment of positive mood may have further reduced the likelihood of discovering such an effect (Voelkle et al., 2013).

LIMITATIONS AND FUTURE DIRECTIONS

We believe the general downward trend in the likelihood of reporting an emotional expression is likely due to participant's increasing fatigue and decreasing motivation. However, it is a shortcoming of the present study that these factors were not assessed in self-report, thus this belief remains speculative. Although we statistically controlled for the downward trend, the remaining variability in mood and emotion perception may have been too small to allow for additional mood regulation effects by means of emotion perception. After all, if an individual's mood is already perfectly adjusted to the situation at hand—or if fatigue effects are very strong—there is little room for additional regulation via mood-incongruent information processing.

This may be viewed as a shortcoming of the present study. However, it also shows that while natural mood (as opposed to experimentally induced mood) is likely to affect the perception of emotions in faces, a possible mood-regulatory effect of such perception seems negligible. In fact, we found that in particular for older adults, positive mood may rather increase the likelihood of perceiving positively valenced facial expressions.

The somewhat undifferentiated take on emotions and mood may be considered another weakness of the study. Future research may profit from more fine-grained distinctions between different aspects of positive and negative mood, including different aspects of valence and arousal, and a discrete emotion perspective as outlined by Kunzmann et al. (2014) in this issue. However, the primary purpose of the present paper was not to offer a comprehensive framework on age-related changes in the intricate interplay between specific aspects of affective experience and the perception (attribution) of additional emotions in faces whose primary emotion were correctly specified. Rather the focus was to place research on emotion perception in faces into the broader context on mood-congruent vs. mood-incongruent information processing. To accomplish this goal it is necessary to remain at a more general level, although we do report more detailed findings. In the same way we encourage future research to focus on more detailed aspects of experienced mood and the perception of emotional expression, we, thus, also encourage more integrative research linking these findings back to more general research on age-related changes in mood-(in)congruent information processing. We hope the present paper will contribute to both ends.

ACKNOWLEDGMENTS

We thank Dulce Erdt, Colin Bauer, Philipp Möller, Luara Santos-Ferreira, Giorgi Kobakhidze, and the COGITO-Team for their assistance in study implementation, data collection, and data management. We thank Janek Berger for editorial assistance.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://www.frontiersin.org/journal/10.3389/fpsyg.2014.00635/abstract

REFERENCES

Adolphs, R. (2003). Cognitive neuroscience of human social behaviour. *Nat. Rev. Neurosci.* 4, 165–178. doi: 10.1038/nrn1056

Baron-Cohen, S. E., Tager-Flusberg, H. E., and Cohen, D. J. (2000). *Understanding Other Minds: Perspectives from Developmental Cognitive Neuroscience.* 2nd Edn. Oxford: Oxford Univeristy Press.

Bates, D., Maechler, M., Bolker, B., and Walker, S. (2013). *lme4: Linear Mixed-Effects Models using Eigen and S4 (Version 1.0-4) [R package].* Available online at: http://CRAN.R-project.org/package=lme4

Becker, M. W., and Leinenger, M. (2011). Attentional selection is biased toward mood-congruent stimuli. *Emotion* 11, 1248–1254. doi: 10.1037/a0023524

Beevers, C. G., and Carver, C. S. (2003). Attentional bias and mood persistence as prospective predictors of dysphoria. *Cogn. Ther. Res.* 27, 619–637. doi: 10.1023/A:1026347610928

Bower, G. H. (1981). Mood and memory. *Am. Psychol.* 36, 129–148. doi: 10.1037/0003-066X.36.2.129

Bower, G. H. (1991). "Mood congruity of social judgements," in *Emotion and Social Judgements,* ed J. P. Forgas (New York, NY: Pergamon), 31–53.

Carstensen, L. L. (2006). The influence of a sense of time on human development. *Science* 312, 1913–1915. doi: 10.1126/science.1127488

Carstensen, L. L., Isaacowitz, D. M., and Charles, S. T. (1999). Taking time seriously: a theory of socioemotional selectivity. *Am. Psychol.* 54, 165–181. doi: 10.1037/0003-066X.54.3.165

Clark, D. A., Beck, A. T., and Alford, B. A. (1999). *Scientific Foundations of Cognitive Theory and Therapy for Depression*. New York, NY: John Wiley and Sons.

Cohen, J., Cohen, P., West, S. G., and Aiken, L. S. (2003). *Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences.* 3rd Edn. Hillsdale, NJ: Erlbaum.

Coupland, N. J., Sustrik, R. A., Ting, P., Li, D., Hartfeil, M., Singh, A. J., et al. (2004). Positive and negative affect differentially influence identification of facial emotions. *Depress. Anxiety* 19, 31–34. doi: 10.1002/da.10136

Ebner, N. C., Riediger, M., and Lindenberger, U. (2010). FACES—A database of facial expressions in young, middle-aged, and older women and men: development and validation. *Behav. Res. Methods* 42, 351–362. doi: 10.3758/BRM.42.1.351

Eizenman, M., Yu, L. H., Grupp, L., Eizenman, E., Ellenbogen, M., Gemar, M., et al. (2003). A naturalistic visual scanning approach to assess selective attention in major depressive disorder. *Psychiatry Res.* 118, 117–128. doi: 10.1016/S0165-1781(03)00068-4

Ekman, P. (1993). Facial expression and emotion. *Am. Psychol.* 48, 384–392. doi: 10.1037/0003-066X.48.4.384

Elliott, R., Rubinsztein, J. S., Sahakian, B. J., and Dolan, R. J. (2002). The neural basis of mood-congruent processing biases in depression. *Arch. Gen. Psychiatry* 59, 597–604. doi: 10.1001/archpsyc.59.7.597

Erber, R., and Erber, M. W. (1994). Beyond mood and social judgment: mood incongruent recall and mood regulation. *Eur. J. Soc. Psychol.* 24, 79–88. doi: 10.1002/ejsp.2420240106

Forgas, J. P. (1992). Mood and the perception of unusual people: affective asymmetry in memory and social judgments. *Eur. J. Soc. Psychol.* 22, 531–547. doi: 10.1002/ejsp.2420220603

Forgas, J. P. (1995). Mood and judgment: the affect infusion model (AIM). *Psychol. Bull.* 117, 39–66. doi: 10.1037/0033-2909.117.1.39

Forgas, J. P., and Ciarrochi, J. V. (2002). On managing moods: evidence for the role of homeostatic cognitive strategies in affect regulation. *Pers. Soc. Psychol. Bull.* 28, 336–345. doi: 10.1177/0146167202286005

Hall, D. B. (2000). Zero-Inflated poisson and binomial regression with random effects: a case study. *Biometrics* 56, 1030–1039. doi: 10.1111/j.0006-341X.2000.01030.x

Hampel, R. (1977). Adjektiv-Skalen zur Einschätzung der Stimmung (SES) [Adjective scales to assess mood]. *Diagnostica* 23, 43–60.

Hunter, P. G., Schellenberg, E. G., and Griffith, A. T. (2011). Misery loves company: mood-congruent emotional responding to music. *Emotion* 11, 1068–1072. doi: 10.1037/a0023749

Isaacowitz, D. M., Allard, E. S., Murphy, N. A., and Schlangel, M. (2009a). The time course of age-related preferences toward positive and negative stimuli. *J. Gerontol. B Psychol. Sci. Soc. Sci.* 64B, 188–192. doi: 10.1093/geronb/gbn036

Isaacowitz, D. M., Toner, K., Goren, D., and Wilson, H. R. (2008). Looking while unhappy: mood-congruent gaze in young adults, positive gaze in older adults. *Psychol. Sci.* 19, 848–853. doi: 10.1111/j.1467-9280.2008.02167.x

Isaacowitz, D. M., Toner, K., and Neupert, S. D. (2009b). Use of gaze for real-time mood regulation: Effects of age and attentional functioning. *Psychol. Aging* 24, 989–994. doi: 10.1037/a0017706

Koster, E. H. W., De Raedt, R., Leyman, L., and De Lissnyder, E. (2010). Mood-congruent attention and memory bias in dysphoria: exploring the coherence among information-processing biases. *Behav. Res. Ther.* 48, 219–225. doi: 10.1016/j.brat.2009.11.004

Kunzmann, U., Kappes, C., and Wrosch, C. (2014). Emotional aging: a discrete emotions perspective. *Front. Psychol.* 5:380. doi: 10.3389/fpsyg.2014.00380

Matt, G. E., Vázquez, C., and Campbell, W. K. (1992). Mood-congruent recall of affectively toned stimuli: a meta-analytic review. *Clin. Psychol. Rev.* 12, 227–255. doi: 10.1016/0272-7358(92)90116-P

Mayer, J. D., McCormick, L. J., and Strong, S. E. (1995). Mood-congruent memory and natural mood: new evidence. *Pers. Soc. Psychol. Bull.* 21, 736–746. doi: 10.1177/0146167295217008

Meissner, C. A., and Brigham, J. C. (2001). Thirty years of investigatin the own-race bias in memory for faces: a meta-analytic review. *Psychol. Public Policy Law* 7, 3–35. doi: 10.1037/1076-8971.7.1.3

Morris, W. N., and Reilly, N. P. (1987). Toward the self-regulation of mood: theory and research. *Motiv. Emot.* 11, 215–249. doi: 10.1007/BF01001412

Olsen, M. K., and Schafer, J. L. (2001). A two-part random-effects model for semicontinuous longitudinal data. *J. Am. Stat. Assoc.* 96, 730–745. doi: 10.2307/2670310

Phillips, L., and Allen, R. (2004). Adult aging and the perceived intensity of emotions in faces and stories. *Aging Clin. Exp. Res.* 16, 190–199. doi: 10.1007/BF03327383

Pinheiro, J. C., and Bates, D. M. (2000). *Mixed-Effects Models in S and S-Plus*. New York, NY: Springer. doi: 10.1007/978-1-4419-0318-1

R Core Team. (2012). *R: a Language and Environment for Statistical Computing.* Vienna: R Foundation for Statistical Computing. Available online at: http://www.R-project.org/

Riediger, M., Voelkle, M. C., Ebner, N. C., and Lindenberger, U. (2011). Beyond "happy, angry, or sad?": age-of-poser and age-of-rater effects on multi-dimensional emotion perception. *Cogn. Emotion* 25, 968–982. doi: 10.1080/02699931.2010.540812

Rinck, M., Becker, E. S., Kellermann, J., and Roth, W. T. (2003). Selective attention in anxiety: distraction and enhancement in visual search. *Depress. Anxiety* 18, 18–28. doi: 10.1002/da.10105

Ruffman, T., Henry, J. D., Livingstone, V., and Phillips, L. H. (2008). A meta-analytic review of emotion recognition and aging: implications for neuropsychological models of aging. *Neurosci. Biobehav. Rev.* 32, 863–881. doi: 10.1016/j.neubiorev.2008.01.001

Schwarz, N., and Clore, G. L. (1983). Mood, misattribution, and judgments of well-being: informative and directive functions of affective states. *J. Pers. Soc. Psychol.* 45, 513–523. doi: 10.1037/0022-3514.45.3.513

Schwarz, N., and Clore, G. L. (2003). Mood as information: 20 years later. *Psychol. Inq.* 14, 296–303. doi: 10.1080/1047840X.2003.9682896

Sedikides, C. (1994). Incongruent effects of sad mood on self-conception valence: it's a matter of time. *Eur. J. Soc. Psychol.* 24, 161–172. doi: 10.1002/ejsp.2420240112

Stuhrmann, A., Dohm, K., Kugel, H., Zwanzger, P., Redlich, R., Grotegerd, D., et al. (2013). Mood-congruent amygdala responses to subliminally presented facial expressions in major depression: associations with anhedonia. *J. Psychiatry Neurosci.* 38, 249–258. doi: 10.1503/jpn.120060

Suzuki, A., Hoshino, T., Shigemasu, K., and Kawamura, M. (2007). Decline or improvement? Age-related differences in facial expression recognition. *Biol. Psychol.* 74, 75–84. doi: 10.1016/j.biopsycho.2006.07.003

Voelkle, M. C., Ebner, N. C., Lindenberger, U., and Riediger, M. (2012). Let me guess how old you are: effects of age, gender, and facial expression on perceptions of age. *Psychol. Aging* 27, 265–277. doi: 10.1037/a0025065

Voelkle, M. C., Ebner, N. C., Lindenberger, U., and Riediger, M. (2013). Here we go again: anticipatory and reactive mood responses to recurring unpleasant situations throughout adulthood. *Emotion* 13, 424–433. doi: 10.1037/a0031351

Wechsler, D. (1981). *Wechsler Adult Intelligence Scale - Revised (WAIS-R)*. New York, NY: Psychological Corporation.

Wyer, R. S., and Carlston, D. E. (1979). *Social Cognition, Inference, and Attribution*. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 13 January 2014; accepted: 04 June 2014; published online: 26 June 2014.
Citation: Voelkle MC, Ebner NC, Lindenberger U and Riediger M (2014) A note on age differences in mood-congruent vs. mood-incongruent emotion processing in faces. Front. Psychol. ***5****:635. doi: 10.3389/fpsyg.2014.00635*
This article was submitted to Emotion Science, a section of the journal Frontiers in Psychology.

ORIGINAL RESEARCH ARTICLE
published: 27 May 2014
doi: 10.3389/fpsyg.2014.00480

No smile like another: adult age differences in identifying emotions that accompany smiles

***Michaela Riediger* [1]*, *Markus Studtmann* [1], *Andrea Westphal* [1†], *Antje Rauers* [1] *and Hannelore Weber* [2]**

[1] *Max Planck Research Group "Affect Across the Lifespan," Max Planck Institute for Human Development, Berlin, Germany*
[2] *Institute for Psychology, University of Greifswald, Greifswald, Germany*

Edited by:
Natalie Ebner, University of Florida, USA

Reviewed by:
Natalie Ebner, University of Florida, USA
Andrew E. Reed, Stanford University, USA
Tammy English, Washington University in St. Louis, USA

****Correspondence:***
Michaela Riediger, Max Planck Institute for Human Development, Lentzeallee 94, 14195 Berlin, Germany
e-mail: riediger@mpib-berlin.mpg.de

† Present address:
Andrea Westphal, University of Potsdam, Potsdam, Germany

People smile in various emotional contexts, for example, when they are amused or angry or simply being polite. We investigated whether younger and older adults differ in how well they are able to identify the emotional experiences accompanying smile expressions, and whether the age of the smiling person plays a role in this respect. With this aim, we produced 80 video episodes of three types of smile expressions: positive-affect smiles had been spontaneously displayed by target persons as they were watching amusing film clips and cartoons. Negative-affect smiles had been displayed spontaneously by target persons during an interaction in which they were being unfairly accused. Affectively neutral smiles were posed upon request. Differences in the accompanying emotional experiences were validated by target persons' self-reports. These smile videos served as experimental stimuli in two studies with younger and older adult participants. In Study 1, older participants were less likely to attribute positive emotions to smiles, and more likely to assume that a smile was posed. Furthermore, younger participants were more accurate than older adults at identifying emotional experiences accompanying smiles. In Study 2, both younger and older participants attributed positive emotions more frequently to smiles shown by older as compared to younger target persons, but older participants did so less frequently than younger participants. Again, younger participants were more accurate than older participants in identifying emotional experiences accompanying smiles, but this effect was attenuated for older target persons. Older participants could better identify the emotional state accompanying smiles shown by older than by younger target persons. Taken together, these findings indicate that there is an age-related decline in the ability to decipher the emotional meaning of smiles presented without context, which, however, is attenuated when the smiling person is also an older adult.

Keywords: smile expressions, age differences, emotion recognition, Duchenne, adulthood

INTRODUCTION

Facial expressions are a pivotal component of non-verbal communication. They can convey information about the emotional state of the expressive person (e.g., Ekman, 1972; Izard, 1994), and about accompanying behavioral intentions and action requests (e.g., Fridlund, 1994, 1997). Facial displays can thus help to coordinate and regulate social interactions, provided, of course, that the perceiver recognizes the emotional states associated with the expression and responds accordingly (Keltner et al., 2006). This, however, is not always easy because people can show similar facial expressions in disparate emotional situations. A prime example is smiling. Even though smiling is regarded in many cultures as a prototypical sign of pleasure (e.g., Ekman, 1972; Elfenbein and Ambady, 2002), people do not smile only when they are joyful or amused. They also smile when they experience negative affect, such as sadness (e.g., Bonanno and Keltner, 1997; Papa and Bonanno, 2008), and they also smile in the absence of intense feelings, for example, to be polite. The purpose of the present research was to investigate whether adults of different age groups differ in how well they are able to identify such diverse emotional experiences accompanying smiles, and whether the age of the smiling persons plays a role in this respect. Below, we elucidate the theoretical background for our investigation. We first review findings from previous research on adult age differences in the ability to interpret the emotional meaning of posed facial expressions and explain methodological criticisms that have been raised regarding this line of research. We then argue that studying age differences in the ability to understand the emotional meaning of authentic smile expressions can circumvent these criticisms. We briefly introduce the state of the art of research on smile expressions, and review the available evidence from age-comparative studies on identifying different types of smiles. Following that, we explain the steps we have taken in the present studies to further advance this line of research, and derive our research questions and predictions.

RESEARCH ON AGE DIFFERENCES IN IDENTIFYING THE EMOTIONAL MEANING OF FACIAL EXPRESSIONS: THE TRADITIONAL PARADIGM

One might expect that as adults accumulate life experience with age, they should become better at identifying the emotional meaning of other people's facial expressions. Most of the empirical evidence available to date, however, speaks to the contrary. With few exceptions, the majority of these findings stem from a paradigm that we will refer to here as the traditional paradigm: participants were presented with photographs of individuals who pose prototypic expressions of highly intense basic emotions. Their task was to select the displayed emotion from a number of response options. A meta-analysis of 17 data sets demonstrated that younger adults outperform older participants in this task (Ruffman et al., 2008). This has been shown for recognizing posed facial expressions of fear, anger, sadness, and, with smaller effect sizes, also surprise and happiness. The only exception to this overarching pattern involved the recognition of posed disgust expressions, for which no significant differences between younger and older adults emerged. Overall, however, the performance advantage of younger adults in this traditional paradigm is undisputed. These findings suggest that older adults are less adept than younger adults in recognizing emotions from facial expressions. This interpretation has recently been challenged however by various authors who pointed out important limitations in the traditional approach. Two major points of criticism have been raised, pertaining to the limited age fairness and ecological validity of the traditional paradigm (Ruffman et al., 2008; Isaacowitz and Stanley, 2011; Richter et al., 2011; Richter and Kunzmann, 2011; Riediger et al., 2011).

The first criticism, limited age fairness, argues that the selection of expression stimuli may have often put older participants at a disadvantage compared to younger participants. Most studies in this research tradition have derived their stimuli from picture sets provided by Ekman and Friesen (1976) or Matsumoto and Ekman (1988). These picture sets were selected on the basis of prototypicality judgments by younger adults, which might disadvantage older study participants if such judgments vary with age. Furthermore, these stimulus sets include facial expressions shown by younger or middle-aged, but not older, posers. This, too, might have put older participants at a disadvantage. Empirical evidence shows that people are better at interpreting emotional expressions of individuals who are similar to themselves as opposed to individuals who are dissimilar. This has been demonstrated for similarity in terms of sharing the same interests, nationality, ethnicity, cultural group, or university affiliation (Elfenbein and Ambady, 2002; Thibault et al., 2006). Several explanations for these in-group effects have been proposed, such as that one has a better knowledge base for interpreting facial expressions shown by individuals belonging to a group with which one identifies, or that one has a higher motivation to attend to, and process, the expressions of such individuals. It has been argued that age-group membership might be relevant in this regard as well, although empirical evidence to date is still rare and inconclusive (e.g., Malatesta, 1987; Ebner and Johnson, 2009; Ebner et al., 2011; Riediger et al., 2011).

The second criticism, limited ecological validity, involves the argument that spontaneous emotional expressions in "real" life differ markedly from the stimuli used in the traditional paradigm. The experimental stimuli typically showcase photographs of prototypical displays, as proposed by the Affect Program Theory of facial expressions (APT, e.g., Ekman, 1972, 1993). Evidence is amounting, however, that facial expressions that are spontaneously shown while experiencing emotions are often more subtle, and typically comprise the activation of fewer and sometimes different muscular components (action units) than proposed by APT, even when the self-rated intensity of the emotional experience is high (for a review, see Reisenzein et al., 2013).

Another characteristic of the traditional paradigm that delimits its ecological validity is that still pictures of facial expressions are used as experimental stimuli. The spontaneous facial expressions that people encounter in their daily lives, however, are dynamic and rapidly changing. Evidence that partly different brain structures subserve the processing of static and dynamic stimuli underscores that the temporal dimension is an important characteristic of facial expressions (e.g., Adolphs et al., 2003; LaBar et al., 2003; Schultz and Pilz, 2009).

Like limited age fairness, the limited ecological validity may also have disadvantaged older adults more than younger adults because solving tasks that have not been practiced before appears to be more challenging for older than for younger adults. Age differences in various types of cognitive performance, for example, have been found to be more pronounced for unfamiliar or artificial problems and considerably smaller for ecologically valid problems that older adults encounter in their daily life contexts (e.g., Phillips et al., 2006; Kliegel et al., 2007). It seems reasonable to expect that this effect would generalize to differences between artificial and ecologically valid emotion-recognition tasks as well.

In essence, research on whether adults from different age groups differ in their ability to identify the emotional experiences accompanying facial expressions has a long tradition. The paradigm that has predominantly been used to date to investigate this question, however, has been criticized for various reasons. These criticisms have inspired researchers to search for alternative paradigms. One novel approach, which we consider promising and pursue further in the research reported here, is to investigate whether adults from various age groups differ in how well they are able to identify the emotional experiences accompanying smile expressions that were displayed in different emotional situations (McLellan, 2008; Murphy et al., 2010; Slessor et al., 2010a). Another approach to enhance ecological validity has been to study age differences in emotion recognition in naturalistic (e.g., Rauers et al., 2013) or semi-naturalistic situations (e.g., Richter and Kunzmann, 2011; Sze et al., 2012). In such situations, multiple information sources can be available (e.g., previously acquired knowledge about the interaction partner, the content of verbal communication, and other channels of nonverbal communication in addition to facial expressions, like pitch of voice, body posture and -movements). Therefore, this alternative research approach is well suited to examine age differences in the overarching ability to understand other people's emotional experiences—an ability that derives from integrating information from these multiple sources. In these studies, however, it is difficult to separate the specific components that contribute to this integrative ability. One of these specific skills is in the fore of the present paper: the ability to infer emotional states specifically from facial expressions.

IDENTIFYING EMOTIONAL EXPERIENCES THAT ACCOMPANY SMILE EXPRESSIONS

Smiles are subtle facial displays that frequently occur in natural interactions. The smile expression involves lifting the corner of the mouth through contraction of the zygomaticus major muscle. It can, but need not, be accompanied by activation of other facial muscles as well (e.g., Ambadar et al., 2009). Smiling differs from laughing in that neither the characteristic laughing acoustic nor the typical laughing movements (e.g., rhythmically repeated head and shoulder movements) accompanies it.

Smile expressions are shown in different emotional situations. People often smile in positive emotional contexts, for example, when they feel happy or amused. In fact, smiling is regarded as a prototypical sign of pleasure in many cultures (e.g., Ekman, 1972; Elfenbein and Ambady, 2002). People also however occasionally smile in the absence of pleasant feelings, and even in the context of negative emotional experiences, such as feeling embarrassed (e.g., Keltner, 1995) or sad (Bonanno and Keltner, 1997; Papa and Bonanno, 2008). It has been argued that smiling in the absence of positive affect serves self-regulatory as well as social functions (Gross, 1999). It has been found, for example, that smiling can help to alleviate negative and enhance positive affect (Soussignan, 2002; Ansfield, 2007). People may also smile in the absence of positive affect to conform to social norms and expectations, for example, to conceal how they are feeling, or to appease their interaction partner (e.g., Keltner, 1995; Hecht and LaFrance, 1998; Keltner and Haidt, 1999).

The smile displays that accompany different emotional experiences are assumed to vary subtly in their expressive characteristics. What exactly these expressive differences are, is subject of an ongoing debate. Two types of smiles have been most extensively investigated in this regard, namely, those that are spontaneously shown when experiencing positive emotional states, and those that are deliberately posed in the absence of positive experiences (for overviews, see Ambadar et al., 2009; Johnston et al., 2010). An assumption that is still widely spread, but critically questioned today, traces back to the 19th century French physiologist Duchenne de la Boulogne. It pertains to the lateral part of the muscle surrounding the eye (i.e., the pars lateralize of the orbicularis oculi muscle, also referred to as the Duchenne marker), which has been proposed to contract during spontaneous smiles (thus narrowing the eyes and creating characteristic crow's feet), but not during deliberate smiles (e.g., Ekman et al., 1990; Soussignan, 2002). Empirical evidence, however, contradicts the assumption that the Duchenne marker indicates spontaneous, positive-affect smiles. Neither do positive-affect smiles reliably involve the presence, nor do non-positive smiles reliably involve the absence of the Duchenne marker (see overviews in Messinger et al., 1999; Krumhuber and Manstead, 2009). That is, contraction of the Duchenne marker also occurs at a considerable number of occasions when people deliberately pose smiles (Schmidt and Cohn, 2001; Schmidt et al., 2006, 2009; Krumhuber and Manstead, 2009), or when they smile while experiencing negative affect, such as embarrassment (e.g., Keltner, 1995; Papa and Bonanno, 2008). Also the proposal that spontaneous positive-affect smiles may be more symmetrical than posed smiles (e.g., Ekman et al., 1981) has not been supported by studies using precise measures of expression symmetry (e.g., Schmidt et al., 2006). Instead, evidence is accumulating that types of smiles may differ in their temporal characteristics (see overview in Schmidt et al., 2009). Compared to posed smiles, for example, spontaneous positive smiles have been found to involve longer onset and offset phases (Schmidt et al., 2006), and a smoother progression of muscle movements (Hess and Kleck, 1990). Overall, there is considerable agreement among smile researchers that there are expressive differences between smiles accompanying different emotional experiences. The exact nature of these expressive differences, however, still is an ongoing field of research.

Let us return to the question of whether adults from different age groups differ in their ability to identify emotional experiences accompanying facial expressions. One novel approach in this line of research, taken so far by three studies, has been to use the smile expressions that had been shown in different emotional situations as the experimental stimuli (as opposed to posed expressions of highly intense basic emotions in the traditional paradigm). Adults from different age groups were asked to choose among several response options the emotional context in which they believed that the specific smile expression had been shown (McLellan, 2008; Murphy et al., 2010; Slessor et al., 2010a). As described in more detail below, these studies suggest that the conclusion from studies with the traditional paradigm (namely, that the ability to identify emotions from facial expressions uniformly declines with age) needs to be modified. This novel approach is interesting because it circumvents shortcomings of the traditional paradigm, yet still maximizes experimental control: smile expressions are highly relevant in people's everyday life contexts and hence the requirement of ecological validity discussed above is fulfilled. In addition, smiles occur in different emotional contexts and therefore lend themselves as stimuli for the study of individual differences in the ability to identify emotional experiences accompanying facial expressions. Smile expressions thus do indeed appear to be well suited as experimental stimuli in studying adult age differences in the ability to identify emotional facial expressions. The smiles studies available to date, however, have had some limitations so that further evidence is necessary. The above review indicates that several requirements need to be met to fully exploit the potential advantages of using smile expressions as experimental stimuli. First, given the potential diagnostic value of the temporal characteristics in identifying the emotional experiences accompanying smile expressions, the smile stimuli should be dynamic rather than static. Second, because the research on mimic characteristics that reliably indicate the emotional experience during a smile episode is still evolving, the smiling persons' emotional experiences should not be determined on the basis of expression characteristics. In particular, the Duchenne criterion should be avoided, given accumulating evidence that it does not reliably differentiate between different types of smiles. An alternative approach to maximizing the content validity of smile types could be, for example, to establish that the smiling persons' self-reported emotional experiences correspond to the emotional nature of the situations in which they displayed the smile. Third, in light of previous evidence on in-group advantages in understanding emotional facial expressions, the age of the smiling person should be varied to enhance the age fairness of the task and to determine the role that the age of the smiling person plays for participants' recognition accuracy. Fourth, the range of emotional experiences that accompany the selected smile expressions should be wide and ideally include positive, negative, as well as emotionally neutral states. This latter stipulation is in line with the claim that to understand adult age differences in various aspects of emotional functioning, it is important to consider the valence dimension of emotional experiences. This claim derives from the assumption that as older adults become increasingly aware of their narrowing perspective of remaining life time, they should become progressively more motivated to optimize their emotional well-being in the here and now. This, in turn, should be reflected in an increasing preference to attend to and process positive rather than negative information from their surroundings (e.g., Carstensen et al., 2003). Indeed, there is ample evidence to support this claim, primarily in the domains of attention and memory (for overviews, see Carstensen and Mikels, 2005; Reed and Carstensen, 2012), but also in the ways how adults from different age groups interpret still pictures of emotional poses as used in the traditional paradigm (Riediger et al., 2011). It is possible that these preferences might also influence how individuals from different age groups interpret the emotional meaning of different type of smiles.

To the best of our knowledge, no previous study has been published thus far that fulfilled all of these requirements. We are aware of three previous publications on adult age differences in reading different types of smiles (McLellan, 2008; Murphy et al., 2010; Slessor et al., 2010a). All of these studies were interested in the ability to differentiate spontaneous, positive-affect smiles from posed, emotionally neutral smiles. None of these studies included smile expressions accompanying negative emotional experiences. The results of these studies indicated either no significant differences between younger and older adults in the ability to differentiate smile expressions (McLellan, 2008; Murphy et al., 2010, Study 1; Slessor et al., 2010a), or better performance in older as compared to younger adults (Murphy et al., 2010, Study 2). McLellan (2008) and Slessor et al. (2010a) used still pictures of smile expressions and thus did not provide the potentially diagnostic information of the smile dynamics. Furthermore, they included smile expressions only from young, but not older target persons, and used the Duchenne marker as a selection criterion for their smile stimuli, in addition to the targets' self-reported emotional experiences. Murphy et al. (2010) did use dynamic smile stimuli and also varied the age of the smiling person in one of the reported studies. They relied, however, exclusively on the Duchenne criterion to categorize their smile stimuli as positive-affect vs. posed smiles, without further verifying this, for example, with the smiling persons' self-reported experience or information on the emotional nature of the situation in which the smile was shown.

The purpose of the present research was to further advance this line of research by creating a content-valid set of dynamic smile stimuli that fulfills all of the requirements summarized above. This set of dynamic stimuli comprised smile expressions that were spontaneously displayed while experiencing elevated levels of either positive or negative affect, or that were displayed upon our request while being in an emotionally neutral state. We employed these stimuli in two studies. In Study 1, positive, negative, and neutral smile expressions displayed by younger targets were presented to younger and older adults. The participant's task was to identify the emotional experience accompanying the presented smile expressions. Because of their accumulated exposure to, and experience with, subtle emotional expressions of other persons, we expected older participants to be more accurate in their performance of this ecologically and content-valid smile emotion-recognition task than younger adults would be. We also explored whether this age effect would differ between positive-affect, negative-affect, and posed smiles. This exploration was motivated by prior evidence of age-related increases during adulthood in preferential attention toward positive and away from negative information (Carstensen and Mikels, 2005; Reed and Carstensen, 2012). We were interested in exploring whether these positivity effects would generalize to interpretations of smile expressions as well.

In Study 2, we presented positive and neutral smile expressions of younger and older targets to younger and older adults. Our aim was to investigate whether the age of the smiling person matters for the perceiver's accuracy in identifying emotional experiences accompanying smiles. Previous research suggests that people are better able to identify emotional experiences from facial expressions shown by individuals that belong to the same social group, broadly defined (Elfenbein and Ambady, 2002). We hypothesized that age-group membership may have similar effects on identifying the emotional meaning of dynamic smile expressions shown by target persons from different age groups. We are aware of only one prior study that investigated this possibility (Murphy et al., 2010). There was no indication of own-age effects in smile recognition in this study. This, however, could have been because the smile expressions in this study had been classified exclusively on the basis of the Duchenne criterion (i.e., without reference to the situations in which the smiles were shown or to the smiling persons' self-reported emotional experience). Because of previous evidence that the Duchenne marker is not a reliable indicator of emotional experiences accompanying smile expressions, we assumed that a different pattern might emerge in our study, which used smile stimuli that had been selected when the smiling person's self-reported emotional experience and the emotional nature of the situation in which the smile had been expressed corresponded with one another.

PRE-STUDY: STIMULUS DEVELOPMENT

To fulfill the four requirements introduced above, we developed a new set of dynamic and content-valid smile expressions that were displayed in different emotional situations by target persons varying in age and gender whose self-reported emotional experiences matched the intended emotional context. The collection included negative-affect, positive-affect, and emotionally neutral smiles. The videos recorded the head and shoulders of the target persons. They started with the onset of the smile expression, ended with its offset, and did not include sound. Their average duration was 6.99 s ($SD = 2.27$). Smile duration differed neither between the three smile types, $F_{(2,\ 77)} = 0.031$, $p = 0.970$, partial $\eta^2 = 0.001$, nor between the two age groups of target persons, $F_{(1,\ 77)} = 0.\ 385$, $p = 0.537$, partial $\eta^2 = 0.005$, and there was also no significant

Smile Type × Age Group interaction, $F_{(1, 77)} = 0.131$, $p = 0.718$, partial $\eta^2 = 0.002$.

Below, we describe the development and selection of these smile stimuli and demonstrate that the target persons' self-reported emotional experiences during the smile episodes matched the intended emotional situation and differed significantly between the three types of smiles. We also report the prevalence rates of the Duchenne marker, which confirm prior evidence that this marker is not suited to distinguish between different types of smiles.

SELECTION OF NEGATIVE-AFFECT SMILES DISPLAYED BY YOUNGER TARGET PERSONS

Negative-affect smiles were extracted from video-recordings of a previously published anger-induction experiment with $N = 157$ non-psychology majors of the University of Greifswald, Germany, who had signed up to participate in a study allegedly investigating associations between personality and concentration (Weber and Wiedig-Allison, 2007). Of these participants, 34 persons were excluded because they reported suspicions during debriefing about the true study purposes, leaving recordings of 123 persons (60 female, $M = 22.9$ years of age, $SD = 3.0$) as material for the extraction of negative-affect smiles. Prior to the anger-induction phase, these target persons first completed, among other things, baseline measures of state anger and momentary negative affect. They were then instructed to work on a computerized task, and to only use certain keys for their responses. The task was programmed to break down after several minutes and trained experimenters accused the target persons of having caused the breakdown by pressing a wrong key. The experimenters also commented in a brusque and condescending way on the situation, implying that the participants had failed on a very simple task. After pretending that restarting the task had failed, the experimenter announced that the data had been lost due to the target person's fault and that he or she might therefore not receive the promised reimbursement. Following that, the target persons again completed, among other things, measures of momentary state anger and negative affect. Then they were debriefed about the true nature of the experiment and asked whether they still consented to be part of the study and whether they would permit their videotapes to be used in further studies and analyses (which all target persons did).

State anger was measured before and after the anger induction phase using four items from the German version of the State Anger Scale (Schwenkmezger et al., 1992). Items were responded to on a four-point rating scale. A sum score was determined as an indicator of the target person's momentary state anger and rescaled such that absence of anger was indicated by a value of zero. Negative affect was assessed with 10 items from the German version of the Positive and Negative Affect Schedule (Krohne et al., 1996), which were responded to on a five-point rating scale. A sum score of these items served as an indicator of momentary negative affect and was rescaled such that absence of negative affect was indicated by a value of zero.

In the video recordings, smile episodes during the anger-induction phase were identified as contractions of the zygomaticus major muscle (lip corner puller AU12 in the Facial Action Coding System FACS, Ekman and Friesen, 1978). From the resulting pool of 72 smile episodes, 16 negative-affect smiles (50% from female target persons) were selected that fulfilled the following criteria: (1) The smile was shown following insulting remarks by the experimenter; (2) The smile was displayed by target persons with an increase in momentary negative affect or an increase in state anger from baseline to post-induction, respectively; and (3) The smile expression was complete (i.e., included onset, apex, and offset phases) and unambiguous (i.e., included no more than one contraction of the zygomaticus major muscle). The average momentary state anger and the average momentary negative affect reported by the respective target persons after the anger induction phase are summarized in the first row of **Table 1** for the negative-affect smiles that were selected.

SELECTION OF POSITIVE-AFFECT AND NEUTRAL SMILES DISPLAYED BY YOUNGER AND OLDER TARGET PERSONS

Episodes of positive-affect and neutral smiles were recorded at the Max Planck Institute for Human Development in Berlin during

Table 1 | Self-reported emotional experiences accompanying the negative-affect, positive-affect, and neutral smile episodes selected as stimulus material for Studies 1 and 2.

Smile type	Age group of target	State anger[a]		Negative affect[a]		Amusement[b]	
		M (POMP[c])	*SD*	*M* (POMP[c])	*SD*	*M* (POMP[c])	*SD*
Negative-affect smile	Younger	3.75 (31.25%)	2.82	12.69 (31.73%)	6.99	–	–
	Older	–	–	–	–	–	–
Positive-affect smile	Younger	0.00 (0.00%)	0.00	0.69 (1.73%)	1.25	80.42 (80.42%)	12.46
	Older	0.00 (0.00%)	0.00	0.94 (2.35%)	1.06	79.38 (79.38%)	12.06
Neutral smile	Younger	0.00 (0.00%)	0.00	0.69 (1.73%)	1.14	10.83 (10.83%)	8.48
	Older	0.00 (0.00%)	0.00	0.38 (0.95%)	1.09	15.00 (15.00%)	10.11

Sixteen smile episodes per smile type and age group of targets.

[a] *State anger and negative affect were assessed after the anger-induction phase, amusement-induction phase, and posing-instruction phase for negative-affect, positive-affect, and neutral smiles, respectively.*

[b] *Amusement was assessed immediately after each smile episode.*

[c] *POMP, percent of maximum possible score.*

an amusement-induction phase that was followed by a posing-instruction phase. The setting meticulously mirrored that of the negative-affect smile recordings with regard to furniture, background, and lighting. Contrast, depth of focus, brightness, and light temperature of the camera recordings were also matched to the negative-affect smile recordings, as were the clothing and movements of the target persons.

The sample of target persons included 42 younger adults ($M = 23.64$ years, $SD = 2.36$, 21 female), and 48 older adults ($M = 74.25$, $SD = 3.37$, 22 female). All target persons were residents of the Berlin area, Germany, and were recruited via the participant database of the Max Planck Institute for Human Development, Berlin. After giving their informed consent, they practiced various head and body movements that re-enacted those shown during the negative-affect smile interactions, where target persons had rarely sat still, but often had looked toward or away from the insulting experimenter. To ensure comparability between the three smile types with regard to the accompanying movements, we instructed the target persons to re-enact these movements (e.g., "Move your head to look at the red dot on the wall."). These instructed movements were practiced further while four emotionally neutral video clips were being watched. Following that, the target persons completed, among other things, baseline measures of momentary state anger and negative affect, using the same instruments as in the anger-induction experiment. Then, the target persons were video-recorded while watching funny video-clips ($n = 10$) and cartoons ($n = 5$) and performing the practiced movements upon request. Of the amusement stimuli, eleven were shown to all target persons, whereas four (3 cartoons and 1 clip) were selected to accommodate assumed differences in what younger and older persons might consider funny and thus differed between the two age groups. Following each amusement stimulus, target persons rated how amused, exhilarated, and cheerful they momentarily felt on a scale ranging from 0 (not at all) to 100 (very much). A mean score of these items served as an indicator of momentary amusement. Target persons also indicated after each amusement stimulus whether they had experienced any other feeling besides amusement. If yes, they reported the respectively most dominant feeling in an open response format (which was later content-coded by two independent coders) and rated its intensity on a scale from 0 to 100. This open-response item was included to ensure that the affective experience accompanying the smile expression was unequivocal in valence (and not, for example, also accompanied by feelings of awkwardness due to the experimental situation or the instructed movements). Following the amusement induction phase, participants again reported their momentary state anger and negative affect.

After that, participants were instructed to put themselves into an emotionally neutral state as much as possible. The experimenter described six to ten situations in which people smile without experiencing intense positive or negative feelings (e.g., "Imagine a friend telling a joke that you find neither funny nor juicy. To be polite, you smile.") The target persons' task was to display the smile expression they would show in such a situation and to also perform the movements practiced before upon request. The recording of the neutral smile expressions was scheduled last because, to do the recordings, we had to reveal our interest in smile expressions and we wished to avoid that the target persons' awareness of our interest in smile expressions might affect the genuineness of the positive-affect smiles they displayed while watching the amusing material.

After each posed smile, the target persons again rated their momentary amusement and potential other feelings, using the same items as in the amusement-induction phase. The experimenter ended the posing phase after six to ten posing attempts, when at least one suitable smile expression had been recorded. Following that, the target persons again rated their momentary state anger and negative affect.

Smile episodes during the amusement induction and posing instructions were identified from the video recordings as contractions of the zygomaticus major muscle (AU12). From the resulting pool of smile episodes, 16 positive-affect smiles from younger target persons (50% female) and 16 positive-affect smiles from older target persons (50% female) were selected that fulfilled the following criteria: (1) The smile was spontaneously shown in response to an amusing stimulus; (2) The smile was displayed by target persons (a) who reported intense amusement (at least 60 on a scale from 0 to 100) and no other feelings, and (b) who reported low negative affect (no more than 4 on a scale from 0 to 40) and no state anger after the amusement-induction phase; and (3) The smile expression was complete (i.e., included onset, apex, and offset phases) and unambiguous (i.e., included no more than one contraction of the zygomaticus major muscle).

We also selected 16 neutral smiles from younger target persons (50% female) and 16 neutral smiles from older target persons (50% female) according to the following criteria: (1) The smile was displayed in response to the experimenter's instruction to pose a smile; (2) The smile was displayed by target persons who reported little amusement (no more than 30 on a scale from 0 to 100) and no additional feelings after the smile episode, and who reported low negative affect (no more than 4 on a scale from 0 to 40) and no state anger after the posing-instruction phase; and (3) The smile expression was unambiguous, included onset, apex, and offset phases, but did not involve multiple contractions of the zygomaticus major muscle.

The second and third rows in **Table 1** summarize, for the positive-affect and neutral smiles chosen, the average momentary state anger and negative affect reported by the target persons after the amusement-induction and posing-instruction phases, respectively, and the average amusement reported immediately after the selected smile episodes.

MANIPULATION CHECK: DIFFERENCES BETWEEN SMILE TYPES IN RELATION TO TARGET PERSONS' ACCOMPANYING EMOTIONAL EXPERIENCES

To statistically substantiate that the selected episodes for the three types of smiles significantly differed with regard to the targets' self-reported emotional experiences, we first compared the positive-affect and neutral smile episodes expressed by younger and older target persons. A multivariate analysis of variance on negative affect (reported after the amusement induction and the posing instruction, respectively) and amusement (reported immediately after each selected smile episode) confirmed a significant multivariate effect of smile type, $F_{(2, 59)} = 1298.12$, $p = 0.000$, partial $\eta^2 = 0.91$, according to Wilks Lambda, whereas neither the main effect of age group of target, $F_{(2,59)} = 0.17$, $p = 0.847$, partial $\eta^2 = 0.01$, nor the Age Group × Smile Type interaction, $F_{(2, 59)} = 0.92$, $p = 0.405$, partial $\eta^2 = 0.03$, reached statistical significance. (State anger was not included in this analysis because none of the targets reported any anger experiences for the positive and neutral smile episodes.) A multivariate main effect of smile type also emerged when we compared negative, positive, and neutral smile expressions by younger targets with regard to state anger and negative affect, $F_{(4, 88)} = 16.24$, $p = 0.000$, partial $\eta^2 = 0.43$, according to Wilks Lambda. (Older targets were not included in this analysis because no negative-affect smiles were available for them; amusement ratings were not included because they were not available for negative-affect smiles).

Pairwise comparisons confirmed that targets had experienced significantly higher state anger and negative affect when displaying negative-affect smiles than when displaying positive-affect smiles [state anger: $T_{(15)} = 3.75$, $p = 0.000$; negative affect: $T_{(15.41)} = 6.75$, $p = 0.000$] and neutral smiles [state anger: $T_{(15)} = 5.33$, $p = 0.000$; negative affect: $T_{(15.38)} = 6.91$, $p = 0.000$]. Positive-affect and neutral smiles did not differ with regard to state anger and negative affect (all $p > 0.05$). Compared to neutral smiles, however, positive-affect smiles were accompanied by significantly more intense amusement, $T_{(62)} = 24.74$, $p = 0.000$.

Overall, these analyses indicate that the aims of the stimulus development were met. The three smile types differed significantly in the target persons' self-reported emotional experiences, which in turn matched the intended emotional nature of the situation in which the smile expression was shown. There was no indication that this effect differed between younger and older target persons.

DUCHENNE CODING OF SMILE SELECTION

The third author rated the presence/absence of the Duchenne marker (AU6, Ekman and Friesen, 1978) for the selected smile episodes. Coding was instructed and supervised by the second author who is an experienced FACS coder. Coding agreement with a second independent coder was satisfactory (across all smile episodes: $\kappa = 0.91$; across smile episodes from younger targets: $\kappa = 0.95$; across smile episodes from older targets: $\kappa = 0.76$; both coders were young adults). Of the 80 smile episodes, 10 (2 negative-affect smiles, 4 positive-affect smiles, and 4 neutral smiles) could not be reliably coded because hair or glasses partially obscured the eye region. Activation of the Duchenne marker was present in 57.1% of the remaining negative-affect smiles (younger targets only), in 57.1% of the remaining positive-affect smiles shown by younger targets; in 71.4% of the remaining positive-affect smiles shown by older targets; in 35.7% of the remaining neutral smiles shown by younger targets; and in 92.9% of the remaining neutral smiles shown by older targets. These findings are consistent with previous evidence that the Duchenne marker does not reliably distinguish between different emotional experiences accompanying smile expressions (see overviews in Messinger et al., 1999; Krumhuber and Manstead, 2009).

STUDY 1

METHODS

Sample

The sample consisted of $N = 100$ participants living in or around Berlin, Germany. Participants were recruited via a participant database of the Max Planck Institute for Human Development. Requirements for study participation were (a) that the participants were either between 20 and 30 years of age ($n = 48$, $M = 25.75$, $SD = 2.61$), or between 70 and 80 years of age ($n = 52$, $M = 74.53$, $SD = 3.05$); (b) that their mother tongue was German, (c) that they had sufficient (corrected) vision to see videos presented on a computer screen clearly; and (d) that they had not taken part in the Pre-Study for stimulus development. Both age groups were approximately stratified by gender (50 and 46.2% female in the younger and older age groups, respectively) and education (54.2% and 40.4% with German university-entrance qualification in the younger and older age groups, respectively). Informed consent was obtained from all participants, and the ethics committee of the Max Planck Institute for Human Development had approved of the study.

Measures

Smiles task. Participants watched 48 videos of positive-affect smiles ($n = 16$), negative-affect smiles ($n = 16$), and neutral smiles ($n = 16$) expressed by younger targets. The presentation sequence of the videos was randomized. Prior to each video, participants saw a still picture of the start frame for 3 s, showing the target with a neutral expression that preceded the onset of the smile. It was presented so that participants could acquaint themselves with the physiognomy of the target before the smile task. After each video, participants completed the sentence stem "The person smiled in a situation ..." by selecting one of three response options: (a) "in which he or she experienced a pleasant feeling (e.g., amusement)," (b) "in which he or she experienced an unpleasant feeling (e.g., anger)," or (c) "in which he or she posed a smile without feeling anything." For the sake of simplicity, we will refer to these response categories as positive-affect, negative-affect, and neutral smiles below. The smiles task was programmed in DMDX (Forster and Forster, 2003).

Accuracy of categorization was determined as unbiased hit rate, following the procedure proposed by Wagner (1993). This measure accounts for the potentially distorting effects of response tendencies (which can be illustrated by the example of a blindfolded person who would obtain an uncorrected hit rate of 100% in one category without even looking at the stimuli if he always chose the same response). The unbiased hit rate is the joint probability that a smile type was correctly identified and that the response option was correctly used, and is thus insensitive to such a bias in responding. It is determined as the product of the conditional probability that a given smile type was correctly identified (i.e., the number of correctly identified stimuli from that smile type divided by the total number of stimuli from that smile type) and the conditional probability that a response category is correctly used, given that it is used (i.e., the number of correct uses of a response category divided by the total number of uses of that response category).

Control variables. As control variables in the present research, we included measures of participants' education, as well as of crystallized cognitive, fluid cognitive, and visual abilities, all of which have been discussed as possible mechanisms that might underlie age-related differences in emotion recognition (e.g., Phillips et al., 2002; Keightley et al., 2006; Murphy et al., 2010). More specifically, participants indicated their *years of education* for the number of school years completed and the number of years in professional training. A sum score indicating the total number of years of education was used as a covariate. *Perceptual-motor speed* was measured using the Digit-Symbol Substitution Test of the Wechsler Intelligence Scales (Wechsler, 1981). Participants were given mappings of symbols and digits, and their task was to draw the corresponding symbols for a series of digits as fast as possible. The number of correct responses completed within 90 s served as an indicator of perceptual-motor speed. Participants' *vocabulary* was assessed with a test in which participants had to find real words among various pseudo-words (MWT-A, Lehrl et al., 1991). Participants' vision was assessed with two subtests of the computerized Freiburg Visual Acuity and Contrast Test (FrACT, Bach, 2007). In the Acuity Landolt C subtest of the FrACT assessing *visual acuity*, participants were presented with a series of 24 Landolt rings (i.e., rings that have a gap, thus looking similar to the letter C) varying in size. The position of the gap varied across stimuli. The participant's task was to choose, via button press, the gap's correct position out of eight possibilities. The size of the Landolt rings was varied depending on the participant's performance, and visual acuity was determined as decimal acuity (Snellen's fraction; higher values indicate better visual acuity). *Contrast sensitivity* was measured as the Michelson contrast using the subscale Contrast of the FrACT in which participants were presented with a series of 24 Landolt rings that varied in their luminance (smaller values indicate better contrast sensitivity).

In **Table 2** these control variables are compared for the younger and older subsamples. Compared to older participants, younger participants reported more years of school education, obtained higher scores in the perceptual-speed task, lower scores in the vocabulary task, and had better visual acuity and contrast sensitivity. Younger and older participants did not differ significantly with regard to years of professional training. Overall, this pattern of age-group differences is consistent with what is to be expected based on the developmental literature.

RESULTS

In the following, we first report analyses of potential age-related differences in participants' response tendencies (irrespective of whether the responses were correct). Then we report age differences in the unbiased hit rates for identifying emotional experiences accompanying smiles and analyze whether the observed unbiased hit rates differed significantly from chance.

Response tendencies

Figure 1 shows the percentages with which younger and older participants chose each of the three response options for evaluating the emotional experience accompanying smiles, irrespective of whether or not the chosen responses were correct. Results of a multivariate analysis of variance on the percentage of chosen responses with age group (younger and older participants) as between-person factor, and response option (positive-affect smile, negative-affect smile, neutral smile) as within-person factor are summarized in **Table 3**. The significant interaction of Age Group × Response Option indicates younger and older participants varied in their response preferences. This underscores the importance of using the unbiased hit rate (Wagner, 1993) when analyzing how well participants from different age groups were able to identify emotional experiences accompanying smiles. Follow-up analyses of this interaction showed that in comparison to younger adults, older adults evaluated smile

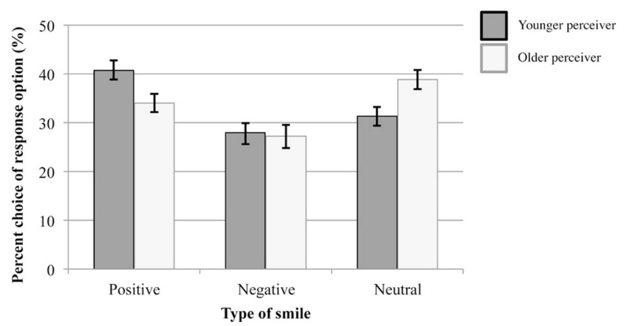

FIGURE 1 | Use of response options in Study 1 (irrespective of whether response choice was correct). Error bars represent ±1 standard errors from the mean.

Table 2 | Descriptives of control variables in Study 1.

Construct	Younger participants (perceiver)		Older participants (perceiver)				
	M	*SD*	*M*	*SD*	*F*	*df*	*p*
Years of school education	12.33	1.55	10.98	2.21	11.860	1, 96	0.001
Years of professional training	3.60	2.00	5.04	5.84	2.477	1, 94	0.119
Perceptual-motor speed (Digit-Symbol)	61.90	11.36	41.67	7.69	110.075	1, 98	0.000
Vocabulary knowledge (MWT-A)	28.94	2.95	32.52	1.75	55.462	1, 98	0.000
Visual acuity (decimal acuity)	1.47	0.28	0.83	0.39	87.808	1, 98	0.000
Contrast sensitivity (Michelson contrast)[a]	0.66	0.34	1.94	1.20	50.416	1, 98	0.000

Multivariate age group effect according to Wilks Lambda: $F_{(6, 87)} = 41.68$, $p = 0.000$, partial $\eta^2 = 0.74$.

[a] *Smaller values indicate better contrast sensitivity.*

expressions less frequently as being accompanied by positive affect, $F_{(1)} = 5.84$, $p = 0.018$, partial $\eta^2 = 0.06$, and more frequently as being emotionally neutral, $F_{(1)} = 7.64$, $p = 0.007$, partial $\eta^2 = 0.07$. Younger and older adults did not differ in the percentage with which they judged smile expressions as being accompanied by negative affect, $F_{(7)} = 0.07$, $p = 0.799$, partial $\eta^2 = 0.001$. Comparisons within age-group showed that younger adults chose the response option positive-affect smile significantly more frequently than each of the other two response options [negative-affect smile: $F_{(1)} = 13.00$, $p = 0.001$, partial $\eta^2 = 0.22$; neutral smile: $F_{(1)} = 7.49$, $p = 0.009$, partial $\eta^2 = 0.14$]. Their percentages of choosing the response options negative-affect smile and neutral smile did not differ significantly ($p > 0.05$). In contrast, older adults chose the response option neutral smile significantly more often than the response option negative-affect smile, $F_{(1)} = 8.55$, $p = 0.005$, partial $\eta^2 = 0.14$. All other pairwise comparisons of older adults' percentages of chosen response options were non-significant (all $p > 0.05$).

Age differences in unbiased hit rate of identifying emotional expressions accompanying smiles

Solid bars in **Figure 2** represent the average unbiased hit rates of correctly identifying positive, negative, and neutral smiles for younger and older participants. Striped bars indicate the average expected chance levels of performance. In the following, we first analyze age-related differences in unbiased hit rates, and then investigate whether the observed unbiased hit rates were significantly different from chance-level performance.

Table 3 | Predicting use of response options (irrespective of whether response was correct) in Study 1.

Effect	*F*	*df*	*p*	Partial eta squared
Response option[a]	7.331	2, 97	0.001	0.131
Response option × Age group of perceiver[a]	4.901	2, 97	0.009	0.092
Age group of perceiver	0.055	1	0.816	0.001

[a] *Multivariate F-test based on Wilks Lambda.*

Results of a multivariate analysis of variance with age group of participants (younger and older) as between-person factor, and smile type (positive-affect smile, negative-affect smile, neutral smile) as within-person factor on unbiased hit rates are summarized in **Table 4**. Particularly important for our hypotheses is the significant main effect for age group of participant, which was qualified by the significant interaction of Age Group × Smile Type. Follow-up analyses on this interaction indicated that younger participants, contrary to our prediction, outperformed older participants in correctly identifying the accompanying emotional experiences for all three types of smile [positive-affect smiles: $F_{(1)} = 47.96$, $p = 0.000$, partial $\eta^2 = 0.33$; negative-affect smiles: $F_{(1)} = 8.59$, $p = 0.004$, partial $\eta^2 = 0.08$; neutral smiles: $F_{(1)} = 10.27$, $p = 0.002$, partial $\eta^2 = 0.10$], and this age difference was most pronounced for positive-affect smiles (see **Figure 2**)[1].

Table 4 | Predicting unbiased hit rates in Study 1.

Effect	*F*	*df*	*p*	Partial eta squared
Type of smile[a]	22.674	2, 97	0.000	0.319
Type of smile × Age group of perceiver[a]	5.545	2, 97	0.005	0.103
Age group of perceiver	49.519	1	0.000	0.336

[a] *Multivariate F-test based on Wilks Lambda.*

[1] This was due to differential patterns within age groups for the relative accuracies in identifying the different types of smiles. Younger adults' unbiased hit rates for identifying negative-affect smiles were significantly lower than those for identifying positive-affect [$F_{(1)} = 14.63$, $p = 0.000$, partial $\eta^2 = 0.24$] and neutral smiles [$F_{(1)} = 27.84$, $p = 0.000$, partial $\eta^2 = 0.37$], which did not differ significantly from each other ($p > 0.05$). Among older adults, the unbiased hit rate for negative-affect smiles did not differ significantly from that for positive-affect smiles ($p > 0.05$), and unbiased hit rates for both negative-affect and positive-affect smiles were significantly lower than the unbiased hit rate for neutral smiles [positive smile: $F(1) = 24.81$, $p = 0.000$, partial $\eta^2 = 0.33$]; negative smiles [$F_{(1)} = 18.04$, $p = 0.000$, partial $\eta^2 = 0.26$]. Note, however, that this age group × smile type interaction did not remain significant in our control analysis.

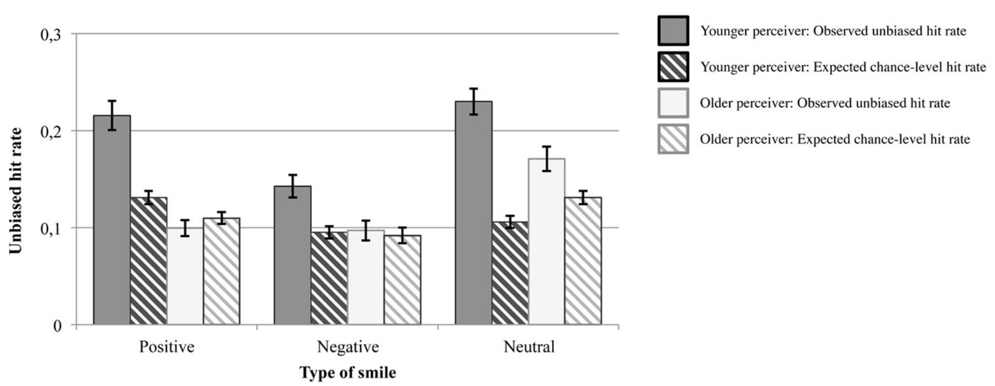

FIGURE 2 | Observed unbiased hit rates and expected chance-level hit rates in Study 1. Error bars represent ±1 standard errors from the mean.

The central finding of this analyses—the main effect of age group of participants remained—significant when we controlled for participants' years of education, processing speed, vocabulary knowledge, visual acuity, and visual contrast sensitivity, $F_{(1)} = 14.67$, $p = 0.000$, partial $\eta^2 = 0.14$. The main effect of type of smile as well as the interaction of Age Group × Smile Type no longer reached significance in this control analysis, $F_{(2, 92)} = 0.70$, $p = 0.502$, partial $\eta^2 = 0.02$, and $F_{(2, 92)} = 2.27$, $p = 0.109$, partial $\eta^2 = 0.05$, according to Wilks Lambda, respectively.

In a next step, we followed the procedure proposed by Wagner (1993, p. 18 f.) to investigate whether the observed unbiased hit rates differed significantly from chance-level performance. We first determined, separately for each participant, the unbiased hit rates that were to be expected by chance for each of the three smile types, given the participants' use of response options (i.e., we determined the probability with which a given participant would choose a correct response option by chance when a particular smile type was presented). This was achieved by multiplying the relative frequency of a given smile type (among all smile stimuli) with the relative frequency with which a given participant had chosen the corresponding response option (among all responses). The average resulting chance-level probabilities for correct responses are depicted as striped bars in **Figure 2**. To investigate statistically whether the observed unbiased hit rates were significantly different from these chance-level probabilities, we specified a multivariate analysis of variance with age group (younger and older participants) as between-person factor, and smile type (positive-affect smile, negative-affect smile, neutral smile) as well as type of hit rate (observed unbiased hit rate and chance-level hit rate) as within-person factors. This analysis yielded a significant three-way interaction of Age Group × Smile Type × Type of Hit Rate, $F_{(2, 97)} = 4.54$, $p = 0.013$, partial $\eta^2 = 0.09$, according to Wilks Lambda.

Follow-up analyses revealed that the unbiased hit rates of younger participants were significantly above chance levels for all three smile types [positive-affect smiles: $F_{(1, 47)} = 46.56$, $p = 0.000$, partial $\eta^2 = 0.50$; negative-affect smiles: $F_{(1, 47)} = 25.40$, $p = 0.000$, partial $\eta^2 = 0.35$; neutral smiles: $F_{(1, 47)} = 75.05$, $p = 0.000$, partial $\eta^2 = 0.62$]. Older adults' unbiased hit rates, however, were only significantly better than chance in correctly identifying neutral smiles [$F_{(1, 47)} = 14.30$, $p = 0.000$, partial $\eta^2 = 0.22$], but did not differ significantly from chance levels for positive-affect and negative-affect smiles (all $p > 0.05$).

SUMMARY OF CENTRAL FINDINGS IN STUDY 1

Study 1 revealed that younger and older participants differed from each other in their tendencies to endorse the available response options for categorizing smile expressions, irrespective of whether the endorsed response was correct. Younger participants chose the category "positive-affect smile" significantly more frequently, and the category "neutral smile" significantly less frequently than older participants did. Younger and older participants did not differ from each other in the frequency of categorizing smile expressions as "negative-affect smile."

In addition, younger participants had higher unbiased hit rates than older adults for categorizing younger targets' smile expressions as positive-affect, negative-affect, or neutral smiles. In fact, older participants' unbiased hit rates for positive-affect and negative-affect smiles were not significantly different from performance levels that were to be expected by chance, given the participants' use of the response options. Younger participants' unbiased hit rates, in contrast, were significantly above chance-level performance for all three types of smiles. Control analyses showed that the age difference in unbiased hit rates was robust to simultaneously controlling for age-related differences in years of education, processing speed, vocabulary knowledge, and vision.

STUDY 2

The purpose of Study 2 was to replicate findings from Study 1 and to investigate whether they were moderated by the age of the smiling persons. To fulfill this purpose, the smile task in Study 2 involved distinguishing between positive-affect and neutral smile expressions shown by younger and older targets. Negative-affect smiles were available only from younger targets and were thus not included in Study 2.

SAMPLE

The sample consisted of $N = 97$ participants living in or around Berlin, Germany. Participants were recruited from a participant database of the Max Planck Institute for Human Development, Berlin. Requirements for participation were the same as in Study 1. In addition, we ensured that none of the participants had taken part in Study 1. Younger participants were between 20.2 and 30.9 years of age ($n = 48$, $M = 25.67$, $SD = 2.72$); older participants were between 70.0 and 78.8 years of age ($n = 49$, $M = 73.55$, $SD = 2.53$). Both participant age groups were approximately stratified by gender (50 and 51% female in the younger and older age groups, respectively) and education (52.1 and 38.8% with German university-entrance qualification in the younger and older age groups, respectively). Informed consent was obtained from all participants, and the ethics committee of the Max Planck Institute for Human Development had approved of the study.

MEASURES

Smiles task

With two exceptions, the smiles task followed the same logic as in Study 1. The first difference involves the smile stimuli presented. In Study 2, participants watched 64 video recordings of positive-affect smiles shown by younger targets ($n = 16$) and older targets ($n = 16$), and of neutral smiles shown by younger targets ($n = 16$) and older targets ($n = 16$). The second difference involved the number of response options. This time, participants completed the sentence stem "The person smiled in a situation ..." by choosing one of two response options: (a) "in which he or she experienced a pleasant feeling (e.g., amusement)," or (b) "in which he or she posed a smile without feeling anything."

Control variables

Information on *years of education* (self report), *perceptual-motor speed* (Digit Symbol Substitution Test), *vocabulary knowledge* (MWT-A), and *visual contrast sensitivity* (FrACT) were obtained as covariates. The measures for these variables were the same as in Study 1. In **Table 5** the younger and older subsample are compared on these control variables. As in Study 1, the overall pattern of age differences is consistent with what would be expected based on the developmental literature. Younger participants reported fewer years of professional training, obtained higher scores in the perceptual-speed task, lower scores in the vocabulary task, and had better visual contrast sensitivity than older participants did. Younger and older participants did not differ significantly with regard to years of school education.

RESULTS

We present the results of Study 2 following the same logic as in Study 1: First we report analyses on age-related differences in participants' response tendencies when evaluating the emotional experience accompanying smile expressions, irrespective of whether these responses were correct. Then we report age differences in the unbiased hit rates for identifying emotional experiences accompanying smiles, and analyze whether the observed unbiased hit rates were significantly different from chance-level performance.

Response tendencies

Figure 3 shows the percentages with which younger and older participants chose each response option in evaluating the emotional experience accompanying the smile expressions, irrespective of whether or not the chosen response was correct. The results of a multivariate analysis of variance on the percentage for choosing the response option "positive-affect smile," with age group of participants (younger and older) as between-person factor, and age group of target (younger and older smiling persons) as within-person factor are summarized in **Table 6**. (The pattern of findings for the other response option "neutral smile" is complementary.) Both main effects were significant, as was the Age of Target × Age of Participant interaction. Follow-up analyses indicated that both younger and older participants chose the response option "positive-affect smile" more often for smile expressions shown by older as compared to younger targets: $F_{(1, 47)} = 56.60$, $p = 0.000$, partial $\eta^2 = 0.55$ and $F_{(1, 48)} = 16.69$, $p = 0.000$, partial $\eta^2 = 0.26$, respectively. This effect,

Table 6 | Predicting choice of response option "positive-affect smile" (irrespective of whether response choice was correct) in Study 2.

Effect	F	df	p	Partial eta squared
Age group of target[a]	69.258	1, 95	0.000	0.422
Age group of target × Age group of perceiver[a]	8.034	1, 95	0.006	0.078
Age group of perceiver	5.733	1	0.019	0.057

[a] *Multivariate F-test based on Wilks Lambda.*

Table 5 | Descriptives of control variables in Study 2.

Construct	Younger participants (perceiver)		Older participants (perceiver)				
	M	*SD*	*M*	*SD*	*F*	*df*	*p*
Years of school education	11.81	1.55	11.04	2.29	3.674	1, 94	0.058
Years of professional training	3.34	2.02	8.16	9.78	10.431	1, 86	0.002
Perceptual-motor speed (Digit-Symbol)	58.94	10.67	41.80	10.19	65.467	1, 95	0.000
Vocabulary knowledge (MWT-A)	29.65	2.77	31.84	2.68	15.669	1, 95	0.000
Contrast sensitivity (Michelson contrast)[a]	0.67	0.31	2.82	3.13	22.444	1, 95	0.000

Multivariate age group effect according to Wilks Lambda: $F_{(4, 81)} = 25.79$, $p = 0.000$, partial $\eta^2 = 0.61$.
[a] *Smaller values indicate better contrast sensitivity.*

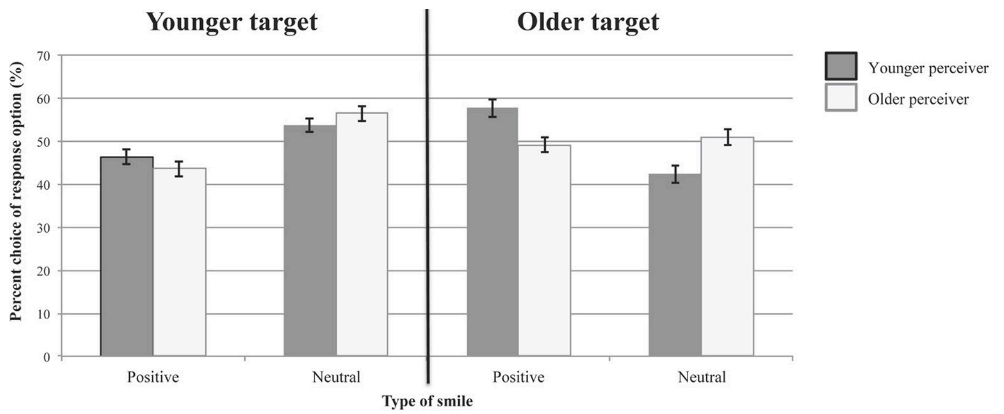

FIGURE 3 | Use of response options in Study 2 (irrespective of whether response choice was correct). Error bars represent ±1 standard errors from the mean.

however, was more pronounced for younger than for older participants (see **Figure 3**). Younger and older participants did not differ in how often they chose the response option "positive-affect smile" for expressions shown by younger targets, $F_{(1, 47)} = 1.30$, $p = 0.257$, partial $\eta^2 = 0.01$. They differed, however, with regard to their response preferences for older targets, with younger participants choosing the response option "positive-affect smile" more frequently than older participants, $F_{(1)} = 9.92$, $p = 0.002$, partial $\eta^2 = 0.10$. When judging smile expressions from younger target persons, both younger and older participants chose the response option "neutral smile" significantly more often than in 50% of the cases, and thus significantly more frequently than the response option "positive-affect smile," one-sample $T_{(47)} = 2.27$, $p = 0.028$ and one-sample $T_{(48)} = 3.64$, $p = 0.001$, respectively. When judging smile expressions from older target persons, however, younger participants chose the response option "positive-affect smile" more frequently than in 50% of the cases, and hence significantly more often than the response option "neutral smile," one-sample $T_{(47)} = 3.75$, $p = 0.000$. Older participants, in contrast, chose both response options about equally often when judging smile expressions of older target persons, one-sample $T_{(48)} = -0.49$, $p = 0.627$. These findings indicate differences between age group of participants in the preferential use of response categories and thus again underscore the importance of using the unbiased hit rate (Wagner, 1993) when analyzing how well participants from different age groups were able to identify emotional experiences accompanying smiles shown by targets of different age groups.

Age differences in unbiased hit rate for identifying emotional expressions accompanying smiles

Solid bars in **Figure 4** represent the average unbiased hit rates in the younger and older participants for correctly identifying positive-affect and neutral smiles shown by younger and older targets. Striped bars in **Figure 4** indicate average expected chance levels of performance. In the following, we first analyze age-related differences in unbiased hit rates, and then investigate whether the observed unbiased hit rates were significantly different from chance-level performance.

Table 7 summarizes the results of a multivariate analysis of variance on the unbiased hit rate with age group of participants (younger and older) as between-person factor, and smile type (positive-affect smile and neutral smile) and age group of target (younger and older) as within-person factors. This analysis yielded a significant Age Group of Target × Age Group of Participant × Type of Smile interaction. Consistent with our prediction, follow-up analyses revealed that the Age Group of Target × Age Group of Participant interaction was significant both for positive-affect smiles, $F_{(1, 95)} = 4.74$, $p = 0.032$, partial $\eta^2 = 0.048$, and for neutral smiles, $F_{(1, 95)} = 12.30$, $p = 0.001$, partial $\eta^2 = 0.12$. With regard to positive-affect smiles, older participants were more accurate in identifying positive-affect smiles shown by older as compared to those shown by younger targets, $F_{(1, 48)} = 21.27$, $p = 0.000$, partial $\eta^2 = 0.31$; whereas younger participants' unbiased hit-rates for identifying positive-affect smiles was independent of the age of the smiling person, $F_{(1, 47)} = 2.77$, $p = 0.103$, partial $\eta^2 = 0.06$. For the neutral smiles, older perceivers were again more accurate in identifying neutral smiles posed by older as opposed to by younger targets, $F_{(1, 48)} = 4.10$, $p = 0.049$, partial $\eta^2 = 0.08$; whereas younger perceivers were more accurate at identifying neutral smiles posed by younger than by older targets, $F_{(1, 47)} = 8.19$, $p = 0.006$, partial $\eta^2 = 0.15$.

Compared to older participants' unbiased hit rates, younger participants' unbiased hit rates were generally higher, which is contrary to our hypotheses and to results from previous studies, but consistent with the findings in Study 1. Corresponding to our prediction, however, the size of these age differences in unbiased hit rates was more pronounced for smile expressions shown by younger targets than for smile expressions shown by older targets (age-of-participant effect for positive-affect smiles shown by younger targets: $F_{(1)} = 66.67$, $p = 0.000$, partial $\eta^2 = 0.41$; for positive-affect smiles shown by older targets: $F_{(1)} = 37.06$, $p = 0.000$, partial $\eta^2 = 0.28$; for neutral smiles posed by younger targets: $F_{(1)} = 49.49$, $p = 0.000$, partial $\eta^2 = 0.34$; and for neutral smiles posed by older targets, $F_{(1)} = 11.17$, $p = 0.001$, partial $\eta^2 = 0.11$).

All effects of relevance for our predictions remained robust after controlling for participants' years of education, processing

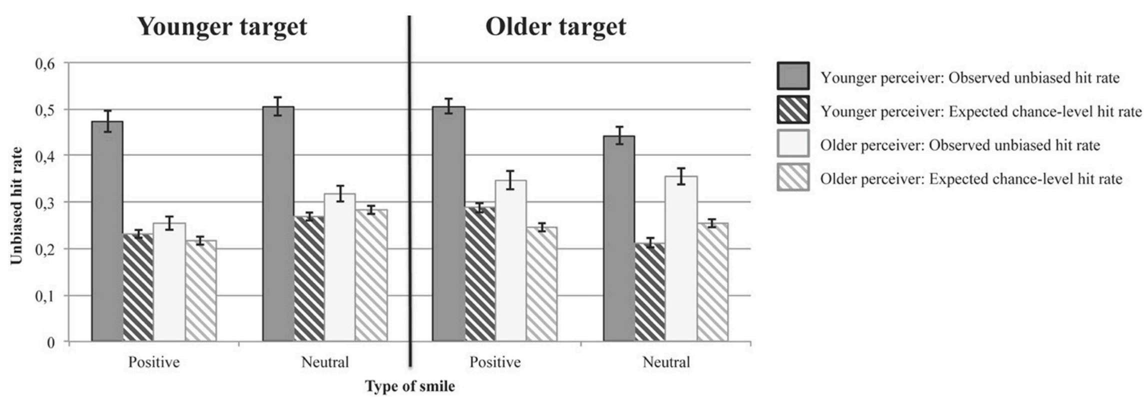

FIGURE 4 | Observed unbiased hit rates and expected chance-level hit rates in Study 2. Error bars represent ±1 standard errors from the mean.

speed, vocabulary knowledge, and visual contrast sensitivity. In other words, the main effect of age group of participants remained significant, $F_{(1)} = 41.65$, $p = 0.000$, partial $\eta^2 = 0.31$, as did the Age Group of Target × Age Group of Participant interaction, $F_{(1,\ 91)} = 4.91$, $p = 0.029$, partial $\eta^2 = 0.05$ according to Wilks Lambda, and the Type of Smile × Age Group of Participant interaction, $F_{(1,\ 91)} = 6.62$, $p = 0.012$, partial $\eta^2 = 0.07$ according to Wilks Lambda. The other significant effects shown in **Table 7** ceased to reach significance in this control analysis, all $p > 0.05$.

To investigate whether the observed unbiased hit rates differed significantly from chance-level performance, we again followed the procedure proposed by Wagner (1993). As in Study 1, we determined, separately for each participant, the unbiased hit rates that were to be expected by chance given the participant's use of response options. These chance probabilities for correct responses are depicted as striped bars in **Figure 4**. Observed unbiased hit rates for positive-affect smiles were significantly larger than the respective expected chance-level probabilities. This was the case in both age groups of participants and for positive-affect and neutral smile expressions shown by younger and older targets, respectively [effects of observed vs. chance-level hit rates for positive smiles by younger targets: $F_{(1,\ 47)} = 141.71$, $p = 0.000$, partial $\eta^2 = 0.75$ for younger and $F_{(1,\ 48)} = 7.69$, $p = 0.008$, partial $\eta^2 = 0.14$ for older participants, respectively; for positive smiles by older targets: $F_{(1,\ 47)} = 200.90$, $p = 0.000$, partial $\eta^2 = 0.81$ for younger and $F_{(1,\ 48)} = 33.10$, $p = 0.000$, partial $\eta^2 = 0.41$ for older participants, respectively; for neutral smiles by younger targets: $F_{(1,\ 47)} = 134.09$, $p = 0.000$, partial $\eta^2 = 0.74$ for younger and $F_{(1,\ 48)} = 7.21$, $p = 0.010$, partial $\eta^2 = 0.13$ for older participants, respectively; and for neutral smiles by older targets: $F_{(1,\ 47)} = 207.66$, $p = 0.000$, partial $\eta^2 = 0.82$ for younger and $F_{(1,\ 48)} = 34.27$, $p = 0.000$, partial $\eta^2 = 0.42$ for older participants, respectively; all according to Wilks Lambda].

SUMMARY OF CENTRAL FINDINGS IN STUDY 2

Younger and older participants in Study 2 did not differ from each other in their response tendencies in evaluating smiles of younger target persons, and chose the response option "neutral smile" more frequently for younger targets' smile expressions than the response option "positive-affect smile." Furthermore, both younger and older participants ascribed positive-affective experiences more frequently to smile expressions shown by older as compared to younger target persons, but this age-of-target effect was particularly pronounced among younger participants. This was because younger participants in Study 2 chose the response option "positive-affect smile" more frequently and the response option "neutral smiles" less frequently than older participants did when evaluating the emotional nature of smile expressions displayed by older target persons.

Unbiased hit rates for younger and older participants were significantly above chance levels for all smile types. Having to choose between two categories of smile expressions in Study 2 was obviously an easier task than the three-fold categorization required in Study 1. (The similarity of both samples with regard to education, cognitive abilities, and vision that is evident in **Tables 2** and **5** renders the possibility unlikely that the difference in task performance is due to differences between the two samples tested.) Despite this difference in task difficulty, Study 2 replicated the better performance of younger participants for correctly identifying all types of smiles. It also indicated, however, that the size of this age difference was moderated by the age of the target person, such that age differences in unbiased hit rates were more pronounced for smile expressions from younger targets and less pronounced for those from older targets. As in Study 1, the age differences in unbiased hit rates were robust to simultaneously controlling for age-related differences in years of education, processing speed, vocabulary knowledge, and vision.

Table 7 | Predicting unbiased hit rates in Study 2.

Effect	*F*	*df*	*p*	Partial eta squared
Age group of target[a]	3.295	1, 95	0.073	0.034
Type of smile[a]	0.921	1, 95	0.340	0.010
Age group of perceiver	68.753	1	0.000	0.420
Age group of target × Age group of perceiver[a]	9.024	1, 95	0.003	0.087
Type of smile × Age group of perceiver[a]	5.977	1, 95	0.016	0.059
Age group of target × Type of smile[a]	72.971	1, 95	0.000	0.434
Age group of target × Type of smile × Age group of perceiver[a]	4.810	1, 95	0.031	0.048

[a] *Multivariate F-test based on Wilks Lambda.*

DISCUSSION

Smile expressions can accompany diverse emotional experiences, such as amusement or anger, but can also occur in the absence of intense emotions. The current study contributes to an emerging line of research on adult age differences in the ability to identify the emotional meaning of other people's smile expressions. We compiled a set of 80 dynamic smile expressions displayed in different contexts by adults of different age groups whose self-reported affective experience matched the intended emotional nature of the situation. Comparisons of the target person's self-reported affective experiences while smiling in the three different contexts (i.e., while being the target of an unfair accusation, while watching amusing material, and while being instructed to pose a smile) demonstrated that we had successfully compiled groups of three emotionally distinct types of smile expressions (i.e., negative-affect, positive-affect, and neutral smiles).

FACS-coding of the Duchenne marker (AU6, Ekman and Friesen, 1978) confirmed prior evidence that contraction of the lateral part of the muscle surrounding the eyes does not reliably distinguish between the different emotional experiences that can accompany smile expressions (for overviews, see Messinger et al., 1999; Krumhuber and Manstead, 2009). Contrary to the assumption in many previous studies that activation of the Duchenne marker is an indicator of positive affect, we found that it was not reliably present in our selection of positive-affect smiles, and not reliably absent in our selection of negative-affect and neutral smiles. On the contrary, substantial proportions of the smile expressions in all three smile categories involved activation of the Duchenne marker. A limitation of our study was that only younger adults conducted the FACS-coding. In future studies it would be desirable to obtain FACS codings from older adult raters as well.

We used this newly developed set of content-valid and dynamic smile stimuli as stimulus material in two studies. In Study 1, we investigated potential differences between younger and older adults in their ability to distinguish positive-affect, negative-affect, and neutral smile expressions shown by younger target persons. In Study 2, we investigated the potential role of the target persons' age by investigating younger and older adults' ability to identify the emotional experiences accompanying positive-affect and neutral smile expressions shown by both younger and older targets.

AGE DIFFERENCES IN USE OF RESPONSE OPTIONS (IRRESPECTIVE OF WHETHER RESPONSES WERE CORRECT)

In both studies, younger and older participants differed in their tendencies to endorse the available response options, irrespective of whether the endorsed response was correct. It is worth noting that the pattern of response preferences was different from previous findings of an age-related increase in preferential attention to and memory for positive over negative information (for overviews, see Carstensen and Mikels, 2005; Reed and Carstensen, 2012), which are also reflected in the ways how adults from different age groups interpret still pictures of posed expressions of highly intense basic emotions as used in the traditional paradigm (Riediger et al., 2011). The present studies demonstrate that such positivity effects do not generalize to how older adults interpret the emotional meaning of other people's dynamic smile expressions. In fact, the observed pattern for reading smile expressions was in part opposite to what has been found in the domain of attention and memory or the reading of emotional poses in the traditional paradigm: older participants ascribed *less* positive affective experiences to smile expressions than younger participants did. Of interest is also the observation that participants' response tendencies varied depending on the age of the smiling person. Both younger and older participants ascribed positive affective experiences more frequently to smile expressions shown by older target persons than to smile expressions shown by younger adults. The underlying causes remain to be investigated in future studies. They may include characteristics of the smiling persons, such as aging-related differences in skin texture and facial appearance, but also characteristics of the perceiving persons (participants), such as their subjective theories of cohort differences in emotional expressiveness (Otta, 1998). Indeed, social conventions for when smiling is appropriate and expected have changed throughout the 20th century. This is evident, for example, in a greater likelihood for younger as opposed to older cohorts to present themselves smiling in wedding or yearbook photographs (DeSantis and Sierra, 2000). The present results indicated that people were, in fact, more inclined to assume that a smile expression is emotionally neutral when it was displayed by a younger than by an older adult. This effect was particularly pronounced among the younger participants, which could reflect an age difference in subjective theories about the frequency with which older adults show emotionally neutral smile expressions, and possibly arises from differences in the frequency of contact with older individuals.

The observed age differences in response tendencies are interesting not only because they hint at possible age differences in people's subjective theories about the emotional nature of smile expressions. These results also underscore the importance of accounting for the potentially distorting effects of response tendencies on accuracy indices of smile categorizations, because the more often a particular response option is chosen, the higher the unbiased likelihood is to correctly categorize smile stimuli that belong to that smile type.

AGE DIFFERENCES IN THE ACCURACY OF IDENTIFYING EMOTIONAL EXPERIENCES FROM FACIAL EXPRESSIONS

We determined participants' accuracy of smile categorizations as unbiased hit rates according to Wagner (1993). This indicator removes the potentially biasing effects of response tendencies by determining the joint probabilities that a given participant had correctly identified the smile type and that she had correctly used the respective response category. Contrary to our expectations and to evidence from previous studies on age differences in identifying the emotional meaning of smile expressions (McLellan, 2008; Murphy et al., 2010; Slessor et al., 2010a), younger participants outperformed older participants in both studies and with regard to all investigated types of smile. Corresponding to our hypotheses, however, older participants in Study 2 were more accurate in identifying the emotional meaning of smile expressions shown by older as compared to younger targets, which could have resulted from their better knowledge, or greater experience with smile expressions shown by older as opposed to younger individuals (e.g., Harrison and Hole, 2009). For younger participants, a corresponding own-age advantage was evident only in identifying neutral smiles; that is, younger participants were better at identifying neutral smile expressions stemming from younger target persons as opposed to older target persons. A limitation of the present research, which future studies should remedy, is that we were not able to investigate whether similar own-age advantages would also be evident for negative-affect smiles.

The observed own-age advantage for older participants' accuracy in identifying the emotional meaning of neutral and positive-affect smile expressions supports the argument that age differences in recognizing emotion from facial expressions are likely to be over-estimated in studies that only consider facial expressions from younger or middle-aged, but not older target persons. The unbiased hit rates of older participants were smaller than those of younger participants, however, even for smile expressions from the older targets. Overall, the present research thus supports the view that the ability to decipher emotional meaning from facial expressions alone, presented without the accompanying context, is not as good in older than for in younger adults. Control analyses in both studies showed that the age differences in unbiased hit rates were robust to simultaneously controlling for age-related differences in years of education, processing speed, vocabulary knowledge, and vision, showing that differences in these control variables did not account for the observed age differences in reading smiles. It thus remains an open question for future research to identify the mechanisms that underlie these effects. Future studies should examine, for example, the potential respective roles of age-related differences in subjective conceptions of when and by whom smile expressions are displayed, or in the ability to integrate information from various (e.g., structural and temporal) dimensions of smile expressions (Slessor et al., 2010b).

The results from the present studies are strikingly different from those of earlier studies that used smile stimuli. It seems likely that this is due to diverging strategies of compiling smile expressions. In contrast to the previous investigations, our collection of smile stimuli was both dynamic and content-valid in the sense that we selected smile expressions for different smile types based on the convergence between the affective nature of the situation in which the smile was shown (i.e., while being the target of an unfair accusation, watching amusing stimuli, or being asked to pose a smile) and the target persons' self-reported affective experiences in that situation. The earlier studies, in contrast, used the Duchenne marker either as the sole criterion for the categorization of smile expressions (Murphy et al., 2010), or as one criterion among several (McLellan, 2008; Slessor et al., 2010a). In replication of evidence from other studies, all categories of our content-valid selection of smile expressions included a substantial proportion of stimuli that involved the Duchenne marker, suggesting that the Duchenne marker is not a reliable criterion for distinguishing between different types of smiles. Another possible explanation for the disparity of findings could relate to the different cultural contexts (i.e., in Germany, the US, and the UK) in which the respective investigations had been conducted. An interesting task for future investigations remains to explore whether cultural differences in smile expressions, or in smile recognition, may have contributed to the observed differences in findings. Another open question for further studies is the identification of contexts in which the observed age differences in recognizing affective experiences that accompany smile expressions might be reduced (or perhaps even reversed). One might speculate, for example, that familiarity with the smiling person might play a moderating role in this regard.

Future research should also aim at overcoming some methodological limitations of the present research. Among the most notable of these is the present cross-sectional design. Future research should explore the extent to which the observed cross-sectional differences between age groups reflect cohort differences as opposed to aging-related changes within persons over time. Another important task for future research is closing the gap to real-life emotion-recognition demands: even though the smiles paradigm (in contrast to the traditional paradigm) employs expressions that participants frequently encounter in diverse emotional contexts of their daily lives, it is nevertheless still quite different from real-life emotion-recognition demands. One obvious difference is that real-life smile expressions occur within the context of a particular situation and that perceivers might have accumulated knowledge about the smiling person. Investigating potential age-related differences in the ability to decipher smile expressions when such contextual information is available remains an open task for future research. Another realm for future investigation would be to further increase the breadth of smile types under investigation, and to also consider the role of arousal. In the present study, we focused on smile expressions that accompanied emotional states that were unambiguous with regard to their valence (negative, positive, neutral); however, different elicitation methods were employed to obtain each of the three smile types, making it possible that the smile stimuli might differ in other factors than valence as well. Furthermore, the positive-affect and negative-affect smiles were recorded in potentially activating emotional contexts (i.e., anger and amusement). This leaves an open question as to whether the observed age differences would generalize to smile expressions accompanying other emotional states, for example, mixed emotional states (e.g., feeling joyful and sad at the same time) or low-arousal states (e.g., sadness or contentment).

SUMMARY AND CONCLUSION

Two studies provided converging evidence that younger adult participants were better able to identify the emotional experiences accompanying different types of smile expressions than older participants were. Results further showed that these age differences were attenuated for smile expressions displayed by older target persons. Older adults were better able to identify the emotional meaning of smile expressions shown by older as compared to younger target persons. We conclude that dynamic and content-valid smile expressions provide a promising venue for studying age-differences in emotion recognition, and that it is important to vary the age of the expressing persons to further the understanding of adult age differences in the ability to recognize the emotional meaning of facial expressions.

ACKNOWLEDGMENTS

We thank Dulce Erdt, Anne Böger, Laura Wolf, Lisa Thiele, Robert Neumann, Elisabeth Blanke, Teresa Holtfreter, Alexander Mielke, Doreen Müller, Caroline Cohrdes, Sandy Jahn, Anna Maria Jäger, Anika Schulz, Claudia Medel, and Manuela Meermann for their help with data collection and preparation, and Amy Michéle for editorial assistance.

REFERENCES

Adolphs, R., Tranel, D., and Damasio, A. R. (2003). Dissociable neural systems for recognizing emotions. *Brain Cogn.* 52, 61–69. doi: 10.1016/S0278-2626(03)00009-5

Ambadar, Z., Cohn, J. F., and Reed, L. I. (2009). All smiles are not created equal: morphology and timing of smiles perceived as amused, polite, and embarrassed/nervous. *J. Nonverbal Behav.* 33, 17–34. doi: 10.1007/s10919-008-0059-5

Ansfield, M. E. (2007). Smiling when distressed: when a smile is a frown turned upside down. *Pers. Soc. Psychol. Bull.* 33, 763–775. doi: 10.1177/0146167206297398

Bach, M. (2007). The freiburg visual acuity test-variability unchanged by *post-hoc* reanalysis. *Graefe's Arch. Clin. Exp. Ophthalmol.* 245, 965–971. doi: 10.1007/s00417-006-0474-4

Bonanno, G. A., and Keltner, D. (1997). Facial expressions of emotion and the course of conjugal bereavement. *J. Abnorm. Psychol.* 106, 126–137. doi: 10.1037/0021-843X.106.1.126

Carstensen, L. L., Fung, H. H., and Charles, S. T. (2003). Socioemotional selectivity theory and the regulation of emotion in the second half of life. *Mot. Emot.* 27, 103–123. doi: 10.1023/A:1024569803230

Carstensen, L. L., and Mikels, J. A. (2005). At the intersection of emotion and cognition: aging and the positivity effect. *Curr. Dir. Psychol. Sci.* 14, 117–121. doi: 10.1111/j.0963-7214.2005.00348.x

DeSantis, M., and Sierra, N. (2000). Women smiled more often and openly than men when photographed for a pleasant, public occasion in 20th century United States society. *Psychol. A J. Hum. Behav*. 37, 21–31.

Ebner, N. C., He, Y., and Johnson, M. K. (2011). Age and emotion affect how we look at a face: visual scan patterns differ for own-age versus other-age emotional faces. *Cogn. Emot.* 25, 983–997. doi: 10.1080/02699931.2010.540817

Ebner, N. C., and Johnson, M. K. (2009). Young and older emotional faces: are there age group differences in expression identification and memory? *Psychol. Aging* 9, 329–339. doi: 10.1037/a0015179

Ekman, P. (1972). Universals and cultural differences in facial expressions of emotion. *Nebraska Symp. Mot.* 19, 207–283.

Ekman, P. (1993). Facial expression and emotion. *Am. Psychol.* 48, 384–392. doi: 10.1037/0003-066X.48.4.384

Ekman, P., Davidson, R. J., and Friesen, W. V. (1990). The Duchenne smile: emotional expression and brain physiology: II. *J. Pers. Soc. Psychol.* 58, 342–353. doi: 10.1037/0022-3514.58.2.342

Ekman, P., and Friesen, W. V. (1976). *Pictures of Facial Affect*. Palo Alto, CA: Consulting Psychologists Press.

Ekman, P., and Friesen, W. V. (1978). *Facial Action Coding System: A Technique for the Measurement of Facial Movement*. Palo Alto, CA: Consulting Psychologists Press.

Ekman, P., Hager, J. C., and Friesen, W. V. (1981). The symmetry of emotional and deliberate facial actions. *Psychophysiology* 18, 101–106. doi: 10.1111/j.1469-8986.1981.tb02919.x

Elfenbein, H. A., and Ambady, N. (2002). On the universality and cultural specificity of emotion recognition: a meta-analysis. *Psychol. Bull.* 128, 203–235. doi: 10.1037/0033-2909.128.2.203

Forster, K. I., and Forster, J. C. (2003). DMDX: a Windows display program with millisecond accuracy. *Behav. Res. Methods Instrum. Comput.* 35, 116–124. doi: 10.3758/BF03195503

Fridlund, A. J. (1994). *Human Facial Expression: an Evolutionary View*. San Diego, CA: Academic Press.

Fridlund, A. J. (1997). "The new ethology of human facial expressions," in *The Psychology of Facial Expression*, eds J. A. Russell and J. M. Fernandez-Dols (New York, NY; Paris: Cambridge University Press; Editions de la Maison des Sciences de l'Homme), 103–129.

Gross, J. J. (1999). "Emotion and emotion regulation," in *Handbook of Personality: Theory and Research, 2nd Edn*, eds L. A. Pervin and O. P. John (New York, NY: Guilford Press), 525–552.

Harrison, V., and Hole, G. J. (2009). Evidence for a contact-based explanation of the own-age bias in face recognition. *Psychon. Bull. Rev.* 16, 264–269. doi: 10.3758/PBR.16.2.264

Hecht, M. A., and LaFrance, M. (1998). License or obligation to smile: the effect of power and sex on amount and type of smiling. *Pers. Soc. Psychol. Bull*. 24, 1332–1342. doi: 10.1177/01461672982412007

Hess, U., and Kleck, R. E. (1990). Differentiating emotion elicited and deliberate emotional facial expressions. *Eur. J. Soc. Psychol.* 20, 369–385. doi: 10.1002/ejsp.2420200502

Isaacowitz, D. M., and Stanley, J. T. (2011). Bringing an ecological perspective to the study of aging and recognition of emotional facial expressions: past, current, and future methods. *J. Nonverbal Behav*. 35, 261–278. doi: 10.1007/s10919-011-0113-6

Izard, C. E. (1994). Innate and universal facial expressions: evidence from developmental and cross-cultural research. *Psychol. Bull.* 115, 288–299. doi: 10.1037/0033-2909.115.2.288

Johnston, L., Miles, L., and Macrae, C. (2010). Why are you smiling at me? Social functions of enjoyment and non-enjoyment smiles. *Br. J. Soc. Psychol.* 49, 107–127. doi: 10.1348/014466609X412476

Keightley, M., Winocur, G., Burianova, H., Hongwanishkul, D., and Grady, C. L. (2006). Age effects in social cognition: faces tell a different story. *Psychol. Aging* 21, 558–572. doi: 10.1037/0882-7974.21.3.558

Keltner, D. (1995). Signs of appeasement: evidence for the distinct displays of embarrassment, amusement, and shame. *J. Pers. Soc. Psychol.* 68, 441–454. doi: 10.1037/0022-3514.68.3.441

Keltner, D., and Haidt, J. (1999). Social functions of emotions at four levels of analysis. *Cogn. Emot*. 13, 505–521. doi: 10.1080/026999399379168

Keltner, D., Haidt, J., and Shiota, M. N. (2006). "Social functionalism and the evolution of emotions," in *Evolution and Social Psychology*, eds M. Schaller, J. A. Simpson, and D. T. Kenrick (Madison, CT: Psychosocial Press), 115–142.

Kliegel, M., Martin, M., McDaniel, M. A., and Phillips, L. H. (2007). Adult age differences in errand planning: the role of task familiarity and cognitive resources. *Exp. Aging Res.* 33, 145–161. doi: 10.1080/03610730601177395

Krohne, H. W., Egloff, B., Kohlmann, C. W., and Tausch, A. (1996). Untersuchungen mit einer deutschen Version der "Positive and Negative Affect Schedule" (PANAS) [Studies on a German version of the Positive and Negative Affect Schedule (PANAS)]. *Diagnostica* 42, 139–156.

Krumhuber, E. G., and Manstead, A. S. (2009). Can Duchenne smiles be feigned? New evidence on felt and false smiles. *Emotion* 9, 807–820. doi: 10.1037/a0017844

LaBar, K. S., Crupain, M. J., Voyvodic, J. T., and McCarthy, G. (2003). Dynamic perception of facial affect and identity in the human brain. *Cereb. Cortex* 13, 1023–1033. doi: 10.1093/cercor/13.10.1023

Lehrl, S., Merz, J., Burkhard, G., and Fischer, S. (1991). *Mehrfachwahl—Wortschatz—Intelligenztest, MWT-A [Multiple-choice Vocabulary Intelligence Test, MWT-A]*. Göttingen: Hogrefe.

Malatesta, C. Z. (1987). Emotion communication skills in young, middle-aged, and older men and women. *Psychol. Aging* 2, 193–203. doi: 10.1037/0882-7974.2.2.193

Matsumoto, D., and Ekman, P. (1988). *Japanese and Caucasian Facial Expressions of Emotion and Neutral Faces (JACFEE and JACNeuF)*. Available online at: http://www.davidmatsumoto.com/research.php

McLellan, T. L. (2008). *Sensitivity to Emotion Specified in Facial Expressions and the Impact of Aging and Alzheimer's Disease*. Doctoral thesis, University of Canterbury, Christchurch.

Messinger, D. S., Fogel, A., and Dickson, K. (1999). What's in a smile? *Dev. Psychol.* 35, 701–708. doi: 10.1037/0012-1649.35.3.701

Murphy, N. A., Lehrfeld, J. M., and Isaacowitz, D. M. (2010). Recognition of posed and spontaneous dynamic smiles in young and older adults. *Psychol. Aging* 25, 811–821. doi: 10.1037/a0019888

Otta, E. (1998). Sex differences over age groups in self-posed smiling in photographs. *Psychol. Rep.* 83, 907–913. doi: 10.2466/pr0.1998.83.3.907

Papa, A., and Bonanno, G. A. (2008). Smiling in the face of adversity: the interpersonal and intrapersonal functions of smiling. *Emotion* 8, 1–12. doi: 10.1037/1528-3542.8.1.1

Phillips, L. H., Kliegel, M., and Martin, M. (2006). Age and planning tasks: the influence of ecological validity. *Int. J. Aging Hum. Dev.* 62, 175–184. doi: 10.2190/EM1W-HAYC-TMLM-WW8X

Phillips, L. H., MacLean, R. D. J., and Allen, R. (2002). Age and the understanding of emotions: neuropsychological and sociocognitive perspectives. *J. Gerontol. Psychol. Sci.* 57B, P526–P530. doi: 10.1093/geronb/57.6.P526

Rauers, A., Blanke, E., and Riediger, M. (2013). Everyday empathic accuracy in younger and older couples: do you need to see your partner to know his or her feelings? *Psychol. Sci.* 24, 2210–2217. doi: 10.1177/0956797613490747

Reed, A. E., and Carstensen, L. L. (2012). The theory behind the age-related positivity effect. *Front. Psychol.* 3, 1–9. doi: 10.3389/fpsyg.2012.00339

Reisenzein, R., Studtmann, M., and Horstmann, G. (2013). Coherence between emotion and facial expression: evidence from laboratory experiments. *Emot. Rev.* 5, 16–23. doi: 10.1177/1754073912457228

Richter, D., Dietzel, C., and Kunzmann, U. (2011). Age differences in emotion recognition: the task matters. *J. Gerontol. B Psychol. Sci. Soc. Sci.* 66B, 48–55. doi: 10.1093/geronb/gbq068

Richter, D., and Kunzmann, U. (2011). Age differences in three facets of empathy: performance-based evidence. *Psychol. Aging* 26, 60–70. doi: 10.1037/a0021138

Riediger, M., Voelkle, M. C., Ebner, N. C., and Lindenberger, U. (2011). Beyond "happy, angry, or sad?" Age-of-poser and age-of-rater effects on multi-dimensional emotion perception. *Cogn. Emot.* 25, 968–982. doi: 10.1080/02699931.2010.540812

Ruffman, T., Henry, J. D., Livingstone, V., and Phillips, L. H. (2008). A meta-analytic review of emotion recognition and aging: implications for neuropsychological models of aging. *Neurosci. Biobehav. Rev.* 32, 863–881. doi: 10.1016/j.neubiorev.2008.01.001

Schmidt, K. L., Ambadar, Z., Cohn, J. F., and Reed, L. (2006). Movement differences between deliberate and spontaneous facial expressions: zygomaticus major action in smiling. *J. Nonverbal Behav.* 30, 37–52. doi: 10.1007/s10919-005-0003-x

Schmidt, K. L., Bhattacharya, S., and Denlinger, R. (2009). Comparison of deliberate and spontaneous facial movement in smiles and eyebrow raises. *J. Nonverbal Behav*. 33, 35–45. doi: 10.1007/s10919-008-0058-6

Schmidt, K. L., and Cohn, J. F. (2001). Human facial expressions as adaptations: evolutionary questions in facial expression research. *Am. J. Phys. Anthropol.* 116, 3–24. doi: 10.1002/ajpa.20001

Schultz, J., and Pilz, K. S. (2009). Natural facial motion enhances cortical responses to faces. *Exp. Brain Res.* 194, 465–475. doi: 10.1007/s00221-009-1721-9

Schwenkmezger, P., Hodapp, V., and Spielberger, C. D. (1992). *Das State-Trait-Ärgerausdrucks-Inventar (STAXI) [The State-Trait Anger Expression Inventory]*. Bern: Huber.

Slessor, G., Miles, L. K., Bull, R., and Phillips, L. H. (2010a). Age-related changes in detecting happiness: discriminating between enjoyment and nonenjoyment smiles. *Psychol. Aging* 25, 246–250. doi: 10.1037/a0018248

Slessor, G., Phillips, L. H., and Bull, R. (2010b). Age-related changes in the integration of gaze direction and facial expressions of emotion. *Emotion* 10, 555–562. doi: 10.1037/a0019152

Soussignan, R. (2002). Duchenne smile, emotional experience, and autonomic reactivity: a test of the facial feedback hypothesis. [Empirical Study]. *Emotion* 2, 52–74. doi: 10.1037/1528-3542.2.1.52

Sze, J. A., Goodkind, M. S., Gyurak, A., and Levenson, R. W. (2012). Aging and emotion recognition: not just a losing matter. *Psychol. Aging* 27, 940–950. doi: 10.1037/a0029367

Thibault, P., Bourgeois, P., and Hess, U. (2006). The effect of group-identification on emotion recognition: the case of cats and basketball players. *J. Exp. Soc. Psychol.* 42, 676–683. doi: 10.1016/j.jesp.2005.10.006

Wagner, H. L. (1993). On measuring performance in category judgment studies on nonverbal behavior. *J. Nonverbal Behav*. 17, 3–28. doi: 10.1007/BF00987006

Weber, H., and Wiedig-Allison, M. (2007). Sex differences in anger-related behaviour: comparing expectancies to actual behaviour. *Cogn. Emot.* 21, 1669–1698. doi: 10.1080/02699930701202111

Wechsler, D. (1981). *Wechsler Adult Intelligence Scale-Revised (WAIS-R)*. New York, NY: Psychological Corporation.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 23 December 2013; accepted: 02 May 2014; published online: 27 May 2014.
Citation: Riediger M, Studtmann M, Westphal A, Rauers A and Weber H (2014) No smile like another: adult age differences in identifying emotions that accompany smiles. Front. Psychol. ***5****:480. doi: 10.3389/fpsyg.2014.00480*
This article was submitted to Emotion Science, a section of the journal Frontiers in Psychology.

frontiers in PSYCHOLOGY
ORIGINAL RESEARCH ARTICLE
published: 28 April 2014
doi: 10.3389/fpsyg.2014.00338

Proficiency in positive vs. negative emotion identification and subjective well-being among long-term married elderly couples

Raluca Petrican *, Morris Moscovitch and Cheryl Grady

Department of Psychology and Psychiatry, Rotman Research Institute, University of Toronto, Toronto, ON, Canada

Edited by:
Natalie Ebner, University of Florida, USA

Reviewed by:
Tara L. Queen, University of Utah, USA
Natalie Ebner, University of Florida, USA
Hakan Fischer, Stockholm University, Sweden

****Correspondence:***
Raluca Petrican, Rotman Research Institute, 3560 Bathurst Street, Toronto, ON M6A 2E1, Canada
e-mail: raluca.petrican@gmail.com

Evidence is accruing that positive emotions play a crucial role in shaping a healthy interpersonal climate. Inspired by this research, the current investigation sought to shed light on the link between proficiency in identifying positive vs. negative emotions and a close partner's well-being. To this end, we conducted two studies with neurologically intact elderly married couples (Study 1) and an age-matched clinical sample, comprising married couples in which one spouse had been diagnosed with Parkinson's Disease (Study 2), which tends to hinder emotional expressivity. To assess proficiency in identifying emotions from whole body postures, we had participants in both studies complete a pointlight walker task, featuring four actors (two male, two female) expressing one positive (i.e., happiness) and three negative (i.e., sadness, anger, fear) basic emotions. Participants also filled out measures of subjective well-being. Among Study 1's neurologically intact spouses, greater expertise in identifying positive (but not negative) emotions was linked to greater partner life satisfaction (but not hedonic balance). Spouses of PD patients exhibited increased proficiency in identifying positive emotions relative to controls, possibly reflective of compensatory mechanisms. Complementarily, relative to controls, spouses of PD patients exhibited reduced proficiency in identifying negative emotions and a tendency to underestimate their intensity. Importantly, all of these effects attenuated with longer years from PD onset. Finally, there was evidence that it was increased partner expertise in identifying negative (rather than positive) emotional states that predicted greater life satisfaction levels among the PD patients and their spouses. Our results thus suggest that positive vs. negative emotions may play distinct roles in close relationship dynamics as a function of neurological status and disability trajectory.

Keywords: emotion recognition, well-being, marriage, Parkinson's Disease, point light walker, older adults

INTRODUCTION

Close relationships constitute a critical ingredient of psychological and physical health (e.g., Beach and O'Leary, 1993; Berscheid and Reis, 1998; Diener and Seligman, 2002). Perhaps unsurprisingly, numerous well-being theories identify fulfilling close relationships as a prerequisite for optimal hedonic balance (e.g., Ryff, 1995; Keyes, 1998; Diener and Biswas-Diener, 2008). Although traditionally relationship researchers focused on the role of negative emotions (e.g., Levenson and Gottman, 1983; Gottman, 1998), there is mounting evidence that positive emotions are crucial in shaping a healthy interpersonal environment (Gable et al., 2006, 2012). Inspired by this research, in the present studies, we sought to examine the link between proficiency in recognizing positive vs. negative emotions and spousal well-being among neurologically intact couples and couples where one partner has been diagnosed with Parkinson's Disease. To situate our present investigation in the literature, we begin by reviewing extant evidence on the role of close relationship quality in health and well-being, followed by a summary of the research on emotions within intimate partnerships, with a focus on social support and care giving circumstances. We conclude the Introduction with an overview of the literature on how emotion recognition proficiency—and thus the ability to provide responsive social support and effective care giving—may be impacted by normal aging and among couples, where one partner is afflicted by neurological conditions, typical of older age, such as Parkinson's Disease.

CLOSE RELATIONSHIP QUALITY AND HEALTH

Most of the extant research focuses on the direct pathways through which poor close relationship—most often, marriage—quality can adversely impact well-being and health. For example, relationship turmoil has been found to contribute to psychopathological symptoms such as depression, anxiety, and substance abuse (e.g., Davila et al., 1997; Whisman, 2001; Whisman et al., 2010). Likewise, poorer marital quality and more hostile marital interactions have been linked to abnormal immune responses (Kiecolt-Glaser et al., 1993; Miller et al., 1999), greater cardiovascular reactivity (Morell and Apple, 1990; Ewart et al., 1991; Smith and Brown, 1991; Brown and Smith, 1992; Brown et al., 1998; Newton and Sanford, 2003), higher incidence of cardiac events (Orth-Gomer et al., 2000) and mortality (Eaker et al., 2007). Complementing these findings on the adverse health effects of poor marital quality, there is evidence on the beneficial consequences of greater marital adjustment, such as healthier physiological profiles (i.e., lower blood pressure, Holt-Lunstad et al., 2008), superior immune responses (Kiecolt-Glaser et al., 1987), better cardiovascular health (Baker et al., 2000), and lower mortality following cardiac incidents (among women; Hibbard and Pope, 1993; Rohrbaugh et al., 2006).

SOCIAL SUPPORT IN CLOSE RELATIONSHIPS

Extending investigations on the direct consequences of marital adjustment on health, there is recent research on the role of marital quality in moderating the effects of non-relationship factors (e.g., work, disease) on physical and psychological well-being. The majority of these studies focused on the stress buffering function of positive marital environments and documented their beneficial effect on rehabilitation among cardiac patients (Wang et al., 2007), recovery from work-related stress (Saxbe et al., 2008) and reduced physiological reactivity to chronic problems at work (Ditzen et al., 2008).

One factor assumed to underlie the stress buffering function of happier marriages is the perception of social support availability, intrinsically linked to being part of a fulfilling intimate partnership (e.g., Kaul and Lakey, 2003). Indeed, there is extensive evidence that such perceptions of emotional support during stressful times constitute a pivotal determinant of physical and psychological health (Cohen and Wills, 1985; Cohen, 1988; Lakey and Cassady, 1990; Uchino et al., 1996; Sarason et al., 1997; Kaul and Lakey, 2003).

Intriguingly, though, perceptions of social support availability are only loosely based on the reality of actual support received during challenging times (e.g., Haber et al., 2007). Instead, they appear to be more heavily rooted in enacted support from others during propitious times (Gable et al., 2012). Moreover, it seems that only the latter is consistently linked to benign personal and relational outcomes (e.g., Gable et al., 2006, 2012), whereas enacted support from others during trying times is only sparsely associated with favorable outcomes, being occasionally even linked to adverse consequences (e.g., Collins et al., 1993; Bolger et al., 2000; Kaul and Lakey, 2003).

The apparent paradox of such findings has been illuminated by studies documenting that it is only provision of social support, perceived to be responsive by the recipient, that contributes to the latter's well-being and feeds his or her perceptions that a close other may be available for assistance during stressful times (Maisel and Gable, 2009; Gable et al., 2012). Provision of responsive support is reportedly easier during auspicious, rather than inauspicious, times, since any visible assistance during the latter periods may only augment the recipient's emotional turmoil by indirectly highlighting his/her inadequacy in coping with the stressor and rendering salient feelings of indebtedness to the support provider (Bolger et al., 2000; Gleason et al., 2003; Shrout et al., 2006). Taken together, the findings reviewed above thus imply that the stress buffering function of close relationships, instantiated in perceptions of emotional support availability during trying times, may be most dependent upon the intimates' ability to read each other's emotions accurately and thus provide each other with responsive support, particularly during favorable times.

NEGATIVE EMOTIONS IN CARE GIVING AND RECEIVING

Spousal disease and disability create a dyadic environment in which negative emotions can flourish. Indeed, there is evidence that under such circumstances, it is not only the diseased who struggles with negative emotions, but also the care giver who must manage the challenges of both actively helping his/her ill spouse and dealing with potentially long "on-call" hours (Poulin et al., 2010). Importantly, though, the challenges of attending to an ill spouse are not the sole culprit for the significant hedonic and physical health costs incurred by prolonged care giving (Schulz et al., 2009). Instead, it has been proposed that the affective burden of care giving may be also rooted in the extensive exposure to the suffering of a close other and the intrinsic potential for emotion contagion between the care recipient and giver (for a review, see Monin and Schulz, 2009). Indeed, consistent with a suffering contagion model, several studies provided evidence of significant, positive associations in emotional distress between cancer patients and their caregivers (Given et al., 1993; Northouse et al., 2001). Moreover, longitudinal studies have documented the positive link between spousal suffering and subsequent decay in well-being or even development of depression and physical health problems (e.g., cardiovascular disease) in the care giving partner (Revenson and Majerovitz, 1990; Pakenham, 2001; Schulz et al., 2009).

Although witnessing the suffering of a close other may incur significant hedonic and physical health costs to the care givers, expression of negative emotions by care recipients is nonetheless a key component of effective care giving, because it conveys the need for support and thus enables the caregiver to be more responsive to a care recipient's needs (cf. Monin and Schulz, 2009). Consistent with this interpretation, there is evidence that expression of "vulnerable" negative emotions, such as fear, sadness, anxiety, predicts less caregiver stress (at least among female caregivers, Monin et al., 2009). Indeed, it seems plausible to posit that within a care giving context, the ability to accurately recognize negative emotions may be a critical asset for both the care giver and the care recipient. On one hand, accurate identification of a care recipient's negative emotions may enable the care giver to direct his/her efforts toward maximizing the patient's well-being. Complementarily, accurate identification of a caregiver's negative emotions may aid the care recipient in gauging the impact of his/her illness and adjust behavior (where possible) to reduce care giver burden and, thus, foster a more positive dyadic climate.

EMOTION RECOGNITION AND AGING

An accumulating body of research suggests that, despite the increasing importance placed on emotions in older adulthood (Carstensen, 1992; Mather and Carstensen, 2005), the ability to decode them accurately decays with advancing age (e.g., Ruffman et al., 2009). The bulk of the investigations to date focused on the recognition of facial emotional cues and documented most consistent age-related deficits in the identification of negative emotions, specifically fear, anger, and sadness (Malatesta et al., 1987; Moreno et al., 1993; MacDowell et al., 1994; Brosgole and Weisman, 1995; MacPherson et al., 2002, 2007; Phillips et al., 2002; Calder et al., 2003; Sullivan and Ruffman, 2004a,b; Wong et al., 2005; Keightley et al., 2006; Isaacowitz et al., 2007; Sullivan et al., 2007; Suzuki et al., 2007; Henry et al., 2008; Orgeta and Phillips, 2008; for a recent meta-analysis, see Ruffman et al., 2008).

More recent studies, using a broader array of stimuli, suggest that age-related deficits in emotion identification are not restricted to the decoding of facial cues, but also extend to auditory and postural affective cues (e.g., Brosgole and Weisman, 1995; Montepare et al., 1999; Wong et al., 2005; Ruffman et al., 2009). Moreover, beyond the well-documented global age-related decline in reading emotional expressions, there is also evidence of some modality-specific patterns of impairment. For example, although older adults are reportedly most impaired at recognizing negative emotions from facial cues (cf. Ruffman et al., 2008), they seem to experience greater difficulties with recognizing auditory cues of positive, rather than negative (e.g., fear), emotions (Wong et al., 2005). Similarly, whole-body cues of positive emotions are less legible to older, relative to younger, adults, although age-related deficits in deciphering postural cues have also been detected in response to negative emotions, most notably, sadness, and anger (Montepare et al., 1999; Ruffman et al., 2009).

EMOTION EXPRESSION AND RECOGNITION IN PARKINSON'S DISEASE

Deficits in emotion recognition are also a hallmark of psychopathological conditions, typical of older age, such as Parkinson's Disease (PD). PD is a degenerative neurological disorder with a prevalence of 1/1000 (Peto et al., 1995). Uncommon before age 40, PD affects around 1% of people over 60 and around 2% of people over 80 (MacPhee and Stewart, 2007). The clinical signs of PD are primarily motor and include slowness of movement, rigidity, resting limb tremors, and postural and balance problems (Ferguson et al., 2008). Recently, though, there has been increasing recognition that despite their salience, motor symptoms are not the only clinical features of PD, which often also is characterized by cognitive deficits (Pillon et al., 1996) and affect dysregulation (Marsh, 2000).

Consistent with the clinical emphasis on motor symptoms, most of the extant empirical investigations on emotion in PD focused on the expressive deficits associated with the disorder. There is thus evidence that PD patients exhibit impairments in producing spontaneous (Buck and Duffy, 1980; Katsikitis and Pilowsky, 1988, 1991; Smith et al., 1996) and, to a somewhat lesser degree, voluntary (Simons et al., 2004) emotional expressions. Such expressive deficits constitute the likely cause of why they tend to be misunderstood and poorly evaluated by their interlocutors (Ellgring et al., 1993), even when the latter are health care professionals (Pentland et al., 1987, 1988). Of note, the motor difficulties associated with PD render the patients least apt at expressing positive emotions. Thus, in the laboratory, PD patients have been found to produce less legible voluntary facial expressions of happiness (Simons et al., 2004). Likewise, outside the laboratory, the facial movement difficulties, which typify PD, cause the patients' spontaneous smiles to be misread as "unfelt" (i.e., inauthentic because of a lack of accompanying cheek raises, Pitcairn et al., 1990).

Complementing the aforementioned investigations on the expressive deficits associated with PD, there is a recently growing body of research on the patients' impairments in decoding emotions. Most of these studies focused on recognition of facial or prosodic cues and provided evidence of marked deficits among PD patients, relative to controls (e.g., Kan et al., 2002; Pell and Leonard, 2003; Yip et al., 2003; Dujardin et al., 2004; Suzuki et al., 2006; Lawrence et al., 2007; Ariatti et al., 2008; Clark et al., 2008; Dara et al., 2008). Indeed, in a recent meta-analysis of the literature on emotion recognition in PD, Gray and Tickle-Degnen (2010) concluded that there is a robust link between PD and impaired recognition of both auditory and facial emotional cues, with deficits being particularly salient for negative emotions.

Despite compelling evidence that PD may incur significant emotion recognition deficits (Gray and Tickle-Degnen, 2010), some inconsistencies do exist in the literature. For example, although robust (adverse) effects of PD on (negative) emotion recognition have been documented among un-medicated, hence, somewhat paradoxically, early stage patients (Sprengelmeyer et al., 2003; Buxton et al., 2013), such impairments have been somewhat harder to detect among medicated patients in the later stages of PD (e.g., Adolphs et al., 1998; Assogna et al., 2010). Moreover, although the bulk of the evidence to date implies that PD may lead to most marked deficits in reading negative emotional cues (Gray and Tickle-Degnen, 2010), a recent study suggests that this may be an artifact of the affective stimuli used by prior research, since PD-related deficits in reading positive emotional cues have been detected when subtler affective expressions are employed (Buxton et al., 2013).

In sum, despite some inconsistencies, extant literature suggests that PD incurs significant deficits both in expressing and decoding affective cues. Interestingly, although deciphering of negative emotions may pose greatest difficulties to PD patients (cf. Gray and Tickle-Degnen, 2010, but see also Buxton et al., 2013), it appears that it is deficient expression of positive emotions that may afflict their social life the most (Pitcairn et al., 1990; Simons et al., 2004).

PRESENT RESEARCH

The purpose of the present research was to investigate the link between individual differences in the ability to identify positive vs. negative emotions and a spouse's well-being among neurologically intact elderly couples (Study 1), as well as in an age- and marriage length-matched clinical sample, comprising married couples in which one spouse had been diagnosed with PD (Study 2).

Prior findings suggest that it is only provision of responsive support to a spouse during a positive event that is unambiguously linked to greater recipient well-being (cf. Gable et al., 2012). In contrast, provision of effective support to a spouse during negative events is not only difficult to enact, but even when perceived by the recipient to be highly responsive, it can still not buffer against the deleterious hedonic consequences associated with negative events (although responsive social support is associated with beneficial *relational* outcomes, see Study 2, Gable et al., 2012). Consequently, we hypothesized that among neurologically intact couples, higher levels of spousal well-being would be linked to greater proficiency in identifying positive, rather than negative, emotions. Indeed, we reasoned that those who are "experts" at recognizing positive emotions would be better skilled at reading their spouse's emotional reactions during a positive event and, thus, be in a better position to respond in a manner that would foster the spouse's well-being (cf. Maisel and Gable, 2009; Gable et al., 2012). In contrast, we reasoned that proficiency in identifying negative emotions, and, thus, presumably greater ability to respond effectively to a spouse during negative events, would evidence a weak (if any) relationship to the spouse's well-being.

Complementarily, prior research with couples, in which one partner struggles with a severe disease or disability, suggests that it is the ability to recognize and respond appropriately to negative emotions that may be a critical determinant of dyadic and individual well-being (cf. Monin et al., 2009). Indeed, on one hand, a care giver's ability to read accurately the patient's negative emotions may put him/her in a better position to provide the most responsive and efficient support (cf. Monin and Schulz, 2009). On the other hand, a care recipient's ability to recognize a care giver's negative emotions may allow him/her to adjust behavior (where possible) to minimize care giver burden. Thus, it seemed plausible that in our clinical sample, in which one of the spouses was evidencing increasing levels of disability and, thus, dependence on the care giving partner, the ability to identify accurately negative emotional cues may be as important (if not more important) a contributor to spousal well-being as the ability to identify positive emotions.

For our clinical sample, we opted to focus on PD patients and their spouses for several reasons. First, because it is a neurodegenerative disorder, PD challenges both patients and their spouses to cope with increasing (rather than stable) levels of patient disability, which, arguably, hinders both the patients' and their spouses' ability to habituate to their (ever changing) life circumstances. We thus reasoned that longer disease duration may render expression of negative emotions by the patients increasingly informative for their care givers because with increasing disability, patients become more dependent on their care givers to help them relieve their distress. Consequently, the PD sample allowed us to test the hypothesis that, consistent with the posited adaptive function of negative emotion expression by care recipients (Monin et al., 2009), spousal care givers would demonstrate increased proficiency in decoding negative emotional cues, an advantage that may accentuate with more years from disease onset and greater patient disability.

Second, PD is reportedly associated with deleterious effects on facial affective expressivity (Buck and Duffy, 1980; Katsikitis and Pilowsky, 1988, 1991; Smith et al., 1996), particularly the production of facial positive emotional cues (Pitcairn et al., 1990; Simons et al., 2004). Consequently, inclusion of the PD patients and their spouses allowed us to test whether, in line with our proposed critical role of positive emotion proficiency in fostering spousal well-being, a spouse's declining ability to produce positive emotional cues would be "compensated" by the other's spouse's increasing proficiency in decoding them. Although such effects may generalize across modalities, we reasoned that we may be particularly likely to find evidence of them in modalities that are relatively less affected by PD, such as the postural domain (see below). Finally, inclusion of the PD patients and their spouses in our research also allowed us to extend the literature on emotion perception in PD by examining whether the patients would exhibit deficits in reading postural emotional cues, similar to the ones previously documented for facial and auditory emotional cues (Gray and Tickle-Degnen, 2010).

To assess the cognitive and affective components of well-being, respectively, we had participants in both studies fill out two validated self-report measures (Diener et al., 1985; Gere et al., 2011). To assess individual differences in emotion recognition, we had them complete a point light walker task (Heberlein and Saxe, 2005; Atkinson et al., 2007). We chose this measure for a couple of reasons. First, there is recent evidence that individual differences in performance on this task may be a good indicator of social expertise, since they have been found to be uniquely predictive of individual differences in higher-order sociocognitive processes (e.g., false belief reasoning, Phillips et al., 2011), involved in extracting and updating multiple aspects of social information (Phillips et al., 2011). Second, to the best of our knowledge, despite accumulating evidence on the emotion recognition deficits associated with PD (Gray and Tickle-Degnen, 2010), there is still a dearth of research on the potential PD-associated impairments in decoding postural (rather than facial or auditory) emotional cues. Consequently, we reasoned that probing any potential deficits in reading whole-body emotional cues in PD may be a valuable extension of the literature.

STUDY 1

METHODS

Participants

Thirty-seven elderly couples, married between 18 and 56 years ($M = 42.22$, $SD = 9.09$, provided informed consent in accordance with the ethical guidelines of the Research Ethics Board at the University of Toronto [women's age: $M = 69.06$ ($SD = 5.67$); men's age: $M = 72.27$ years ($SD = 6.07$)]. All were native English speakers or had lived in Canada and used English as the primary language for at least 30 years. Prior to their laboratory visit, potential participants underwent a phone screening interview, conducted by a senior research assistant, associated with the study. Specifically, they were asked whether (a) they ever had a stroke, tumor, neurological disease, concussion, depression, seizure, head injury, aneurysm, learning disability, psychiatric illness, epilepsy; (b) they had ever been in a serious car accident and/or hit their head badly and/or been unconscious; and (c) what medication (if any) they take on a regular basis. Potential participants who responded "yes" to any of the questions at points "a" and "b" or reported that they were taking psychotropic medication on regular basis were excluded from participating (for the demographic information summary, see **Table 1**).

Measures

Pointlight walker task. To assess participants' ability to read emotions from whole body postures, we presented them with a set of 38 movies, ranging in length from 4 to 14 s, obtained upon request from Andrea Heberlein (see also Heberlein and Saxe, 2005; Atkinson et al., 2007). According to Andrea Heberlein, this set of stimuli most consistently elicited emotionally valenced

Table 1 | Demographic information for the Study 1 and 2 samples.

	Study 1	Study 2
1. Marriage length	42.22 ± 9.09	39.28 ± 11.67 years
2. Females	Age = 69.06 ± 5.67 years	Age = 67.77 ± 9.95 years
3. Males	Age = 72.27 ± 6.07 years	Age = 68.39 ± 10.22 years
4. PD patients		12 males; Age = 69.75 ± 9.34 years 6 females; Age = 66.00 ± 10.99 years
5. PD spouses		12 females; Age = 68.72 ± 9.76 years 6 males; Age = 65.67 ± 12.24 years
6. Years from PD symptom onset		8.06 ± 3.89 years

The above information is based on data from 37 couples (Study 1) and 18 couples (Study 2).

judgments from neurologically intact participants (i.e., the actor in the clip was perceived to express an emotion, rather than being neutral). The stimuli featured professional or student actors, 3 males and 3 females, who walked across the frame of a movie camera from left to right, with movement patterns intended to convey specific emotions (i.e., anger, fear, happiness, or sadness). Small lights were attached to the actors' wrists, ankles, knees, elbows, outer hip, waist, outer shoulder, and head; they were filmed in the dark, so that only the moving lights were visible. At the end of each movie clip, participants were requested to rate on a 7-point scale (from 1 not at all to 7 extremely) the extent to which the actor expressed each of the four emotions (i.e., fear, sadness, anger, happiness) or s/he was neutral (i.e., expressed no emotion at all). Taking our cue from Adolphs et al. (1998) and Dujardin et al. (2004), we chose to use the emotion rating profile, rather than categorical labeling of each movie within one emotion, to account for the fact that subtler, realistic cues are unlikely to be emotion-pure (i.e., other emotions are likely to be expressed together with the targeted one).

Data scoring. For each clip, across all participants, we averaged separately the scores provided for each of the four emotions tested to create the sample's "agreed upon" ratings of each movie. Subsequently, for each participant and for each of the four scrutinized emotions, we created a "deviance" score as the absolute value of the difference between the sample's average rating of the movie on the given emotion and the respective participant's rating. Then, for each participant, we averaged these "deviance" scores across all movies, within each of the four tested emotions. For ease of interpretation, we then subtracted each "deviance" score from 1, so that for the resulting scores, greater values would reflect better recognition performance. Consequently, indicative of our ultimate interest in a participant's ability to accurately read his/her spouse's emotions, we have operationalized "accuracy" in emotion recognition as (greater) agreement between a participant's emotion ratings and the sample's mean emotion ratings. Our rationale was that, beyond any idiosyncratic effects, a significant predictor of whether a participant would successfully decode his/her spouse's emotions is his/her adherence to the affective vocabulary of those most demographically similar to his/her spouse. We also kept the raw values of the difference between a participant's rating of a movie on a given emotion and the sample's corresponding rating. These scores, averaged across all movies, indicated the direction of a participant's leaning on a given emotion judgment (i.e., over- or under-estimation of the intensity of an emotion, relative to the sample).

Subjective well-being. Participants completed a 7-point Likert-type life satisfaction measure (e.g., "I am satisfied with my life."; Diener et al., 1985; $\alpha = 0.86$) and a positive and negative affect scale (e.g., "In general, I felt bad."; (Gere et al., 2011); $\alpha = 0.87$ and 0.90, respectively). To compute an index of hedonic balance, we subtracted participants' average score on the negative affect scale from their average score on the positive affect scale. Consistent with Diener's (1984) proposal that life satisfaction and hedonic balance constitute aspects—cognitive and affective, respectively—, of the same construct, i.e., subjective well-being, their indices were moderately correlated, $r_{(72)} = 0.45$, $p < 0.01$.

Procedure

The study period was comprised of two 90-min sessions separated by a 30-min lunch break. Upon arriving at the lab, spouses were taken to separate testing rooms, where they remained for the duration of the two study sessions, reuniting during the break. At the beginning of the first session, partners were asked to fill out a larger questionnaire package that included the life satisfaction and affective well-being scales. During the second session, they completed the point light walker task. All measures and tasks were administered in this fixed order across all participants.

RESULTS

Data preparation

Due to the dependency in our couples' data, hierarchical linear regression models were regarded as the most appropriate statistical approach (HLM 7.01, Raudenbush et al., 2013). HLM produces essentially the same parameter estimates as simple linear regression, but uses more appropriate estimates of standard errors to test statistical significance. Following the recommendations of Campbell and Kashy (2002) for analysis of dyadic data in HLM, we investigated the interrelationships among our various measures by running fixed slopes regression models. As in simple regression, the outcome variable was uncentered. All predictors were mean-centered. In all the reported analyses, we included both actor and partner variables for all the predictors (all the reported results are unchanged if only the partner variables are introduced as predictors). Because the data violated normality assumptions, we report the robust standard error estimates for all the analyses conducted (cf. Hox, 2002).

Preliminary analyses

Gender effects. A One-Way ANOVA with gender as a fixed factor revealed that males exhibited lower accuracy in reading negative emotions ($M = 0.24$, $SD = 0.67$) relative to females ($M = 0.50$, $SD = 0.30$), $F_{(1, 73)} = 4.49$, $p < 0.05$, which was apparently due to their tendency to overperceive the amount of negative emotions portrayed in the clips ($M = 0.18$, $SD = 0.67$) relative to females ($M = -0.17$, $SD = 0.50$), $F_{(1, 73)} = 6.47$, $p < 0.05$. At the level of discrete emotions, this gender effect appeared to be driven by the males' tendency to overperceive sadness ($M = 0.35$, $SD = 1.07$), $F_{(1, 73)} = 10.75$, $p < 0.01$, and anger ($M = 0.38$, $SD = 1.14$), $F_{(1, 73)} = 8.07$, $p < 0.01$, relative to females ($M = -0.31$, $SD = 0.60$ for sadness and $M = -0.21$, $SD = 0.52$ for anger). In light of these gender differences, all the reported analyses controlled for gender, coded as −1 for males and 1 for females.

Actor-partner correlations. Using a two-level HLM model with individuals (level-1) embedded in couples (level-2) and gender as a control variable, we found a significant positive association between the spouses' satisfaction with life, $b = 0.49$, $SE = 0.11$, $t_{(35)} = 4.45$, $p < 0.01$, but not hedonic balance levels, $b = 0.15$, $SE = 0.15$, $t_{(35)} = 1.05$, $p = 0.30$. Likewise, there was evidence that spouses tended to be similar not only with respect to their global ability to accurately identify the emotions portrayed in the movie clips, $b = 0.45$, $SE = 0.23$, $t_{(35)} = 1.96$, $p = 0.06$, but also with respect to their ability to accurately identify discrete emotions, specifically, happiness, $b = 0.42$, $SE = 0.14$, $t_{(35)} = 2.93$, $p < 0.01$, and fear, $b = 0.30$, $SE = 0.12$, $t_{(35)} = 2.47$, $p = 0.02$ (for the intercorrelations among the Study 1 measures, see **Table 3**).

Hypothesis testing

Positive emotions and partner hedonic balance. Taking our cue from previous findings that provision of responsive support to a close partner during a positive event is a core contributor to the recipient's well-being (e.g., Gable et al., 2012), we tested whether accuracy in identifying positive emotions—and, thus, plausibly, superior ability to respond appropriately to circumstances giving rise to such affect—would predict a spouse's self-ratings of hedonic balance (i.e., the affective component of well-being, cf. Diener, 1984). Results of a regression analysis, predicting an actor's hedonic balance from his/her partner's ability to identify happiness, as well as the actor's own proficiency in detecting happiness disconfirmed our hypothesis, since neither predictor was found to exert a statistically significant effect, $b = 0.43$, $SE = 0.28$, $t_{(34)} = 1.57$, $p > 0.12$ (the partner's ability to identify happiness) and $b = 0.06$, $SE = 0.19$, $t_{(34)} = 0.30$, $p = 0.77$ (the actor's ability to identify happiness) (for the full model, see **Table 2**).

Positive emotions and partner life satisfaction. In contrast, results of the analyses involving the cognitive component of well-being (i.e., life satisfaction, Diener, 1984) supported our hypothesis regarding the unique beneficial effect of a partner's proficiency in identifying positive emotions on an actor's well-being. Specifically, results of a regression analysis, predicting an actor's life satisfaction from his/her partner's ability to identify happiness, as well as the actor's own proficiency in detecting happiness revealed a significant effect of the former predictor, $b = 0.40$, $SE = 0.12$, $t_{(34)} = 3.31$, $p < 0.01$, but not the latter, $b = 0.23$, $SE = 0.19$, $t_{(34)} = 1.20$, $p = 0.24$ (for the full model, see **Table 2**). Indeed, further testifying to the specificity of this effect, a subsequent analysis revealed that a partner's proficiency in identifying happiness remained a significant predictor of an actor's satisfaction with life levels, even after accounting for the actor's hedonic balance, $b = 0.31$, $SE = 0.12$, $t_{(3)} = 2.50$, $p = 0.02$ (for the full model, see **Table 2**).

Post-hoc analyses

Negative emotions and partner well-being. Since prior findings suggest that the partner's responsiveness to an actor's negative

Table 2 | Parameter estimates for the HLM analyses predicting an actor's hedonic balance and life satisfaction from his/her partner's proficiency in identifying positive emotions in Study 1.

Fixed effect	Coefficient	*SE*	*t*-value (dfs)
OUTCOME: ACTOR_HEDONIC_BALANCE			
For overall INTERCEPT, β_0	2.71	0.17	16.00 (36)**
For ACTOR_GENDER slope, β_1	0.06	0.15	0.42 (34)
For PARTNER_HAPPINESS_RECOGNITION slope, β_2	0.43	0.27	1.57 (34)
For ACTOR_HAPPINESS_RECOGNITION slope, β_3	0.06	0.19	0.30 (34)
OUTCOME: ACTOR_SATISFACTION_WITH_LIFE			
For overall INTERCEPT, β_0	5.51	0.11	49.47 (36)**
For ACTOR_GENDER slope, β_1	−0.04	0.07	−0.55 (34)
For PARTNER_HAPPINESS_RECOGNITION slope, β_2	0.40	0.12	3.31 (34)**
For ACTOR_HAPPINESS_RECOGNITION slope, β_3	0.23	0.19	1.20 (34)
OUTCOME: ACTOR_SATISFACTION_WITH_LIFE			
For overall INTERCEPT, β_0	5.51	0.10	56.61 (36)**
For ACTOR_GENDER slope, β_1	−0.05	0.07	−0.75 (33)
For PARTNER_HAPPINESS_RECOGNITION slope, β_2	0.31	0.12	2.50 (33)*
For ACTOR_HAPPINESS_RECOGNITION slope, β_3	0.21	0.19	1.15 (33)
For ACTOR_HEDONIC_BALANCE slope, β_4	0.21	0.06	3.77 (33)**

$^*p < 0.05$; $^{**}p < 0.01$.

Table 3 | Intercorrelations among the Study 1 measures.

	1	2	3	4	5	6	7	8	9	10	11	12
1. Spouse 1 happiness recognition	–											
2. Spouse 1 fear recognition	0.33**	–										
3. Spouse 1 sadness recognition	0.24*	0.55**	–									
4. Spouse 1 anger recognition	0.15	0.36**	0.33*	–								
5. Spouse 2 happiness recognition	0.42**	0.32*	0.17	−0.03	–							
6. Spouse 2 fear recognition	0.32*	0.30*	0.15	0.07	0.33**	–						
7. Spouse 2 sadness recognition	0.17	0.15	0.07	0.10	0.24*	0.55**	–					
8. Spouse 2 anger recognition	−0.03	0.07	0.10	0.05	0.15	0.36**	0.33*	–				
9. Spouse 1 SWLS	0.15	0.21**	0.12	0.07	0.26**	0.19	−0.04	−0.06	–			
10. Spouse 1 AWB	0.08	0.22	0.13	0.01	0.18	0.09	−0.02	−0.05	0.36**	–		
11. Spouse 2 SWLS	0.26**	0.19	−0.04	−0.06	0.15	0.21**	0.12	0.07	0.49**	0.12	–	
12. Spouse 2 AWB	0.18	0.09	−0.02	−0.05	0.08	0.22	0.13	0.01	0.12	0.15	0.36**	–

$^{*}p < 0.05$; $^{**}p < 0.01$. $N = 74$ individuals embedded in 37 couples. To obtain standardized coefficients, correlations were computed using standardized variables in a two-level HLM model, which collapsed across all participants (Level-1), but controlled for gender and accounted for the interdependence in the data provided by the two spouses (Level-2: couple level). The coefficients and significance estimates in the table are based on the robust standard error estimates, provided by HLM. SWLS, satisfaction with life. AWB, hedonic balance.

affective states may have some impact on the latter's well-being (Study 2, Maisel and Gable, 2009; Gable et al., 2012), we explored whether the partner's accuracy in reading negative emotions would predict an actor's subjective well-being levels. Results of this set of analyses provided no support for this conjecture with regards to either the actor's satisfaction with life, $b = 0.13$, $SE = 0.24$, $t_{(34)} = 0.55$, $p = 0.59$, or his/her hedonic balance, $b = -0.02$, $SE = 0.28$, $t_{(34)} = -0.07$, $p = 0.95$. Likewise, there was no evidence that an actor's greater accuracy in reading negative emotions would be a significant predictor of either his/her satisfaction with life, $b = 0.31$, $SE = 0.16$, $t_{(34)} = 1.91$, $p = 0.06$, or hedonic balance, $b = 0.39$, $SE = 0.38$, $t_{(34)} = 1.03$, $p = 0.31$. Because prior research suggested that expertise in recognizing distinct negative emotions may differentially impact social interactions (e.g., Niedenthal and Brauer, 2012), we investigated whether expertise in decoding fear vs. anger vs. sadness would be distinctly associated with partner well-being. Results of these analyses revealed only a significant link between an actor's proficiency in reading fear and his/her life satisfaction levels, $b = 0.31$, $SE = 0.12$, $t_{(34)} = 2.66$, $p = 0.01$ (all other ps > 0.11) (for standardized coefficients, see **Table 4**).

Table 4 | Mean values of happiness and negative emotion recognition accuracy, as well as negative emotion leaning, among spouses of PD patients vs. controls as a function of years from PD symptom onset.

	Early PD spouses symptom onset < 5 years	Late PD spouses symptom onset > 11 years	Controls
1. Happiness recognition accuracy	0.60	0.26	0.36
2. Negative emotion recognition accuracy	0.32	0.78	0.37
3. Negative emotion leaning	−0.73	−0.19	0.00

For Happiness and Negative Emotion Recognition Accuracy, respectively, higher coefficients indicate greater accuracy. For Negative Emotion Leaning, lower (i.e., more negative) values indicate greater under-estimation of the amount of negative emotion. The early and late PD groups comprise 4 couples each (8 in total), in which the number of years from PD symptom onset is 1 SD below and above, respectively, the PD sample's average number of years from PD onset.

Gender differences in the reported effects. Finally, we verified that there were no statistically significant gender differences in the relationship between an actor's proficiency in identifying positive vs. (global/discrete) negative emotions and his/her partner's either satisfaction with life (all ps > 0.18) or hedonic balance (all ps > 0.05).

In sum, Study 1 provided partial support to our hypothesis that greater expertise in identifying positive emotions would be linked to greater spousal well-being, conceivably because such expertise may render one better skilled at reading his/her spouse's emotional reactions during a positive event and, thus, be in a better position to respond in a manner that would foster the spouse's well-being (cf. Gable et al., 2012). Specifically, we found that a partner's proficiency in identifying positive emotions exhibited a significant association with an actor's life satisfaction, but not hedonic balance. Interestingly, this effect points to a potential interpersonal mechanism underlying the observed spousal similarity in life satisfaction (for similar findings, see Bookwala and Schulz, 1996; Schimmack and Lucas, 2010), since spouses were alike not only with respect to their cognitive well-being levels, but also with respect to their ability to identify positive emotions. Finally, Study 1 also revealed a potential intra-individual mechanism supporting spousal similarity on life satisfaction, since it provided evidence of spousal resemblance on fear recognition ability, which was, in turn, a significant intrapersonal predictor of life satisfaction. We will elaborate on the implications of these findings in the General Discussion.

STUDY 2

The purpose of Study 2 was to investigate whether under circumstances that render negative emotions particularly salient and informative, such as spousal disability (Monin and Schulz, 2009; Monin et al., 2009), expertise in decoding negative (rather than positive) emotions would be a stronger predictor of spousal well-being. Moreover, we sought to replicate the Study 1 findings that it is an actor's cognitive, rather than affective, well-being levels that are most susceptible to the influence of spousal proficiency in (here, negative) emotion processing.

In a secondary vein, we also examined whether beyond any adverse effects of PD on the patients' ability to decode postural emotional cues, we would also detect any differences in emotion recognition performance between the patients' spouses and the controls, presumably reflective of the former's adaptations to living with PD. Specifically, we investigated whether in order to compensate for the PD patients' presumed deficits in producing facial expressions of positive emotions (cf. Pitcairn et al., 1990), their spouses would be particularly attuned and, thus, demonstrate increased accuracy in decoding expressions of happiness. Although it is plausible that such an adaptation effect (if it exists) may generalize across modalities, we reasoned that we may be particularly likely to detect it in a modality that is presumably less affected by PD (i.e., by using postural, rather than facial, cues of happiness). Finally, based on the assumption that proficiency in recognizing negative emotions may be a critical asset for care givers (i.e., to minimize care giver stress, cf. Monin et al., 2009), we examined whether relative to controls, PD spouses would also show increased expertise in reading negative emotions, specifically those indicative of vulnerability, such as fear and sadness. In all the reported analyses, the Study 1 participants served as the control group [t-test analyses confirmed that there were no significant differences in either age ($p > 0.10$) or marriage length ($p > 0.28$) between the Study 1 and 2 samples].

METHODS

Participants and procedure

Eighteen PD patients and their spouses completed the same tasks and measures as the Study 1 participants. The patients were recruited through local newspaper advertisements or through their neurologist, who was affiliated with a teaching hospital associated with the University of Toronto. According to the patients' medical records (released with their consent by their neurologist following the patients' laboratory visit), they were all nondemented and not clinically depressed at the time of testing. Prior to their laboratory visit, the patients' spouses underwent the same phone screening interview as the Study 1 participants, in which they verified that they themselves had no known neurological or cognitive impairments. The patients [6 women, 12 men; mean age = 68.50 years ($SD = 11.67$)] averaged 2.56 (range 1.0–3.0) on the modified Hoehn and Yahr (1967) disability scale. On average, they had received the PD diagnosis 8.06 years ($SD = 3.89$ years; range 2–15 years) prior. Excepting one who developed intolerance to L-dopa six months prior, all were taking dopamine precursor treatments (i.e., L-dopa) to alleviate Parkinsonian symptoms. All patients were tested while on normal dosing schedules. They were tested late morning, approximately 3 h after taking their medication. The spouses' average age was 67.28 years ($SD = 10.23$). The couples had been married between 18 and 53 years ($M = 39.28$, $SD = 11.67$). All were native English speakers or had lived in Canada and used English as their primary language for at least 30 years (for the demographic information summary, see **Table 1**). Informed consent was obtained from both PD patients and their spouses in accordance with the ethical guidelines of the Research Ethics Boards at the University of Toronto and the University Health Network.

RESULTS

Preliminary analyses confirmed that all the reported results were unchanged if the patient who became intolerant to L-dopa, and who was thus medication-free during the study period, was kept or eliminated from the sample. Consequently, we opted to keep this patient's data in the analyses. Two PD patients failed to fill out the positive/negative affect scale, whereas one PD spouse failed to complete the satisfaction with life scale. Consequently, all the reported well-being findings are based on data from 18 PD patients and 17 PD spouses (satisfaction with life), as well as 16 PD patients and 18 PD spouses (hedonic balance).

Preliminary analyses

Preliminary correlational analyses revealed no statistically significant association between the patients' and their spouses' satisfaction with life, $r_{(16)} = 0.39$, $p = 0.12$, hedonic balance, $r_{(15)} = -0.32$, $p = 0.24$, proficiency in recognizing positive, $r_{(16)} = 0.15$, $p = 0.56$, or negative, $r_{(16)} = -0.25$, $p = 0.33$, emotions.

Hypothesis testing

To test our hypotheses, we used the same two-level HLM model as in Study 1 and ran two sets of analyses, comparing the healthy controls to the PD patients and the patients' spouses, respectively. As in Study 1, we controlled for gender (coded as −1 for males and 1 for females) in all the reported analyses. For the comparisons involving the PD patients and the controls, two predictor variables were used: patient status, coded 0 for controls and 1 for PD patients and years from PD symptom onset, which had a value of 0 for controls and a number corresponding to the years from the symptom onset for patients. Likewise, for the comparisons involving the spouses of PD patients and controls, two predictors were employed: patient spouse status, coded 0 for controls and 1 for the spouses of the PD patients and years from PD symptom onset, which had a value of 0 for controls and a number corresponding to the years from the symptom onset for the patients' spouses. As in Study 1, we report the robust standard error estimates for all the analyses conducted.

Well-being. As expected, PD patients exhibited significantly lower satisfaction with life levels compared to their age-matched controls, $b = -2.40$, $SE = 0.48$, $t_{(34)} = -4.97$, $p < 0.001$, although the discrepancy between the two groups diminished with more years from PD symptom onset, $b = 0.14$, $SE = 0.06$, $t_{(34)} = 2.46$, $p = 0.02$. Hedonic balance was also poorer among

PD patients, relative to their age-matched controls, $b = -2.11$, $SE = 0.93$, $t_{(34)} = -2.26$, $p = 0.03$, and this effect was impervious to the number of years from PD symptom onset, $b = 0.16$, $SE = 0.14$, $t_{(34)} = 1.13$, $p = 0.27$. In contrast, although spouses of PD patients tended to experience lower satisfaction with life as well, this effect failed to reach conventional levels of statistical significance, $b = -0.97$, $SE = 0.50$, $t_{(34)} = -1.96$, $p = 0.06$. Of note, there was no evidence that spouses of PD patients would exhibit poorer affective balance relative to their age-matched controls, $b = -1.08$, $SE = 0.93$, $t_{(34)} = -1.16$, $p = 0.25$, or that years from PD symptom onset would lead to any significant differences between the two groups in either satisfaction with life, $b = 0.06$, $SE = 0.07$, $t_{(34)} = 0.87$, $p = 0.39$, or hedonic balance, $b = 0.07$, $SE = 0.12$, $t_{(34)} = 0.60$, $p = 0.55$.

Emotion recognition.

PD patients vs. controls.

Positive emotions: We found no evidence that either patient status, $b = -0.09$, $SE = 0.21$, $t_{(34)} = -0.44$, $p = 0.66$, or years from PD symptom onset, $b = 0.00$, $SE = 0.02$, $t_{(34)} = 0.14$, $p = 0.89$, would impact significantly accuracy in identifying positive emotions.

Negative emotions: Likewise, there was no evidence that either patient status, $b = 0.16$, $SE = 0.18$, $t_{(34)} = 0.90$, $p = 0.37$, or years from PD symptom onset, $b = -0.02$, $SE = 0.01$, $t_{(34)} = 1.05$, $p = 0.30$, would affect significantly accuracy in identifying negative emotions. Subsequent analyses focused on accuracy in identifying discrete negative emotions yielded similar, non-significant results (all ps > 0.33).

Spouses of PD patients vs. controls.

Positive emotions: Results of this analysis revealed two significant main effects: Spouses of PD patients were more accurate than controls in identifying happiness, $b = 0.58$, $SE = 0.17$, $t_{(34)} = 3.46$, $p < 0.001$, but their advantage diminished with more years from PD symptom onset, $b = -0.05$, $SE = 0.02$, $t_{(34)} = 2.60$, $p = 0.01$ (see **Table 4**).

Negative emotions: Interestingly, we found evidence that spouses of PD patients tended to be somewhat less accurate than controls in identifying negative emotions, $b = -0.51$, $SE = 0.25$, $t_{(34)} = 2.05$, $p = 0.05$, although their "deficit" was reversed with more years from PD symptom onset, $b = 0.06$, $SE = 0.02$, $t_{(34)} = 2.45$, $p = 0.02$ (see **Table 4**). Follow-up analyses revealed that these effects were due to the PD spouses' tendency to underestimate the intensity of negative emotions (relative to controls), $b = -0.64$, $SE = 0.28$, $t_{(34)} = -2.31$, $p = 0.03$, a tendency that became weaker with longer years from PD symptom onset, $b = 0.07$, $SE = 0.03$, $t_{(34)} = 2.34$, $p = 0.03$ (see **Table 4**). Nevertheless, there was no evidence that the relatively poorer identification of negative emotions was specific to any of the discrete negative emotions under scrutiny (all ps > 0.09).

Emotion recognition and partner well-being. Finally, we tested our hypothesis that among PD patients and their spouses, it would be expertise in decoding negative, rather than positive, emotions that would be a stronger predictor of partner well-being. To this end, we specified a two-level HLM model, with years from PD symptom onset as the level-2 (i.e., couple-level) variable, gender (coded as −1 for males and 1 for females), patient status (coded as −1 for PD patients' spouses and 1 for PD patients), and accuracy in identifying positive vs. negative emotions as the level-1 variables. Both level-1 and -2 continuous predictor variables were mean-centered. In all the reported analyses, we included both actor and partner variables for all the predictors (all the relevant results are unchanged if only the partner variables are introduced as predictors). Because of the small sample size (i.e., 35 and 34 individuals, respectively, embedded in 18 couples for the life satisfaction and hedonic balance analyses, respectively), we report the non-robust standard error regression coefficient estimates, which are preferred in this case for interpretational purposes (all the reported effects remain significant if using the robust standard error estimates).

Hedonic balance. Similar to Study 1, we found no evidence that an actor's proficiency in identifying positive or negative emotions would be a significant predictor of either his/her own or his/her partner's hedonic balance (all ps > 0.15).

Satisfaction with life. Results of two separate sets of analyses revealed that among PD patients and their spouses, greater proficiency in identifying positive emotions did not exert a significant effect on spousal satisfaction with life, $b = -0.30$, $SE = 0.51$, $t_{(9)} = -0.57$, $p = 0.58$, even when accounting for years from PD onset, $b = -0.23$, $SE = 0.14$, $t_{(9)} = -1.65$, $p = 0.13$. Instead, with more years from PD symptom onset, it was proficiency in identifying negative emotions that became an increasingly stronger predictor of spousal satisfaction with life, $b = 0.25$, $SE = 0.11$, $t_{(9)} = 2.22$, $p = 0.05$ (for the full model, see **Table 5**). Follow-up analyses focused on discrete negative emotions revealed that it was greater expertise in identifying sadness that constituted an increasingly reliable predictor of greater spousal life satisfaction with more years from PD symptom onset, $b = 0.22$, $SE = 0.06$, $t_{(9)} = 3.45$, $p < 0.01$ (for the full model, see **Table 6**). Results of similar analyses involving expertise in identifying fear or anger failed to reach traditional levels of statistical significance (all ps > 0.21). Likewise, there was no evidence that an actor's proficiency in identifying either positive or negative emotions would be a significant predictor of his/her own life satisfaction levels (all ps > 0.24).

Patient-spouse differences. Finally, we tested whether expertise in decoding positive vs. negative emotions would exert differential effects on spousal life satisfaction or hedonic balance, as a function of whether the spouse is the PD patient or not. To this end, we introduced the interaction between patient status and positive vs. negative emotion recognition scores as a level-1 predictor of partner well-being. Results of this set of analyses provided no support to the hypothesis that partner expertise in decoding positive vs. negative emotions would impact differentially either the life satisfaction or hedonic balance of the PD patients vs. that of their spouses (all ps > 0.37).

Table 5 | Parameter estimates for the HLM analyses predicting an actor's hedonic balance and life satisfaction from his/her partner's proficiency in identifying negative emotions in Study 2.

Fixed effect	Coefficient	*SE*	*t*-value (dfs)
OUTCOME: ACTOR_SATISFACTION_WITH_LIFE			
For overall INTERCEPT, β_0			
Intercept2, B_{00}	4.66	0.19	24.87(16)**
PD_Symptom_Onset, B_{01}	0.09	0.05	1.73(16)
For ACTOR_GENDER slope, β_1			
Intercept2, B_{10}	−0.33	0.12	−2.78(9)*
PD_Symptom_Onset, B_{11}	−0.05	0.03	−1.85(9)
For ACTOR_PATIENT_STATUS slope, β_2			
Intercept2, B_{20}	−0.48	0.13	−3.78(9)**
PD_Symptom_Onset, B_{21}	0.09	0.03	3.09(9)*
For PARTNER_NEGATIVE_EMOTIONS_RECOGNITION slope, β_3			
Intercept2, B_{30}	0.34	0.39	0.89(9)
PD_Symptom_Onset, B_{31}	0.25	0.11	2.22(9)*
For ACTOR__NEGATIVE_EMOTIONS_RECOGNITION slope, β4			
Intercept2, B_{40}	0.48	0.39	1.23(9)
PD_Symptom_Onset, B_{41}	−0.03	0.11	−0.31(9)

$^*p < 0.05$; $^{**}p < 0.01$. The estimates are the non-robust error estimates (since they are preferred for interpretative purposes).

Table 6 | Parameter estimates for the HLM analyses predicting an actor's hedonic balance and life satisfaction from his/her partner's proficiency in identifying sadness in Study 2.

Fixed effect	Coefficient	*SE*	*t*-value (dfs)
OUTCOME: ACTOR_SATISFACTION_WITH_LIFE			
For overall INTERCEPT, β_0			
Intercept2, B_{00}	4.61	0.17	27.71(16)**
PD_Symptom_Onset, B_{01}	0.08	0.05	1.68(16)
For ACTOR_GENDER slope, β_1			
Intercept2, B_{10}	−0.21	0.09	−2.38(9)*
PD_Symptom_Onset, B_{11}	−0.07	0.02	−3.27(9)**
For ACTOR_PATIENT_STATUS slope, β_2			
Intercept2, B_{20}	−0.41	0.09	−4.37(9)**
PD_Symptom_Onset, B_{21}	0.08	0.02	3.34(9)**
For PARTNER_SADNESS_RECOGNITION slope, β_3			
Intercept2, B_{30}	0.44	0.23	1.95(9)
PD_Symptom_Onset, B_{31}	0.22	0.06	3.45(9)**
For ACTOR_SADNESS_PERCEPTIONRECOGNITION slope, β4			
Intercept2, B_{40}	0.41	0.23	1.82(9)
PD_Symptom_Onset, B_{41}	0.04	0.06	0.65(9)

$^*p < 0.05$; $^{**}p < 0.01$. The estimates are the non-robust error estimates (since they are preferred for interpretative purposes).

GENERAL DISCUSSION

The present research investigated the link between expertise in reading postural cues of positive vs. negative emotions and spousal well-being among neurologically intact elderly couples (Study 1) and a sample of PD patients and their spouses (Study 2). Study 1 provided evidence that among healthy controls, greater expertise in identifying positive, rather than negative, emotions is linked to greater spousal cognitive, but not affective, well-being. Despite its specificity (see discussion below), such an association is broadly in line with our hypothesis that greater expertise in decoding positive emotional cues renders one better skilled at reading his/her spouse's emotional reactions during positive events and, thus, better able to provide adequate support to the spouse, which, in turn, is a well-documented contributor to spousal well-being (cf. Gable et al., 2012).

Study 2 extended the Study 1 findings regarding the unique link between spousal proficiency in emotion processing and an actor's cognitive, rather than affective, well-being levels. Specifically, in line with our hypotheses, Study 2 documented that under conditions that may render a close partner's negative emotions particularly informative for adjusting behavior to protect the dyadic environment, it is proficiency in reading negative, but not positive, emotions that predicts greater spousal life satisfaction. Thus, with more years from PD symptom onset, and, thus, conceivably, greater patient disability and care giver burden, it was proficiency in recognizing negative emotions, most importantly, sadness, that predicted greater spousal life satisfaction among PD patients and their partners. Moreover, although we did not detect any deficits in deciphering postural emotional cues among PD patients, we found suggestive evidence of PD-induced adaptation effects among the patients' spouses. Specifically, complementing earlier findings on the PD patients' deficits in producing facial expressions of positive emotions (Pitcairn et al., 1990; Simons et al., 2004), we found evidence of greater proficiency in decoding whole-body cues of happiness among PD spouses, relative to controls. Given the significance of positive emotion recognition for spousal well-being, documented in Study 1, it seems plausible that the PD spouses' advantage in identifying happiness would reflect a compensation mechanism, whose function would be to preserve the dyadic homeostasis. Further evidence suggestive of adaptation effects among PD spouses is provided by our findings that although in earlier stages, PD spouses may be somewhat less skilled than controls at negative emotion recognition, this deficit reverses with more years from PD symptom onset. Such an effect is indeed noteworthy, since among PD patients and their spouses, proficiency in identifying negative emotions becomes an increasingly reliable predictor of spousal satisfaction with life with more years from symptom onset.

Our present findings suggest several venues for future research on affective proficiency and well-being among married couples. First, the unique role of superior positive emotion recognition in spousal life satisfaction needs to be probed in future studies. For example, a spouse who is better skilled at decoding positive emotions may provide more effective support during propitious times and thus foster an actor's life satisfaction because s/he is better able to facilitate meaning-making processes that integrate an isolated positive event in the context of an actor's broader life goals and strivings. Complementarily, any beneficial effects of spousal positive emotion expertise on an actor's hedonic balance may be only indirect, mediated by changes in the actor's life satisfaction. To the best of our knowledge, there have been no investigations of the unique effects of effective social support on spousal affective vs. cognitive well-being. Consequently, future studies, assessing individual differences not only in well-being and positive emotion processing, but also in reappraisal and meaning making within a dyadic context, are needed to test the viability of our proposed hypotheses.

Second, the mechanisms underlying our observed association between performance on a point light walker task and spousal life satisfaction deserve further investigation. Prior research suggested that individual differences in decoding postural emotional cues are predictive of broader sociocognitive functioning (e.g., false belief reasoning, Phillips et al., 2011). Consequently, the question arises whether the observed link between spousal well-being and performance on the point light walker task is merely due to the fact that the latter is a good indicator of social cue understanding and utilization or whether indeed the ability to read whole-body (rather than facial or auditory, for example) emotional cues is particularly relevant to interpersonal functioning. With respect to the latter hypothesis, it seems indeed plausible that postural affective cues may be more informative to social exchanges than facial cues, because the latter may be easier to control and thus be used to conceal one's inner experience from others. Future studies using a comprehensive sociocognitive assessment package and individual differences or situational manipulations of emotional expression are needed to shed light on this issue.

Third, future studies should examine the implications of our findings that spouses are assorted not only on life satisfaction (cf. Bookwala and Schulz, 1996; Schimmack and Lucas, 2010), but also on traits predictive of life satisfaction, either on the interpersonal (i.e., happiness recognition) or intrapersonal (i.e., fear recognition) level (cf. Study 1). Indeed, in Study 1, we documented the association between expertise in identifying positive emotions and spousal life satisfaction, whereas others provided evidence that fear recognition plays an important role in determining prosocial behavior (for a review, see Niedenthal and Brauer, 2012). It thus seems plausible that the previously documented spousal matching on life satisfaction may be (partly) due to spousal assortment on dispositions that predict behaviors conducive to close others' happiness (i.e., proficiency in positive emotion recognition) or are linked to more fulfilling interpersonal exchanges (i.e., proficiency in fear recognition) and, thus, indirectly, contribute to one's own satisfaction with life. Future studies, examining the early acquaintanceship stages of potential romantic partners, may be required to test this hypothesis.

Fourth, additional research is needed to elucidate the underlying mechanisms and functionality of the PD spouses' proficiency in reading postural cues of positive emotions, as documented in Study 2 of the present manuscript. One venue for future research would be to shed light on whether PD spouses exhibit proficiency in decoding positive emotions across all modalities, or whether their advantage is more modality-specific (i.e., only detectable for non-facial forms of positive emotion expression). Such a distinction is important to be made, since it may also elucidate the pattern of expressive deficits associated for PD. Indeed, support for a more modality-specific (rather than modality-general) advantage in decoding positive affective cues among the PD spouses may suggest that, at least in the earlier stages of the disease, PD patients' ability to express emotions through non-facial cues may be relatively less affected. Nevertheless, future studies are needed to test these hypotheses by incorporating more modality-diverse emotional stimuli and by assessing PD patients' ability to produce and their spouses' proficiency in decoding positive emotional cues across multiple modalities. Likewise, future research should examine the mechanisms underlying the PD spouses' decreasing accuracy in decoding positive emotional cues and increasing accuracy in identifying negative emotional cues with more years from PD symptom onset. For example, one possibility may be that these effects are due to the decreased motivational salience of positive and increased relevance of negative emotional cues (cf. Study 2's link between spousal life satisfaction and proficiency in identifying negative emotions). Alternatively or additionally, in line with the documented PD-related impairments in producing positive emotional cues (Pitcairn et al., 1990; Simons et al., 2004), these effects may arise due to the PD spouses' diminishing exposure to positive emotional cues and relatively heightened exposure to negative emotional cues with more years from PD symptom onset.

Finally, the link between positive vs. negative emotion proficiency and spousal well-being deserves further investigation in more demographically diverse samples. Specifically, it is worth pointing out that our neurologically intact sample was exclusively comprised of older adults, who have been previously shown to exhibit greater sensitivity to positive, and lower sensitivity to negative, emotional stimuli, relative to younger adults (for a review, see Mather and Carstensen, 2005). Consequently, it may be the case that the null effect of proficiency in negative emotion recognition on spousal well-being may be partly due to older adults' superior ability to fend off negative emotions on their own, thereby minimizing the impact of any spousal aide, and/or their reduced tendency to allow negative emotions, evoked by external stressors, to permeate their marital interactions (for evidence on more positive marital interactions in older adulthood, see Levenson et al., 1994). In contrast, among younger adults, who presumably exhibit higher sensitivity to negative emotional stimuli (Mather and Carstensen, 2005), significantly greater interpersonal costs may be incurred by poorer negative emotion recognition and, thus, arguably, poorer ability to provide adequate support to a close partner during inauspicious times. Thus, although extant research suggests that social support provision to a close partner during propitious, rather than adverse, periods is a stronger contributor to the latter's well-being (Study 2, Gable et al., 2012), reduced ability to identify negative emotions and, consequently, respond appropriately to a partner during negative events may still result in significant hedonic damage, among younger, rather than elderly, social support recipients.

LIMITATIONS

Inevitably, our present research has a few limitations. First, our correlational design precludes any conclusions regarding the causal direction of the link between proficiency in identifying positive vs. negative emotions and spousal life satisfaction. For example, in Study 1, it is plausible that individuals with higher, relative to lower, life satisfaction levels may express positive emotions more frequently. Thus, their spouses may have greater exposure to positive emotional cues and, consequently, gain greater expertise in decoding them. Nevertheless, if that were to be the case, then we would expect a stronger relationship between an actor's proficiency in decoding happiness and spousal hedonic balance, rather than life satisfaction. Importantly, this is not what we found in Study 1, where, in fact, the association between a partner's hedonic balance and an actor's ability to read happiness failed to reach conventional levels of statistical significance. Moreover, if frequency of exposure to a spouse's positive/negative emotional cues accounts for the link between an actor's proficiency in decoding emotional cues and spousal life satisfaction, then the Study 2 findings would suggest that among PD patients and their spouses, higher life satisfaction individuals express negative emotions more frequently, thereby fostering their spouses' expertise in deciphering them. Although we argued that expression of negative emotions is informative within a care giving context (cf. Monin and Schulz, 2009; Monin et al., 2009), we would find it difficult to contend that more frequent expression of such emotions is the hallmark of greater happiness among PD patients and their spouses. Nevertheless, future longitudinal studies, assessing the emotion expressive habits of both spouses, as well as their emotion expertise and well-being, are needed to elucidate the causal direction of the link between emotion recognition expertise and spousal well-being.

Second, we did not find any evidence of deficits in reading postural emotional cues among PD patients. To the best of our knowledge, there are no reports of PD-induced impairments in decoding whole-body affective cues in the literature, which renders our present null findings rather uncontroversial. Moreover, even deficits in facial emotion recognition have not been consistently documented among PD patients. Indeed, studies using subtler facial emotional cues and more advanced PD patients, tested on regular dosing schedules—as in our research—either failed to document any impairments (Adolphs et al., 1998; Sprengelmeyer et al., 2003) or documented impairments in disgust recognition (Suzuki et al., 2006; Assogna et al., 2010), an emotion not assessed in our study. Future studies with larger and more diverse PD samples, tested both on and off medication, may be required to elucidate the nature of any potential deficits in deciphering postural emotional cues among PD patients.

Third, although we posited that emotion recognition abilities are crucial to an individual's capacity to provide responsive support to a spouse, our research did not include any social support measures. Future studies, incorporating indicators of both enacted and perceived support during positive and negative events, are needed to characterize the hypothesized link between proficiency in identifying emotional cues and responsive support provision in close relationships.

Fourth, our research focused on a patient population exhibiting irreversibly increasing levels of disability. Future studies, examining care recipients with reversible or stable impairments, are warranted to shed light on any differential effects of spousal expertise in positive vs. negative emotion recognition as a function of disability type.

Fifth, in our present research, we used a rather narrowly defined standard of emotion recognition accuracy, specifically, the mean ratings provided by the neurologically intact sample in response to the point light walker clips. We regarded our operationalization of accuracy as justifiable because, beyond any idiosyncratic effects, a significant predictor of whether an actor would successfully decode his/her spouse's emotions is, arguably, his/her adherence to the affective vocabulary of those most demographically similar to his/her spouse. Nevertheless, future studies, using a broader affective vocabulary, based on the judgments of more demographically diverse samples, are certainly warranted to elucidate the nature of the association between an actor's emotion recognition proficiency and his/her spouse's well-being.

Finally, although the dynamic whole-body emotional stimuli, used in the present research, are more naturalistic than the static facial emotional stimuli, often employed in emotion recognition studies, they still fall short of the affective richness that typifies numerous interpersonal exchanges. For example, in each point light walker clip, the actor was requested to portray a specific emotion (see Heberlein and Saxe, 2005; Atkinson et al., 2007). Such affective "single-mindedness" is probably seldom characteristic of social actor's experiences in real life. Consequently, future studies are needed to elucidate the effect of proficiency in decoding emotions from realistic social interactions on spousal and dyadic well-being.

In conclusion, our present research suggests that expertise in decoding emotional cues may have wide-ranging implications for dyadic well-being. Moreover, our results imply that positive vs. negative emotions may play distinct roles in close relationship dynamics as a function of the spouses' neurological status and disability trajectory. Research is now needed to shed light on the mechanisms underlying the observed links between emotion recognition proficiency and close partner well-being across the lifespan of an intimate partnership.

ACKNOWLEDGMENTS

This research was partially supported by a Canadian Institutes of Health Research doctoral fellowship awarded to Raluca Petrican.

REFERENCES

Adolphs, R., Schul, R., and Tranel, D. (1998). Intact recognition of facial emotion in Parkinson's disease. *Neuropsychology* 12, 253–258. doi: 10.1037/0894-4105.12.2.253

Ariatti, A., Benuzzi, F., and Nichelli, P. (2008). Recognition of emotions from visual and prosodic cues in Parkinson's disease. *Neurol. Sci.* 29, 219–227. doi: 10.1007/s10072-008-0971-9

Assogna, F., Pontieri, F. E., Cravello, L., Peppe, A., Pierantozzi, M. A., Stefani, A., et al. (2010). Intensity-dependent facial emotion recognition and cognitive functions in Parkinson's disease. *J. Int. Neuropsychol. Soc.* 16, 867–876. doi: 10.1017/S1355617710000755

Atkinson, A. P., Heberlein, A. S., and Adolphs, R. (2007). Spared ability to recognise fear from static and moving whole-body cues following bilateral amygdala damage. *Neuropsychologia* 45, 2772–2782. doi: 10.1016/j.neuropsychologia.2007.04.019

Baker, B., Paquette, M., Szalai, J., Driver, H., Perger, T., Helmers, K., et al. (2000). The influence of marital adjustment on 3-year left ventricular mass and ambulatory blood pressure in mild hypertension. *Arch. Int. Med.* 160, 3453–3458. doi: 10.1001/archinte.160.22.3453

Beach, S. R., and O'Leary, K. D. (1993). Marital discord and dysphoria: for whom does the marital relationship predict depressive symptomatology? *J. Soc. Pers. Relat.* 10, 405–420.

Berscheid, E., and Reis, H. T. (1998). "Interpersonal attraction and close relationships," in *Handbook of Social Psychology, 4th Edn.*, eds D. T. Gilbert, S. T. Fiske, and G. Lindzey (New York, NY: Random House), 193–281.

Bolger, N., Zuckerman, A., and Kessler, R. C. (2000). Invisible support and adjustment to stress. *J. Pers. Soc. Psychol.* 79, 953–961. doi: 10.1037/0022-3514.79.6.953

Bookwala, J., and Schulz, R. (1996). Spousal similarity in subjective well-being: the cardiovascular health study. *Psychol. Aging* 11, 582–590. doi: 10.1037/0882-7974.11.4.582

Brosgole, L., and Weisman, J. (1995). Mood recognition across the ages. *Int. J. Neurosci.* 82, 169–189. doi: 10.3109/00207459508999800

Brown, P. C., and Smith, T. W. (1992). Social influence, marriage, and the heart: cardiovascular consequences of interpersonal control in husbands and wives. *Health Psychol.* 11, 88–96. doi: 10.1037/0278-6133.11.2.88

Brown, P. C., Smith, T. W., and Benjamin, L. S. (1998). Perceptions of spouse dominance predict blood pressure reactivity during marital interactions. *Ann. Behav. Med.* 20, 294–301. doi: 10.1007/BF02886378

Buck, R., and Duffy, R. J. (1980). Nonverbal communication of affect in brain-damaged patients. *Cortex* 16, 351–362. doi: 10.1016/S0010-9452(80)80037-2

Buxton, S. L., MacDonald, L., and Tippett, L. J. (2013). Impaired recognition of prosody and subtle emotional facial expressions in Parkinson's Disease. *Behav. Neurosci.* 127, 193–203. doi: 10.1037/a0032013

Calder, A. J., Keane, J., Manly, T., Sprengelmeyer, R., Scott, S., Nimmo-Smith, I., et al. (2003). Facial expression recognition across the adult life span. *Neuropsychologia* 41, 195–202. doi: 10.1016/S0028-3932(02)00149-5

Campbell, L., and Kashy, D. A. (2002). Estimating actor, partner, and interaction effects for dyadic data using PROC MIXED and HLM: a guided tour. *Pers. Relat.* 9, 327–342. doi: 10.1111/1475-6811.00023

Carstensen, L. L. (1992). Social and emotional patterns in adulthood: support for socioemotional selectivity theory. *Psychol. Aging* 7, 331–338. doi: 10.1037/0882-7974.7.3.331

Clark, U. S., Neargarder, S., and Cronin-Golomb, A. (2008). Specific impairments in the recognition of emotional facial expressions in Parkinson's disease. *Neuropsychologia* 46, 2300–2309. doi: 10.1016/j.neuropsychologia.2008.03.014

Cohen, S. (1988). Psychosocial models of the role of social support in the etiology of physical disease. *Health Psychol.* 7, 269–297. doi: 10.1037/0278-6133.7.3.269

Cohen, S., and Wills, T. A. (1985). Stress, social support, and the buffering hypothesis. *Psychol. Bull.* 98, 310–357. doi: 10.1037/0033-2909.98.2.310

Collins, N. L., Dunkel-Schetter, C., Lobel, M., and Scrimshaw, S. C. (1993). Social support in pregnancy: psychosocial correlates of birth outcomes and postpartum depression. *J. Pers. Soc. Psychol.* 65, 1243–1258. doi: 10.1037/0022-3514.65.6.1243

Dara, C., Monetta, L., and Pell, M. D. (2008). Vocal emotion processing in Parkinson's disease: reduced sensitivity to negative emotions. *Brain Res.* 1188, 100–111. doi: 10.1016/j.brainres.2007.10.034

Davila, J., Bradbury, T. N., Cohan, C. L., and Tochluk, S. (1997). Marital functioning and depressive symptoms: evidence for a stress generation model. *J. Pers. Soc. Psychol.* 73, 849–861. doi: 10.1037/0022-3514.73.4.849

Diener, E. (1984). Subjective well-being. *Psychol. Bull.* 95, 542–575. doi: 10.1037/0033-2909.95.3.542

Diener, E., and Biswas-Diener, R. (2008). *Happiness: Unlocking the Mysteries of Psychological Wealth.* Malden, MA: Blackwell Publishing. doi: 10.1002/9781444305159

Diener, E., Emmons, R. A., Larsen, R. J., and Griffin, S. (1985). The satisfaction with life scale. *J. Pers. Assess.* 49, 71–75. doi: 10.1207/s15327752jpa4901_13

Diener, E., and Seligman, M. E. P. (2002). Very happy people. *Psychol. Sci.* 13, 81–84. doi: 10.1111/1467-9280.00415

Ditzen, B., Hoppmann, C., and Klumb, P. (2008). Positive couple interactions and daily cortisol: on the stress-protecting role of intimacy. *Psychosom. Med.* 70, 883–889. doi: 10.1097/PSY.0b013e318185c4fc

Dujardin, K., Blairy, S., Defebvre, L., Duhem, S., Noel, Y., Hess, U., et al. (2004). Deficits in decoding emotional facial expressions in Parkinson's disease. *Neuropsychologia* 42, 239–250. doi: 10.1016/S0028-3932(03)00154-4

Eaker, E. D., Sullivan, L. M., Kelly-Hayes, M., D'Agostino, R. B., and Benjamin, E. J. (2007). Marital status, marital strain, and risk of coronary heart disease or total mortality: the Framingham offspring study. *Psychosom. Med.* 69, 509–513. doi: 10.1097/PSY.0b013e3180f62357

Ellgring, H., Seiler, S., Perleth, B., Frings, W., Gasser, T., and Oertel, W. (1993). Psychosocial aspects of Parkinson's disease. *Neurology* 43 (Suppl. 6), S41–S44.

Ewart, C. K., Taylor, C. B., Kraemer, H. C., and Agras, W. S. (1991). High blood pressure and marital discord: not being nasty matters more than being nice. *Health Psychol.* 10, 155–163. doi: 10.1037/0278-6133.10.3.155

Ferguson, L. W., Rajput, M. L., Muhajarine, N., Shah, S. M., and Rajput, A. (2008). Clinical features at first visit and rapid disease progression in Parkinson's disease. *Parkinsonism Relat. Disord.* 14, 431–435. doi: 10.1016/j.parkreldis.2007.10.012

Gable, S. L., Gonzaga, G., and Strachman, A. (2006). Will you be there for me when things go right? Supportive responses to positive event disclosures. *J. Pers. Soc. Psychol.* 91, 904–917. doi: 10.1037/0022-3514.91.5.904

Gable, S. L., Gosnell, C. L., Maisel, N. C., and Strachman, A. (2012). Safely testing the alarm: close others' responses to personal positive events. *J. Pers. Soc. Psychol.* 103, 963–981. doi: 10.1037/a0029488

Gere, J., Schimmack, U., Pinkus, R., and Lockwood, P. (2011). The effects of romantic partners' goal congruence on affective well-being. *J. Res. Pers.* 45, 549–559. doi: 10.1016/j.jrp.2011.06.010

Given, C. W., Stommel, M., Given, B., Osuch, J., Kurtz, M. E., and Kurtz, J. C. (1993). The influence of cancer patients' symptoms and functional states on patients' depression and family caregivers' reaction and depression. *Health Psychol.* 12, 277–285. doi: 10.1037/0278-6133.12.4.277

Gleason, M. E. J., Iida, M., Bolger, N., and Shrout, P. E. (2003). Daily supportive equity in close relationships. *Pers. Soc. Psychol. Bull.* 29, 1036–1045. doi: 10.1177/0146167203253473

Gottman, J. M. (1998). Psychology and the study of marital processes. *Annu. Rev. Psychol.* 49, 169–197. doi: 10.1146/annurev.psych.49.1.169

Gray, H. M., and Tickle-Degnen, L. (2010). A meta-analysis of performance on emotion recognition tasks in Parkinson's disease. *Neuropsychology* 24, 176–191. doi: 10.1037/a0018104

Haber, M. G., Cohen, J. L., Lucas, T., and Baltes, B. B. (2007). The relationship between self-reported received and perceived social support: a meta-analytic review. *Am. J. Commun. Psychol.* 39, 133–144. doi: 10.1007/s10464-007-9100-9

Heberlein, A. S., and Saxe, R. (2005). Dissociation between emotion and personality judgments: convergent evidence from functional neuroimaging. *Neuroimage* 28, 770–777. doi: 10.1016/j.neuroimage.2005.06.064

Henry, J. D., Ruffman, T., McDonald, S., Peek O'Leary, M.-A., Phillips, L. H., Brodaty, H., et al. (2008). Recognition of disgust is selectively preserved in Alzheimer's disease. *Neuropsychologia* 46, 1363–1370. doi: 10.1016/j.neuropsychologia.2007.12.012

Hibbard, J. H., and Pope, C. R. (1993). The quality of social roles as predictors of morbidity and mortality. *Soc. Sci. Med.* 36, 217–225. doi: 10.1016/0277-9536(93)90005-O

Hoehn, M. M., and Yahr, M. D. (1967). Parkinsonism: onset, progression, and mortality. *Neurology* 17, 427–442. doi: 10.1212/WNL.17.5.427

Holt-Lunstad, J., Birmingham, W., and Jones, B. Q. (2008). Is there something unique about marriage? The relative impact of marital status, relationship quality, and network social support on ambulatory blood pressure and mental health. *Ann. Behav. Med.* 35, 239–244. doi: 10.1007/s12160-008-9018-y

Hox, J. (2002). *Multilevel Analysis Techniques and Applications. Quantitative methodology series.* Mahwah, NJ: Lawrence Erlbaum Associates.

Isaacowitz, D. M., Lockenhoff, C. E., Lane, R. D., Wright, R., Sechrest, L., Riedel, R., et al. (2007). Age differences in recognition of emotion in lexical stimuli and facial expressions. *Psychol. Aging* 22, 147–159. doi: 10.1037/0882-7974.22.1.147

Kan, Y., Kawamura, M., Hasegawa, Y., Mochizuki, S., and Nakamura, K. (2002). Recognition of emotion from facial, prosodic and written verbal stimuli in Parkinson's disease. *Cortex* 38, 623–630. doi: 10.1016/S0010-9452(08)70026-1

Katsikitis, M., and Pilowsky, I. (1988). A study of facial expression in Parkinson's disease using a novel microcomputer-based method. *J. Neurol. Neurosurg. Psychiatry* 51, 362–366. doi: 10.1136/jnnp.51.3.362

Katsikitis, M., and Pilowsky, I. (1991). A controlled quantitative study of facial expression in Parkinson's disease and depression. *J. Nerv. Ment. Dis.* 179, 683–688. doi: 10.1097/00005053-199111000-00006

Kaul, M., and Lakey, B. (2003). Where is the support in perceived support? The role of generic relationship satisfaction and enacted support in perceived support's relation to low distress. *J. Soc. Clin. Psychol*. 22, 59–78. doi: 10.1521/jscp.22.1.59.22761

Keightley, M. L., Winocur, G., Burianova, H., Hongwanishkul, D., and Grady, C. L. (2006). Age effects on social cognition: faces tell a different story. *Psychol. Aging* 21, 558–572. doi: 10.1037/0882-7974.21.3.558

Keyes, C. L. M. (1998). Social well-being. *Soc. Psychol. Q.* 61, 121–140. doi: 10.2307/2787065

Kiecolt-Glaser, J. K., Fisher, L. D., Ogrocki, P., Stout, J. C., Speicher, C. E., and Glaser, R. (1987). Marital quality, marital disruption, and immune function. *Psychosom. Med.* 49, 13–34.

Kiecolt-Glaser, J. K., Malarkey, W. B., Chee, M., Newton, T., Cacioppo, J. T., Mao, H., et al. (1993). Negative behavior during marital conflict is associated with immunological down-regulation. *Psychosom. Med.* 55, 395–409.

Lakey, B., and Cassady, P. B. (1990). Cognitive processes in perceived social support. *J. Pers. Soc. Psychol.* 59, 337–343. doi: 10.1037/0022-3514.59.2.337

Lawrence, A. D., Goerendt, I. K., and Brooks, D. J. (2007). Impaired recognition of facial expressions of anger in Parkinson's disease patients acutely withdrawn from dopamine replacement therapy. *Neuropsychologia* 45, 65–74. doi: 10.1016/j.neuropsychologia.2006.04.016

Levenson, R. W., Carstensen, L. L., and Gottman, J. M. (1994). The influence of age and gender on affect, physiology, and their interrelations: a study of long-term marriages. *J. Pers. Soc. Psychol.* 67, 56–68. doi: 10.1037/0022-3514.67.1.56

Levenson, R. W., and Gottman, J. M. (1983). Marital interaction: physiological linkage and affective exchange. *J. Pers. Soc. Psychol.* 45, 587–597. doi: 10.1037/0022-3514.45.3.587

MacDowell, C. L., Harrison, D. W., and Demaree, H. A. (1994). Is right hemisphere decline in the perception of emotion a function of aging? *Int. J. Neurosci.* 79, 1–11.

MacPhee, G. J. A., and Stewart, D. A. (2007). Parkinson's disease. *Rev. Clin. Gerontol.* 16, 1–21. doi: 10.1017/S0959259806002073

MacPherson, S. E., Phillips, L. H., and Della Sala, S. (2002). Age, executive function, and social decision making: a dorsolateral prefrontal theory of cognitive aging. *Psychol. Aging* 17, 598–609. doi: 10.1037/0882-7974.17.4.598

MacPherson, S. E., Phillips, L. H., and Della Sala, S. (2007). Age related decline in the ability to perceive sad facial expressions. *Aging Clin. Exp. Res.* 18, 418–424. doi: 10.1007/BF03324838

Maisel, N. C., and Gable, S. L. (2009). The paradox of received social support. *Psychol. Sci.* 20, 928 –932. doi: 10.1111/j.1467-9280.2009.02388.x

Malatesta, C. Z., Izard, C. E., and Culver, C. (1987). Emotion communication skills in young, middle-aged, and older women. *Psychol. Aging* 2, 193–202. doi: 10.1037/0882-7974.2.2.193

Marsh, L. (2000). Neuropsychiatric aspects of Parkinson's disease. *Psychosomatics* 41, 15–23. doi: 10.1016/S0033-3182(00)71169-8

Mather, M., and Carstensen, L. L. (2005). Aging and motivated cognition: the positivity effect in attention and memory. *Trends Cogn. Sci.* 9, 496–502. doi: 10.1016/j.tics.2005.08.005

Miller, G. E., Dopp, J. M., Myers, H. F., Stevens, S. Y., and Fahey, J. L. (1999). Psychosocial predictors of natural killer cell mobilization during marital conflict. *Health Psychol.* 18, 262–271. doi: 10.1037/0278-6133.18.3.262

Monin, J., Martire, L., Schulz, R., and Clark, M. (2009). Willingness to express emotions to caregiving spouses. *Emotion* 9, 101–106. doi: 10.1037/a0013732

Monin, J. K., and Schulz, R. (2009). Interpersonal effects of suffering in older adult caregiving relationships. *Psychol. Aging* 24, 681–695. doi: 10.1037/a0016355

Montepare, J., Koff, E., Zaitchik, D., and Albert, M. (1999). The use of body movements and gestures as cues to emotions in younger and older adults. *J. Nonverb. Behav.* 23, 133–152. doi: 10.1023/A:1021435526134

Morell, M. A., and Apple, R. F. (1990). Affect expression, marital satisfaction, and stress reactivity among premenopausal women during a conflictual marital discussion. *Psychol. Women Quart.* 14, 387–402. doi: 10.1111/j.1471-6402.1990.tb00027.x

Moreno, C., Borod, J., Welkowitz, J., and Alpert, M. (1993). The perception of facial emotion across the adult life span. *Dev. Neuropsychol.* 9, 305–319. doi: 10.1080/87565649309540559

Newton, T. L., and Sanford, J. M. (2003). Conflict structure moderates associations between cardiovascular reactivity and negative marital interactions. *Health Psychol.* 22, 270–278. doi: 10.1037/0278-6133.22.3.270

Niedenthal, P. M., and Brauer, M. (2012). Social functionality of human emotion. *Annu. Rev. Psychol.* 63, 259–285. doi: 10.1146/annurev.psych.121208.131605

Northouse, L., Templin, T., and Mood, D. (2001). Couples' adjustment to breast disease during the first year following diagnosis. *J. Behav. Med.* 24, 115–136. doi: 10.1023/A:1010772913717

Orgeta, V., and Phillips, L. H. (2008). Effects of age and emotional intensity on the recognition of facial emotion. *Exp. Aging Res.* 34, 63–79. doi: 10.1080/03610730701762047

Orth-Gomer, K., Wamala, S. P., Horsten, M., Schenck-Gustafsson, K., Schneiderman, N., and Mittleman, M. A. (2000). Marital stress worsens prognosis in women with coronary heart disease: the stockholm female coronary risk study. *JAMA* 284, 3008–3014. doi: 10.1001/jama.284.23.3008

Pakenham, K. I. (2001). Application of a stress and coping model to caregiving in multiple sclerosis. *Psychol. Health Med.* 6, 13–27. doi: 10.1080/13548500125141

Pell, M. D., and Leonard, C. L. (2003). Processing emotional tone from speech in Parkinson's disease: a role for the basal ganglia. *Cogn. Affect. Behav. Neurosci.* 3, 275–288. doi: 10.3758/CABN.3.4.275

Pentland, B., Gray, J. M., Riddle, W. J. R., and Pitcairn, T. K. (1988). The effects of reduced non-verbal communication in Parkinson's disease. *Br. J. Disord. Commun.* 23, 31–34. doi: 10.3109/13682828809019874

Pentland, B., Pitcairn, T. K., Gray, J. M., and Riddle, W. J. R. (1987). The effects of reduced expression in Parkinson's disease on impression formation by health professionals. *Clin. Rehabil.* 1, 307–313. doi: 10.1177/026921558700100410

Peto, V., Jenkinson, C., Fitzpatrick, R., and Greenhall, R. (1995). The development and validation of a short measure of functioning and well being for individuals with Parkinson's disease. *Qual. Life Res.* 4, 241–248. doi: 10.1007/BF02260863

Phillips, L. H., Bull, R., Allen, R., Insch, P., Burr, K., and Ogg, W. (2011). Lifespan aging and belief reasoning: influences of executive function and social cue decoding. *Cognition* 120, 236–247. doi: 10.1016/j.cognition.2011.05.003

Phillips, L. H., MacLean, R. D. J., and Allen, R. (2002). Age and the understanding of emotions: neuropsychological and sociocognitive perspectives. *J. Gerontol. B Psychol. Sci. Soc. Sci.* 57, P526–P530. doi: 10.1093/geronb/57.6.P526

Pillon, B., Dubois, B., and Agid, Y. (1996). Testing cognition may contribute to the diagnosis of movement disorders. *Neurology* 46, 324–334. doi: 10.1212/WNL.46.2.329

Pitcairn, T. K., Clemie, S., Gray, J. M., and Pentland, B. (1990). Nonverbal cues in the self-presentation of Parkinsonian patients. *Br. J. Clin. Psychology* 29, 177–184. doi: 10.1111/j.2044-8260.1990.tb00867.x

Poulin, M. J., Brown, S. L., Ubel, P. A., Smith, D. M., Jankovic, A., and Langa, K. M. (2010). Does a helping hand mean a heavy heart? Helping behavior and well-being among spouse caregivers. *Psychol. Aging* 25, 108–117. doi: 10.1037/a0018064

Raudenbush, S., Bryk, A., and Congdon, R. (2013). *HLM 7.01 for Windows [Hierarchical Linear and Nonlinear Modeling Software]*. Lincolnwood, IL: Multivariate Software, Inc.

Revenson, T. A., and Majerovitz, S. D. (1990). Spouses' support provision to chronically ill patients. *J. Soc. Pers. Relat.* 7, 575–586. doi: 10.1177/0265407590074013

Rohrbaugh, M. J., Shoham, V., and Coyne, J. C. (2006). Effect of marital quality on eight-year survival of patients with heart failure. *Am. J. Cardiol.* 98, 1069–1072. doi: 10.1016/j.amjcard.2006.05.034

Ruffman, T., Henry, J. D., Livingstone, V., and Phillips, L. H. (2008). A meta-analytic review of emotion recognition and aging: implications for neuropsychological models of aging. *Neurosci. Biobehav. Rev.* 32, 863–881. doi: 10.1016/j.neubiorev.2008.01.001

Ruffman, T., Sullivan, S., and Dittrich, W. (2009). Older adults' recognition of bodily and auditory expressions of emotion. *Psychol. Aging* 24, 614–622. doi: 10.1037/a0016356

Ryff, C. D. (1995). Psychological well-being in adult life. *Curr. Direct. Psychol. Sci.* 4, 99–103. doi: 10.1111/1467-8721.ep10772395

Sarason, B. R., Sarason, I. G., and Gurung, R. A. R. (1997). *Close Personal Relationships and Health Outcomes: A Key to The Role of Social Support.* Hoboken, NJ: Wiley.

Saxbe, D., Repetti, R. L., and Nishina, A. (2008). Marital satisfaction, recovery from work, and diurnal cortisol among men and women. *Health Psychol.* 27, 15–25. doi: 10.1037/0278-6133.27.1.15

Schimmack, U., and Lucas, R. E. (2010). Environmental influences on well-being: a dyadic latent panel analysis of spousal similarity. *Soc. Indic. Res.* 98, 1–21. doi: 10.1007/s11205-009-9516-8

Schulz, R., Beach, S. R., Hebert, R. S., Martire, L. M., Monin, J. K., Thompkins, C. A., et al. (2009). Spousal suffering and partner depression and cardiovascular disease: the cardiovascular health study. *Am. J. Geriatr. Psychiatry* 17, 246–254. doi: 10.1097/JGP.0b013e318198775b

Shrout, P. E., Herman, C. M., and Bolger, N. (2006). The costs and benefits of practical and emotional support on adjustment: a daily diary study of couples experiencing acute stress. *Pers. Relat.* 13, 115–134. doi: 10.1111/j.1475-6811.2006.00108.x

Simons, G., Pasqualini, M. C. S., Reddy, V., and Wood, J. (2004). Emotional and nonemotional facial expressions in people with Parkinson's disease. *J. Int. Neuropsychol. Soc.* 10, 521–535. doi: 10.1017/S135561770410413X

Smith, M. C., Smith, M. K., and Ellgring, H. (1996). Spontaneous and posed facial expression in Parkinson's disease. *J. Int. Neuropsychol. Soc.* 2, 383–391. doi: 10.1017/S1355617700001454

Smith, T. W., and Brown, P. C. (1991). Cynical hostility, attempts to exert social control, and cardiovascular reactivity in married couples. *J. Behav. Med.* 14, 581–592. doi: 10.1007/BF00867172

Sprengelmeyer, R., Young, A. W., Mahn, K., Schroeder, U., Woitalla, D., Büttner, T., et al. (2003). Facial expression recognition in people with medicated and unmedicated Parkinson's disease. *Neuropsychologia* 41, 1047–1057. doi: 10.1016/S0028-3932(02)00295-6

Sullivan, S., and Ruffman, T. (2004a). Emotion recognition deficits in the elderly. *Int. J. Neurosci.* 114, 403–432. doi: 10.1080/00207450490270901

Sullivan, S., and Ruffman, T. (2004b). Social understanding: how does it fare with advancing years? *Br. J. Psychol.* 95, 1–18. doi: 10.1348/000712604322779424

Sullivan, S., Ruffman, T., and Hutton, S. (2007). Age differences in emotion recognition skills and the visual scanning of emotion faces. *J. Gerontol. B Psychol. Sci. Soc. Sci.* 62, P53–P60. doi: 10.1093/geronb/62.1.P53

Suzuki, A., Hoshino, T., and Shigemasu, K. (2007). Decline or improvement? Age-related differences in facial expression recognition. *Biol. Psychol.* 74, 75–84. doi: 10.1016/j.biopsycho.2006.07.003

Suzuki, A., Hoshino, T., Shigemasu, K., and Kawamura, M. (2006). Disgust-specific impairment of facial expression recognition in Parkinson's disease. *Brain J. Neurol.* 129, 707–717. doi: 10.1093/brain/awl011

Uchino, B. N., Cacioppo, J. T., and Kiecolt-Glaser, J. K. (1996). The relationship between social support and physiological processes: a review with emphasis on underlying mechanisms and implications for health. *Psychol. Bull.* 119, 488–531. doi: 10.1037/0033-2909.119.3.488

Wang, H. X., Leineweber, C., Kirkeeide, R., Svane, B., Schenck-Gustafsson, K., Theorell, T., et al. (2007). Psychosocial stress and atherosclerosis: family and work stress accelerate progression of coronary disease in women. The stockholm female coronary angiography study. *J. Int. Med.* 261, 245–254. doi: 10.1111/j.1365-2796.2006.01759.x

Whisman, M. A. (2001). "The association between depression and marital dissatisfaction," in *Marital and Family Processes in Depression: A Scientific Foundation for Clinical Practice*, ed S. R. H. Beach (Washington, DC: American Psychological Association), 3–24. doi: 10.1037/10350-001

Whisman, M. A., Uebelacker, L. A., and Settles, T. D. (2010). Marital distress and the metabolic syndrome: linking social functioning with physical health. *J. Family Psychol.* 24, 367–370. doi: 10.1037/a0019547

Wong, B., Cronin-Golomb, A., and Neargarder, S. (2005). Patterns of visual scanning as predictors of emotion identification in normal aging. *Neuropsychology* 19, 739–749. doi: 10.1037/0894-4105.19.6.739

Yip, J. T., Lee, T. M., Ho, S. L., Tsang, K. L., and Li, L. S. (2003). Emotion recognition in patients with idiopathic Parkinson's disease. *Mov. Disord.* 18, 1115–1122. doi: 10.1002/mds.10497

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 12 December 2013; accepted: 31 March 2014; published online: 28 April 2014.

*Citation: Petrican R, Moscovitch M and Grady C (2014) Proficiency in positive vs. negative emotion identification and subjective well-being among long-term married elderly couples. Front. Psychol. **5**:338. doi: 10.3389/fpsyg.2014.00338*

This article was submitted to Emotion Science, a section of the journal Frontiers in Psychology.

frontiers in PSYCHOLOGY

ORIGINAL RESEARCH ARTICLE
published: 14 May 2014
doi: 10.3389/fpsyg.2014.00423

Adult age-differences in subjective impression of emotional faces are reflected in emotion-related attention and memory tasks

***Joakim Svärd*[1]*, *Håkan Fischer*[1,2] *and Daniel Lundqvist*[3]**

[1] *Aging Research Center, Karolinska Institutet and Stockholm University, Stockholm, Sweden*
[2] *Department of Psychology, Stockholm University, Stockholm, Sweden*
[3] *Department of Clinical Neuroscience, Karolinska Institutet, Stockholm, Sweden*

Edited by:
Natalie Ebner, University of Florida, USA

Reviewed by:
Natalie Ebner, University of Florida, USA
Phoebe E. Bailey, University of Western Sydney, Australia
Katja Werheid, Humboldt Universität zu Berlin, Germany

****Correspondence:***
Joakim Svärd, Aging Research Center, Karolinska Institutet, Stockholm University, Gävlegatan 16, 113 30 Stockholm, Sweden
e-mail: joakim.svard@ki.se

Although younger and older adults appear to attend to and remember emotional faces differently, less is known about age-related differences in the subjective emotional impression (arousal, potency, and valence) of emotional faces and how these differences, in turn, are reflected in age differences in various emotional tasks. In the current study, we used the same facial emotional stimuli (angry and happy faces) in four tasks: emotional rating, attention, categorical perception, and visual short-term memory (VSTM). The aim of this study was to investigate effects of age on the subjective emotional impression of angry and happy faces and to examine whether any age differences were mirrored in measures of emotional behavior (attention, categorical perception, and memory). In addition, regression analyses were used to further study impression-behavior associations. Forty younger adults (range 20–30 years) and thirty-nine older adults (range 65–75 years) participated in the experiment. The emotional rating task showed that older adults perceived less arousal, potency, and valence than younger adults and that the difference was more pronounced for angry than happy faces. Similarly, the results of the attention and memory tasks demonstrated interaction effects between emotion and age, and age differences on these measures were larger for angry than for happy faces. Regression analyses confirmed that in both age groups, higher potency ratings predicted both visual search and VSTM efficiency. Future studies should consider the possibility that age differences in the subjective emotional impression of facial emotional stimuli may explain age differences in attention to and memory of such stimuli.

Keywords: emotion, faces, arousal, aging, subjective rating, attention, categorical perception, memory

INTRODUCTION

The effects of age on the processing of emotional facial expression have been investigated in a broad range of emotion-cognition domains, such as attention (e.g., Isaacowitz et al., 2006), memory (e.g., Mather and Carstensen, 2003), and categorical perception (Kiffel et al., 2005). However, age differences in the subjective emotional experience of facial expressions have been less extensively investigated. For example, studies of age differences in ratings of valence (pleasantness/unpleasantness), arousal (active/passive), and potency (weak/strong) (see e.g., Osgood, 1966; Russell, 2003) of such stimuli are rare. Consequently, little is known about whether age-related differences in the subjective emotional impression—that is, the valence, arousal, and potency rating—of emotional stimuli is associated with emotional behavior (e.g., memory, attention).

AGE AND EMOTIONAL PROCESSING OF FACIAL EXPRESSION

Studies on the processing of emotional facial expression, including studies on recognition, attention, and memory, have revealed that aging is associated with less efficient processing of negative than positive faces. More specifically, older adults have repeatedly demonstrated poorer recognition than younger adults of expressions that are fearful (e.g., McDowell et al., 1994; Calder et al., 2003; Keightley et al., 2006; Horning et al., 2012; Svärd et al., 2012; Suzuki and Akiyama, 2013), angry (McDowell et al., 1994; Calder et al., 2003; Ebner and Johnson, 2009; Suzuki and Akiyama, 2013), and sad (McDowell et al., 1994; Calder et al., 2003; Keightley et al., 2006; Horning et al., 2012; Suzuki and Akiyama, 2013). However, they have a preserved or even increased ability to recognize facial expressions that are happy (e.g., McDowell et al., 1994; Calder et al., 2003; Svärd et al., 2012, but see also Horning et al., 2012; Suzuki and Akiyama, 2013) and disgusted (Calder et al., 2003; Horning et al., 2012; Suzuki and Akiyama, 2013). This pattern of results from individual studies has been confirmed in a meta-analysis by Ruffman et al. (2008), who found that the largest age-related decrease occurred in the recognition of angry, fearful, and sad faces and that less of a decrease occurred in the recognition of happy and surprised faces.

A similar age-by-emotion interaction has been demonstrated in memory for emotional faces. For instance, Mather and

Carstensen (2003) have demonstrated that although older adults remembered more positive than negative faces, there was no such difference among younger adults. Similarly, Ebner and Johnson (2009) have reported that older adults' memory for angry faces was poorer than their memory for happy and neutral faces. Enhanced memory for negative faces has also been reported among younger but not older adults (Grady et al., 2007; but see also D'Argembeau and van der Linden, 2004; Fischer et al., 2010). Studies of the effects of age on VSTM for emotional material have shown either a general decrease with age (Borg et al., 2011) or age-by-emotion interactions, findings that are consistent with the above-mentioned pattern of effects. For example, Mikels et al. (2005) found that younger adults were able to maintain intensity judgments of negative emotional pictures to a larger extent than of positive emotional pictures, but the opposite was true for older adults. A similar finding was reported in a study by Langeslag and van Strien (2009) in which younger adults exhibited enhanced VSTM performance for unpleasant but not pleasant stimuli, and older adults exhibited similar VSTM for both types of stimuli. However, to the best of our knowledge, no studies have investigated the effects of age on VSTM of emotional faces.

The attention literature shows that older adults preferentially focus on happy rather than sad faces, whereas younger adults do not (Isaacowitz et al., 2006). Moreover, older adults focus away from negative faces in negative-neutral face-pairs, but younger adults do not (Mather and Carstensen, 2003). However, when the task requires detection of negative (angry) schematic faces, these positivity preferences in older adults diminish (Hahn et al., 2006; Mather and Knight, 2006; Ruffman et al., 2009; Lundqvist et al., 2013a).

The findings from recognition, attention, and memory studies all show that the processing of negative but not positive facial expressions decreases with increasing age. This age-by-emotion interaction is often discussed in the theoretical framework of the *socio-emotional selectivity theory* (SST; Carstensen et al., 1999), which proposes motivational shifts away from negative and toward positive stimuli in the processing of emotional material as a function of limited time perspectives (see e.g., Carstensen, 2006). However, the contribution of subjective emotional impression to emotional processing remains relatively unexplored in the literature on age and emotion. This is intriguing because, as described in the next section, a growing body of research on younger adults shows that subjective emotional impression affect emotional processing.

EFFECTS OF AROUSAL ON EMOTIONAL PROCESSING

Several reviews of studies on the attention-emotion domain in younger adults show that a stimulus' score on emotional arousal measures is more important for processing efficiency than the valence of the stimulus (in particular, see Lundqvist et al., 2013b; also c.f. Phelps and LeDoux, 2005; Lang and Bradley, 2010; Mather and Sutherland, 2011; Harmon-Jones et al., 2012). Recent results support the idea that emotional arousal is also important in older adults; they suggest that arousal may be the main emotional impression factor involved in age-related flattening of affect (Lundqvist et al., 2013a). More specifically, these results showed a significant age-related reduction in minimum and maximum ratings on emotional arousal and potency measures in response to facial stimuli. The results also showed a relationship between arousal ratings, potency ratings, and attention measures for angry (but not for happy) faces, such that higher ratings on those scales were associated with shorter reaction times (RTs) in a visual search task. A growing body of research on younger adults also points to emotional arousal as an important factor in VSTM performance. More specifically, both maintenance (Langeslag et al., 2009; Lindström and Bohlin, 2011) and immediate recall and recognition performance seem to be boosted by emotionally arousing content (Jackson et al., 2009; Langeslag et al., 2009).

A potential mechanisms through which arousal may impact task performance in the reported tasks is by means of activation in core affective arousal-related brain regions such as the amygdala, PAG and orbitofrontal cortex, which, in turn, influence activity in cortical regions and visual cortex to facilitate both higher cognitive processing and more basic visual perception (see e.g., Phelps and LeDoux, 2005).

In summary, studies in younger adults show an association between emotional arousal and efficiency in processing emotional information in both the attention and memory domains. With the exception of one study that found that the association between arousal and attention is preserved in older age (Lundqvist et al., 2013a), the effect of arousal on emotional processing in other emotion-cognition domains remains largely unexplored in the literature on aging.

A THREE DIMENSION APPROACH TO THE STUDY OF EMOTION

In the cognition-emotion literature, the dimension of valence has historically been the emotional dimension of largest interest (see e.g., Lundqvist et al., 2013b), whereas the dimensions of arousal and potency have been investigated to a much lesser degree. All three dimensions reoccur in the literature (since the mid-fifties) as the three main underlying dimensions of affective/emotional responses to a wide array of emotional stimuli (e.g., Osgood and Suci, 1955; Lundqvist et al., 1999). The steady reoccurrence demonstrates the importance of these dimensions in socio-emotional interactions, and makes it meaningful and motivated to include all three dimensions in studies of emotion-cognition relationships.

IMPLICATIONS FOR THE STUDY OF EFFECTS OF AGE ON EMOTIONAL PROCESSING

The findings of an effect of emotional impression on behavior point to the importance of stimulus selection in studies of emotional behavior in younger and older adults. If emotional faces convey different impression to younger and older adults, this may in turn affect attention and memory processing. Given that both memory literature (which indicates that participants remember material and events of emotional character better than those that are neutral; see e.g., Buchanan, 2007, for a review) and recent attention literature, which has found that arousal affects attention processing (e.g., Lundqvist et al., 2013b), a decrease in emotional impression might thus dampen the effect of emotion on memory performance and attention processing. By assuming that younger and older adults perceive emotional material equally in terms of the key dimensions of emotional impression, researchers risk misattributing age effects in emotional behavior.

EXTENSION TO ANOTHER EMOTION-COGNITION DOMAIN

Categorical perception is another emotion-cognition domain that remains relatively unexplored, both in terms of age and arousal effects. The phenomenon of categorical perception refers to the occurrence of perceived categories along a linear continuum of physically changing stimulus (see e.g., Bornstein and Korda, 1984 for a more detailed description). Such phenomena have been shown in studies of color perception (e.g., Bornstein and Korda, 1984), speech perception (Liberman et al., 1957), and facial expression recognition (Etcoff and Magee, 1992). Although the physical differences between pairs of emotional faces in the Etcoff and Magee study (1992) were held constant, discrete perceived boundaries occurred for a variety of the emotion-emotion and emotion-neutral face pairs. Even though this finding of categorical perception of emotional facial expressions has been replicated in numerous studies of younger adults (e.g., Calder et al., 1996; Young et al., 1997; Campanella et al., 2002), less is known about how this type of categorical perception might vary as a function of age. To the best of our knowledge, only one study has investigated the effects of age on categorical perception of emotional facial expressions. That study showed that although categorical perception of identity was affected by age, categorical perception of emotional expressions seemed to remain intact (Kiffel et al., 2005).

THE AIM AND HYPOTHESIS OF THE STUDY

The overall aim of this study was to extend earlier studies on subjective emotional impression and attention in older people. The study had three specific aims. The first was to investigate differences between older and younger adults in subjective emotional impressions. The second was to explore whether any such differences were mirrored in the emotional-cognitive tasks of attention, categorical perception, and VSTM. The third was to analyze whether any differences in the impression were associated with differences in task performance.

The literature on emotion indicates that the emotional properties of stimuli influence stimulus processing in many different domains, from perception to visual attention and memory (see e.g., Phelps and LeDoux, 2005). In this study, these different domains were represented by our categorical perception task (perception), visual search task (attention), and VSTM task (memory). Because of our previous results (Lundqvist et al., 2013a) and the above-mentioned reviews, we expected to replicate our earlier findings, which showed lower ratings in emotional impression of facial expression in older adults and an age-independent association between arousal ratings and visual search performance. We further expected to find performance differences across the perception, attention, and VSTM tasks, in keeping with the idea that high arousal scores are associated with high performance on tasks, and vice versa. This predicted decline in categorical perception would contrast with the Kiffel et al. (2005) finding that categorical perception of emotional expressions seems to remain intact with age. However, their study did not include angry faces, and it is angry faces that we predict will garner lower emotional ratings in older but not younger adults. Because of our previous results (Lundqvist et al., 2013a) and the above-mentioned reviews, we expect arousal to be the dimension that most strongly predicts task performance. However, because of our previous findings (Lundqvist et al., 2013a) and suggestions that at least a third emotional dimension should be incorporated in the study of emotions (Russell and Mehrabian, 1977; Fontaine et al., 2007), we also expected emotional potency to be involved in task performance.

Specifically, we expected: (1) to find lower ratings (i.e., arousal, potency) of emotional stimuli in older than younger adults, (2) to demonstrate that such lower ratings (i.e., arousal, potency) are associated with response latencies on the visual search task, and (3) that subjective emotional impression of facial expressions would be associated with performance on VSTM and categorical perception tasks. We did not have any predictions whether these associations are restricted only to angry faces, because previous results have showed that high arousal ratings of both angry and happy faces visual are associated with increased search efficiency (Lundqvist et al., 2013b).

METHODS

PARTICIPANTS

Table 1 shows the characteristics of the participants in this study. Although younger adults scored higher than older adults on the anxiety items on the Hospital Anxiety and Depression Scale (HADS), this difference most likely did not affect behavioral results because no age-related differences in either trait anxiety (STAI-T) or state anxiety (STAI-S) were measured at test. All participants had normal or corrected-to-normal vision. Written informed consent was collected prior the tests and participants received two movie vouchers for their participation. The same participants were enrolled in all four tasks. The study was approved by the local ethics committee.

MATERIALS

Rating and visual search tasks

Faces from the Averaged Karolinska Directed Emotional Faces set (AKDEF; Lundqvist and Litton, 1998) were used in the study. The AKDEF faces consist of an averaged female and an averaged male face, each composed of 35 individuals (see **Figure 1**). In the emotional rating task and in the visual search task, angry, happy, and neutral expressions from both the averaged female face and the averaged male face were used as stimuli. Ratings of and visual search performance for fear, disgust, sadness, and surprise were also collected but not analyzed in the current study.

Categorical perception and visual short-term memory tasks

The stimuli shown in **Figure 1** were also the basis of the stimuli in the categorical perception and VSTM tasks. However, to enable investigation of categorical boundaries and VSTM performance on a continuum from a neutral to an emotional facial expression, the faces were modified to show emotional expressions at various intensities between 0 and 100%. The modification of the faces was performed using SqirlsMorph 2.1

Table 1 | Participant characteristics by age group.

	Younger	Older	*p*-value	*d*
	M	M		
Age in years (*SD*)	25.2 (10.5)	70.5 (2.8)	<0.001	13.127
Sex	21 F, 19 M	24 F, 15 M		
Education in years (*SD*)	14.6 (2.9)	14.5 (2.9)	0.831	0.049
MMSE (*SD*; range)	29 (0.9; 26–30)	28.7 (1.4; 24–30)	0.295	0.237
HADS[a] (*SD*; range)	5 (3.5; 0–13)	3.4 (3.0; 0–15)	0.028	0.509
HADS[d] (*SD*; range)	3.1 (2.3; 0–12)	2.9 (2.2; 0–10)	0.653	0.102
STAI-T (*SD*)	47.7 (4.8; 27–59)	47 (3.1; 42–56)	0.390	0.196
STAI-S (*SD*)	30.1 (5.8; 20–42)	29 (5.2; 20–40)	0.381	0.201

*MMSE, mini mental state examination (Folstein et al., 1975); HADS, hospital anxiety and depression scale (Zigmond and Snaith, 1983); STAI, state-trait anxiety inventory (Spielberger et al., 1988); -T, Trait; -S, State; [a]anxiety items; [d]depression items; F, female; M, male; *$p < 0.05$.*

FIGURE 1 | Examples of the face stimuli used in all four tasks. Note: Faces from the Averaged Karolinska Directed Emotional Faces set (Lundqvist and Litton, 1998).

(http://www.xiberpix.net/), and key points were used to guide the morph between facial features (e.g., lips, mouth shape, eyes, nose wrinkles, facial outline). For the categorical perception task, 9 face pairs differing 20% in intensity (i.e., 20 steps apart along the 100-step morph) were created in the neutral-to-angry and neutral-to-happy continua for the female and male averaged faces respectively (see **Figure 2**). The size of each face was 7.5 × 10.5 cm.

PROCEDURE

To minimize the risk of initiating any potential biases caused by elaborative processing, the rating task was performed last in the sequence. Although the order in which the tasks were conducted was visual search, categorical perception, visual short-term memory, and rating, to facilitate reading and interpretation of the manuscript, the rating experiment is presented first. The order of the tasks was the same for all participants. At study, participants sat on a chair in front of a computer screen (HP Compaq LA2405wg) at a distance of approximately 0.5 m. Behavioral responses were collected by key presses on an external keyboard. The experiment was programmed using Macromedia Director MX 2004 software (Macromedia Inc.). Total duration of the experiment was approximately 75 min. The visual search task took 30 min, and the rating, VSTM, and categorical perception tasks each took 15 min. Short breaks were given between the tasks to prevent fatigue.

Emotional rating task

During the rating task, facial stimuli (**Figure 1**) with full emotional expressions (100% intensity) were presented one at a time on the computer screen. Participants used a visual analog scale (VAS) to rate the three key emotional dimensions arousal (active-inactive), valence (pleasant-unpleasant), and potency (weak-strong) of seven expressions on male faces and seven on female faces (a total of 42 faces). Cursors on three separated horizontal lines were used for the ratings. The scales ranged from −1 to 1 (actual values were not visible to the participants).

The three VAS scales were presented below the face and maneuvered with the right and left arrow keys. Participants were informed that the task was self-paced. However, they were encouraged to base their rating on the first impression of a face and not spend exaggerated time thinking. Once ratings on the three scales were completed, participants pressed the spacebar to continue to the next trial. The order and polarity of scales were randomized between trials.

Visual search task

During the visual search task, circular displays of 6 faces were presented to the participants. In half of the trials (so-called target-absent trials), all faces in the array had the same emotional expression, while in the other half (so-called target-present trials), one of the faces was different from the other (e.g., an angry face among neutral faces).

Participants were instructed to determine whether each array consisted of faces that were all the same (in which case they were to press a button marked "all same" with their left index finger), or whether one of the faces was different from the others (in which

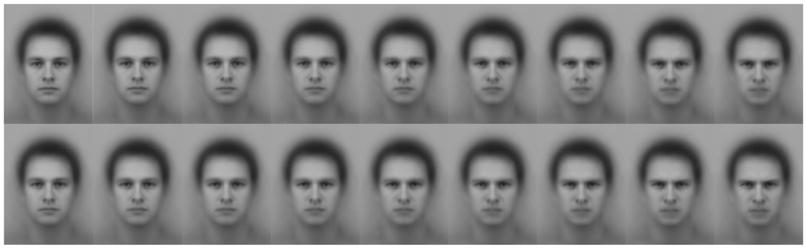

FIGURE 2 | Examples of face pairs used in the categorical perception task (presented vertically). At study, the faces in each pair were presented side by side.

case they were to press a button marked "one deviant" with their right index finger). They were instructed to respond as quickly and accurately as possible. A fixation cross initiated each trial. During target-absent conditions, all faces were afraid, angry, disgusted, happy, neutral, sad, or surprised. During target-present conditions, the background would either be *neutral*, with afraid, angry, disgusted, happy, sad, or surprised faces as the deviating target, or *emotional* (afraid, angry, disgusted, happy, sad, or surprised faces), with neutral as the deviating target. The target face was presented once at each position in the array. The presentation of trials was blocked by condition (emotional background or neutral background) and sex of faces (female or male). Thus, four blocks that included a total 288 faces (2 sexes, 6 expressions, 6 positions, 4 blocks) were used. As soon as a key was pressed ("all similar" or "one deviant"), the trial was terminated and the next trial was initiated. This article only includes information about the analyses of angry and happy emotional faces to make the effects of emotional stimuli (angry, happy) congruent with the stimuli used in the other tasks in the study. The order of blocks was randomized for each participant.

Categorical perception task

During the categorical perception task, pairs of faces were presented side by side on the screen. The physical difference between the faces in each pair was always 20%. Thus, a face showing 0% emotionality (i.e., a neutral face) was always paired with a face showing 20% emotionality, a face 10% emotionality was always paired with a face showing 30% emotionality, and so on (see **Figure 2**). Each pair was shown twice in a randomized order. Presentation of stimuli was however blocked for emotional expression and for the sex of the depicted face. Thus, each of the four blocked conditions (male, neutral to angry; male neural to happy; female, neutral to angry; and female, neutral to happy) contained 2*9 pairs, or a total of 72 pair of faces. The order of blocks was balanced over participants.

Participants were instructed to decide whether the two faces in each pair showed the same facial expression or not. Participants gave their answers by pressing keys labeled "same" or "different." Thus, a shift in Categorical perception from neutral to an emotional expression was investigated. Because pilot tests before start of the study showed that some participants tended to respond "different" on trials where the intensity rather than expression differed, it was emphasized that the task was to judge the facial expression of the face and not whether the expression showed the same intensity or not. The faces stayed on the screen until participants gave their response, which terminated the trial and initiated the next trial.

Visual short-term memory task

In the VSTM task, an emotional face (angry or happy) that varied in expressed emotional intensity in 10% intervals ranging from 10 to 90% was displayed on the screen for three seconds before it disappeared. After a one second interval, a face again appeared on the screen, but at a different (random) intensity level. Participants were instructed to remember the first face and upon display of the second (random) face, adjust the face's intensity level until it matched that of the first face. Intensity adjustments were made with the right and left arrow keys. After completing the adjustments, participants pressed the enter key, and a new trial was initiated. Each intensity interval was shown twice in a randomized order. The presentations were however blocked for emotional expression and for the sex of the depicted face. Thus, each of the four blocked conditions (male, neutral to angry; male neural to happy; female, neutral to angry; and female, neutral to happy) contained 2*9 faces, or a total of 72 presented faces. The order of blocks was balanced over participants.

DATA PREPARATION AND STATISTICAL ANALYSIS

Rating task

Average ratings for the female and male faces were calculated separately for the emotional dimensions valence, arousal, and potency before statistical analyses were run.

Visual search task

Separate ANOVAs were run for reaction times (RTs) and accuracy. Correct responses were included in the analysis of RTs. Before analysis, raw RT data was log10-transformed to achieve normal distribution of data. Furthermore, individual outliers ($M >< \pm 3 * SD$) were replaced by ($M \pm 3 * SD$). However, to facilitate interpretation of the results, raw values are presented in the text and figures.

Categorical perception task

To analyze categorical perception data, a peak intensity interval (e.g., 30–50) was identified for each participant (separately for each of the two emotions). Within each emotion, data for the two AKDEF stimuli genders were collapsed before identifying the peak. Since there were clear differences in how many responses of "different" a participant tended to give (across intervals), the peak was identified by first identifying the interval with the most responses of "different" for that participant and that emotion (e.g., neutral to angry). If there were several responses with the same frequency across a span of intervals (e.g., 20–40; 30–50; 40–60) an average interval was calculated (here 30–50). The most frequent reported "different" pair was thus assumed to be the peak at which categorical perception occurred (Beale and Keil, 1995). The category border itself was assumed to be in the middle of the peak interval (e.g., at 40% if the peak was identified in a 30–50% pair). Thus, peaks were identified for angry and happy faces separately for each individual participant.

Visual short-term memory task

To investigate VSTM performance, the intensity level of the face during encoding was subtracted from the intensity levels reported by the participant. That is, if the face showed 20% intensity at encoding and the participants adjusted the face to show 28% intensity at retrieval, the error score was 8%. Further, to transform all error scores to a positive value, all answers were square root transformed [$\sqrt{}$ (answer∗answer)] at the level of individual responses. The transformation was made after initial analyses where it was discovered that un-transformed errors made in both directions (e.g., −20 and +20% for two trials within one emotion) led to the false impression that this condition was reported with perfect accuracy ($M = 0\%$). Thus, to study effects of age and emotional impression on VSTM performance, transformed data were used in analyses.

RESULTS

To investigate age effects on specific emotion-cognition domains separated ANOVAs were planned for the rating, visual search, VSTM, and categorical perception tasks. Regression analyses were carried out on each of the three behavior tasks to study the effects of emotional impression on emotional behavior. Because of the exploratory nature of this first study on emotional impression and its relation to different emotional behaviors, we decided that the risk of making a type I error was less important than the risk missing important findings. Therefore, corrections for multiple comparisons were not performed.

For all analyses, regular degrees of freedom are reported together with observed significance levels after Greenhouse-Geisser correction. Results were considered significant at $p \leq 0.05$.

ANOVAs

A multivariate analysis revealed a significant effect of age on the combined task performance, $F_{(4, 63)} = 24.62$, $p < 0.001$, $\eta^2 = 0.610$. Analysis of each tasks confirmed the effect of age on rating, $F_{(1, 66)} = 13.22$, $p = 0.001$, $\eta^2 = 0.167$, visual search, $F_{(1, 66)} = 65.60$, $p < 0.001$, $\eta^2 = 0.498$, categorical perception, $F_{(1, 66)} = 12.92$, $p = 0.001$, $\eta^2 = 0.164$, and VSTM, $F_{(1, 66)} = 23.15$, $p < 0.001$, $\eta^2 = 0.260$, performance. Separated repeated ANOVAs were carried out to study effects of age and emotion on each of the tasks.

Rating task

Separate ANOVAs were carried out for the emotional dimensions of valence, arousal, and potency. In the ANOVAs, age (young, old) was used as the between-subject variable and emotion (angry, happy) was used as within-subject variables. Planned t-tests were conducted to study the effect of age on each dimension of emotion. These tests were conducted separately for angry and happy faces. The results are presented in **Figure 3A**.

Valence. The main effect of Emotion $F_{(1, 77)} = 133.73$, $p < 0.001$, $\eta^2 = 0.635$, showed overall higher ratings for Happy ($M = 0.51$, $SD = 0.43$) compared to Angry ($M = -0.35$, $SD = 0.35$)

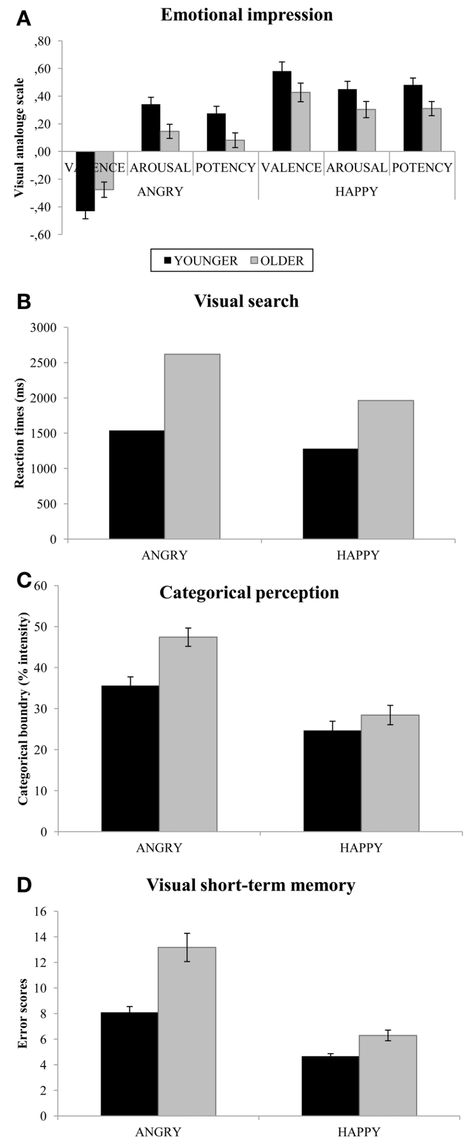

FIGURE 3 | Mean (SE) performance in the rating task (A), visual search task (B), categorical perception task, (C) and visual short-term memory task (D) separately for expression and age. Note. Error bars represent standard error. Results of the ANOVAs and t-tests for age differences are presented in the result section.

faces. There was also an interaction effect between Age and Emotion $F_{(1, 77)} = 4.35$, $p = 0.04$, $\eta^2 = 0.053$, that showed that the largest decrease in responsiveness among Older adults was for Angry faces. Follow up *t*-tests for the interaction revealed that Older adults ratings ($M = -0.28$, $SD = 0.38$) were lower than those of Younger adults ($M = -0.31$, $SD = 0.31$) for Angry faces, $t_{(77)} = 1.99$, $p = 0.05$, $d = 0.087$. For happy faces, there was no difference, $p = 0.11$.

Arousal. The ANOVA on arousal revealed a main effect of Emotion, $F_{(1, 77)} = 7.80$, $p = 0.007$, $\eta^2 = 0.092$, that showed higher ratings for Happy ($M = 0.38$, $SD = 0.37$) compared to Angry ($M = 0.25$, $SD = 0.33$) faces. The main effect of Age, $F_{(1, 77)} = 7.96$, $p = 0.006$, $\eta^2 = 0.094$, showed that Older adults ($M = 0.22$, $SD = 0.23$) gave lower ratings than Younger adults ($M = 0.40$, $SD = 0.30$). The planned *t*-tests revealed that Older adults ratings ($M = 0.15$, $SD = 0.27$) were lower than those of Younger adults ($M = 0.34$, $SD = 0.36$) for Angry faces, $t_{(1, 77)} = 2.74$, $p = 0.008$, $d = 0.597$. For Happy faces, Older adults tended to give lower ratings ($M = 0.30$, $SD = 0.38$) than Younger adults ($M = 0.45$, $SD = 0.35$), which resulted in a trend toward an age difference, $t_{(1, 77)} = 1.78$, $p = 0.078$, $d = 0.411$.

Potency. The main effect of Emotion, $F_{(1, 77)} = 16.95$, $p < 0.001$, $\eta^2 = 0.180$, showed higher ratings for Happy ($M = 0.40$, $SD = 0.33$) than for Angry ($M = 0.18$, $SD = 0.34$) faces. The effect of Age, $F_{(1, 77)} = 12.91$, $p = 001$, $\eta^2 = 0.144$, showed that Older adults ($M = 0.20$, $SD = 0.19$) gave lower ratings than Younger adults ($M = 0.38$, $SD = 0.26$). The planned *t*-tests revealed that Older adults ratings ($M = 0.08$, $SD = 0.29$) were lower than those of Younger adults ($M = 0.27$, $SD = 0.38$) for Angry faces, $t_{(1, 77)} = 2.6$, $p = 0.011$, $d = 0.533$. For Happy faces, Older adults' ratings ($M = 0.31$, $SD = 0.33$) were lower than those of Younger adults, ($M = 0.48$, $SD = 0.31$), $t_{(1, 77)} = 2.38$, $p = 0.020$, $d = 0.531$.

Visual search task

Accuracy (%). The ANOVA on Accuracy revealed a main effect of Emotion, $F_{(1, 77)} = 13.84$, $p < 0.001$, $\eta^2 = 0.152$, showing that across age Happy faces ($M = 96.10$, $SD = 0.07$) were detected with higher accuracy than Angry faces ($M = 90.71$, $SD = 0.14$). There was also a main effect of Age, $F_{(1, 77)} = 8.32$, $p = 0.005$, $\eta^2 = 0.098$, showing that across emotions, Older adults ($M = 96.20$, $SD = 0.01$) detected a deviant emotional face among neutral distractors more accurately than did Younger adults ($M = 90.70$, $SD = 0.10$).

Reaction time (ms). The ANOVA on RTs revealed a main effect of Emotion, $F_{(1, 77)} = 118.23$, $p < 0.001$, $\eta^2 = 0.606$, showing that Happy faces ($M = 1618$, $SD = 525$) were detected faster than Angry faces ($M = 2071$, $SD = 925$). A main effect of Age, $F_{(1, 77)} = 76.30$, $p < 0.001$, $\eta^2 = 0.498$, showed that Older adults ($M = 2290$, $SD = 702$) were slower than Younger adults ($M = 1411$, $SD = 338$) in detecting a deviant face. There was also an interaction between Age and Emotion, $F_{(1, 77)} = 6.51$, $p = 0.013$, $\eta^2 = 0.078$, showing that although Older adults were slower than Younger adults in detecting both Angry and Happy faces, this effect was more pronounced for Angry faces (**Figure 3B**).

Categorical perception task

Because of equipment failure, data from two older women were not collected. In addition, seven (3 younger and 4 older adults) non-responders (i.e., participants who did not report any different response at all) were excluded from the analysis (11.4% excluded in total). Thus, 37 (20 female) younger and 34 (20 female) older adults were included in this analysis.

The ANOVA on Categorical perception data demonstrated a main effect of Emotion, $F_{(1, 69)} = 44.72$, $p < 0.001$, $\eta^2 = 0.393$, showing that the shift in Categorical perception from neutral to an emotional expression occurred earlier for Happy ($M = 26.5$, $SD = 13.8$), than for Angry ($M = 41.3$, $SD = 14.2$) faces. The main effect of Age, $F_{(1, 69)} = 11.88$, $p < 0.001$, $\eta^2 = 0.147$, revealed that across emotions (Angry and Happy), Older adults categorical shift from a neutral to an emotional face occurred at a later stage ($M = 37.9$, $SD = 10.8$) along the continuum compared to Younger adults ($M = 30.2$, $SD = 8.2$). (**Figure 3C**). In addition, there was also an trend toward an Age by Emotion interaction, $F_{(1, 69)} = 3.22$, $p = 0.077$, $\eta^2 = 0.045$.

Visual short-term memory task

Data inspection revealed two outliers (whose mean score was <> $\pm$ 3 *SD*), which were excluded from analyses together with one participant with missing data (3.8% excluded in total). Thus, analyses were computed for 40 younger (21 female) and 35 older (21 female) adults. The statistical design of the ANOVA on VSTM was a 2 (Emotion: Angry, Happy) by 9 (Intensity levels: 10–90%) design with Age (Young, Old) as a between-group variable.

The results revealed a main effect of Emotion, $F_{(1, 73)} = 104.23$, $p < 0.001$, $\eta^2 = 0.588$. Across intensity levels, both Younger and Older adults performed better (fewer errors) for Happy ($M = 5.32$, $SD = 1.90$) than for Angry ($M = 10.18$, $SD = 4.80$) faces. There was also a main effect of Age, $F_{(1, 73)} = 26.83$, $p < 0.001$, $\eta^2 = 0.269$: Older adults ($M = 9.32$, $SD = 3.13$) made more errors than Younger adults ($M = 6.38$, $SD = 1.67$). In addition, there was an interaction between Age and Emotion, $F_{(1, 73)} = 9.99$, $p = 0.002$, $\eta^2 = 0.120$: although Older adults performed worse than Younger adults for both emotions, the poorer performance of Older adults was more pronounced for Angry faces (**Figure 3D**). There was also a main effect of Intensity, $F_{(8, 584)} = 2.33$, $p = 0.029$, $\eta^2 = 0.031$. Contrast tests showed that in both age groups and for both emotions, participants made significantly more errors at the 90% intensity level than at any other level, $ps < 0.05$.

REGRESSION ANALYSES

A multivariate multiple regression analysis revealed an association between emotional impression (all dimensions) and the combined task performance, $F_{(3, 64)} = 3.10$, $p = 0.033$, $\eta^2 = 0.127$. Analysis of each tasks confirmed the association between emotional impression and visual search, $F_{(1, 66)} = 6.92$, $p = 0.011$, $\eta^2 = 0.095$, VSTM, $F_{(1, 66)} = 6.79$, $p = 0.011$, $\eta^2 = 0.093$, but not categorical perception, $F_{(1, 66)} = 0.85$, $p = 0.361$, $\eta^2 = 0.013$, performance. Separated regressions were carried out to study associations between specific dimensions and tasks.

Regression analyses were conducted for each of the behavior tasks (for angry and happy faces separately). In these analyses, three models were used to explore the relationship between emotional impression and behavior. Model one was univariate; each emotional rating scale was tested alone as the predictor. Model 2 was multivariate; all three scales were included as predictors. Thus, in Model 2, any effects were adjusted for the influences of the other scales. Finally, in Model 3, age was included as a predictor, which means that any effect in this model holds even after controlling for age effects. Models 2 and 3 were performed using the enter method.

The univariate analyses for Angry faces revealed that both Arousal and Potency ratings were associated with Visual search performance ($ps < 0.05$). In addition, Potency ratings were also associated with VSTM performance ($p < 0.05$). The association between Arousal ratings and emotional behavior vanished when the analyses were adjusted for the influences of the other scales (Model 2) and the influences of the other scales and age (Model 3). However, the association between Potency ratings and Visual search and VSTM performance remained significant even after these adjustments ($ps < 0.05$). These age-independent relationships can be seen in **Figure 4** in the different location of younger (middle to top left area) and older adults' (middle to bottom right area) scores along the regression line. For Happy faces, there were no associations between any of the emotional rating scales and emotional behavior tasks ($ps > 0.05$). **Table 2** gives information regarding the predictor variables used in the different models.

DISCUSSION

The emotional rating task revealed that older adults rated facial expressions as less emotional than younger adults, and these age differences were more pronounced for angry than happy faces. This age-by-emotion interaction was also evident in visual search and visual short-term memory performance. Regression analyses confirmed that in both age groups, higher potency ratings were the foremost predictor of both visual search and VSTM efficiency for angry faces but not for happy ones. We will briefly discuss the results separately for each task as well as results regarding the associations between subjective emotional impressions and emotional behavior.

SPECIFIC EMOTION-COGNITION DOMAINS

Rating

The results of the rating task revealed a weaker emotional impression of facial expressions in older than in younger adults, which was more pronounced for angry than happy faces (**Figure 3A**, left panel). Older adults rated the angry faces as significantly less unpleasant (valence), less active (arousal), and weaker (potency) than did younger adults. A similar pattern was found for happy faces, but only the difference in the potency measure was statistically significant (see **Figure 3A**, right panel). These results are in line with previous results from our group (Lundqvist et al., 2013a), which show that the emotional impression of faces diminishes with advancing age, and that this dampening is most pronounced for angry faces.

Visual search

An age-by-emotion interaction in RTs revealed that although older adults were generally slower than younger adults, this effect was more pronounced for the detection of angry faces. To the best of our knowledge, this article is the first to report an age-by-emotion interaction in visual search efficiency for emotional faces. It should be noted that our results (which used photographic stimuli) are in disagreement with the results of overall age and emotion effects from previous studies that used schematic (Hahn et al., 2006; Mather and Knight, 2006; Ruffman et al., 2009; Lundqvist et al., 2013a) and photographic (Ruffman et al., 2009) faces. Our finding of faster detection of happy than angry faces is also in disagreement with the findings of the above-mentioned studies. The finding of an angry superiority effect (ASE) in previous studies and a happy superiority effect (HSE; for an overview, see Lundqvist et al., 2013a). in the present study is linked to the emotional impression of the stimuli used and will be discussed below.

The pattern of results in the visual search tasks shows that the older participants generate markedly longer RTs. However, it also shows that this slowness is not without advantages, as the older group also responds with greater accuracy. Whether the high accuracy is a side-effect from the slow responses, or part of a strategy is difficult to say from the present data, since we do not assess or address response strategies.

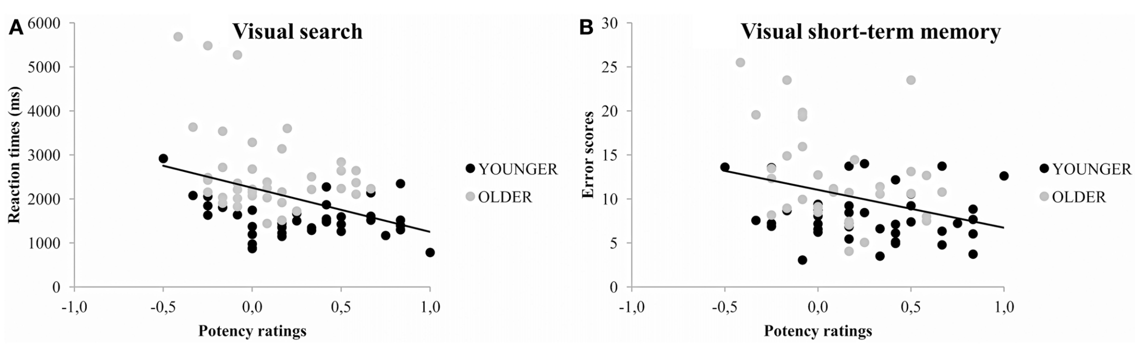

FIGURE 4 | Scatterplots for potency ratings and emotional behavior tasks, separately for visual search (A) and visual short-term memory (B) performance for angry faces across age. Note. Visual search: $r = -0.372$; Visual short-term memory: $r = -0.312$.

Table 2 | β-coefficients (SE) and bivariate correlations for rating scores associated with emotional behavior.

Predictors	Angry			Happy		
By task	**Model 1[a]**	**Model 2[a]**	**Model 3[a]**	**Model 1[a]**	**Model 2[a]**	**Model 3[a]**
VISUAL SEARCH (RT)						
Arousal	−0.25 (0.06)*	−0.08 (0.06)	0.03 (0.05)	−0.14 (0.04)	−0.15 (0.05)	−0.09 (0.04)
Potency	−0.36 (0.05)**	−0.31 (0.06)*	−0.21 (0.05)*	−0.11 (0.05)	−0.08 (0.05)	0.07 (0.04)
Valence	0.13 (0.05)	0.01 (0.05)	−0.07 (0.04)	−0.03 (0.04)	0.08 (0.04)	0.11 (0.03)
VISUAL SHORT-TERM MEMORY (ERROR SCORES)						
Arousal	−0.09 (1.68)	0.12 (1.97)	0.21 (1.78)	−0.10 (0.61)	−0.07 (0.73)	−0.04 (0.69)
Potency	−0.31 (1.53)*	−0.37 (1.86)*	−0.32 (1.67)*	−0.19 (0.66)	−0.20 (0.74)	−0.11 (0.72)
Valence	0.11 (1.57)	0.04 (1.62)	−0.04 (1.47)	−0.03 (0.52)	0.09 (0.62)	0.12 (0.59)
CATEGORICAL PERCEPTION (PEAK)						
Arousal	−0.19 (5.05)	−0.17 (6.26)	−0.12 (5.82)	0.10 (4.41)	0.05 (5.14)	0.07 (5.13)
Potency	−0.12 (4.97)	−0.03 (6.11)	0.07 (5.78)	0.04 (5.07)	−0.03 (5.66)	0.00 (5.67)
Valence	0.07 (5.03)	0.00 (5.43)	−0.03 (5.05)	0.15 (4.04)	0.14 (4.84)	0.16 (4.82)
Correlations	**Angry**			**Happy**		
Between predictors	**Arousal**	**Potency**	**Valence**	**Arousal**	**Potency**	**Valence**
Arousal	–	0.539**	−0.306*	–	0.379**	0.522**
Potency		–	−0.288*		–	0.410**

[a] Model 1 was univariate; Model 2 was multivariate, adjusted for the other rating scales; and Model 3 was additionally adjusted for age. $^{**}p \leq 0.01$; $^{*}0.01 < p \leq 0.05$.

Categorical perception

The results of the categorical perception task show that both angry and happy faces were perceived categorically by both age groups. These results are in line with the results of several other studies on younger adults (e.g., Calder et al., 1996; Young et al., 1997; Campanella et al., 2002) and on older adults (Kiffel et al., 2005). The present study adds new information to the existing literature by showing that the perceptual category boundaries can vary as a function of both age and emotion. The current study used a neutral expression as a reference and paired it separately with an angry or a happy expression; the results showed reliable differences in the locus of boundaries for angry and happy faces. More specifically, our results showed that in both age groups, the locus of the boundary was further forward for angry than for happy faces, indicating that the angry faces were processed more ambiguously than the happy ones. In light of the results from the other tasks, the trend toward an interaction between age and emotion in this task is noteworthy. Although it did not reach a conventional statistical threshold, the relationship agrees with the general pattern of results in this article, which shows that older adults process angry faces less readily than younger adults.

Visual short-term memory

The results of the VSTM task showed that the older adults performed less accurately than younger adults, and the difference in accuracy was greater for angry than for happy faces. Earlier studies have shown that older adults have a decreased ability to maintain unpleasant non-facial stimuli (Langeslag and van Strien, 2009) and negative intensity judgments (Mikels et al., 2005). Our results extend these previous findings into the domain of emotional expression by showing a relatively larger reduction in VSTM performance for angry than for happy facial expressions. The results agree on the general pattern of results in this article, which shows that older adults process angry faces less readily than younger adults.

EMOTIONAL IMPRESSION-BEHAVIOR RELATIONSHIPS

A central aim of this study was to replicate and extend our previous findings (Lundqvist et al., 2013a) of an association between emotional impression and visual search efficiency to include new cognitive-emotion domains. As seen in **Table 2**, the emotional dimension of potency was associated with the results of two out of three emotional behavior tasks for angry faces.

The association between arousal and potency ratings and visual search efficiency replicates our previous findings of a similar relationship for schematic emotional faces (Lundqvist et al., 2013a). In that study, higher arousal and potency ratings were correlated with lower search times for angry but not happy faces. In accordance with the findings of the current study, this association was age-independent, which indicates that visual search performance in both younger and older adults is associated with potency measures. In the present analyses, this relationship can also be seen in **Figure 4A** in the differing location of younger (middle to top left area) and older adults' (middle to bottom right area) scores along the regression line. Both our previous findings (Lundqvist et al., 2013a) and our present results indicate that although older adults generally have lower visual search efficiency than younger adults, search efficiency is associated with the same underlying emotional dimensions (potency and arousal) regardless of age. This notion is also partially supported by the work of Leclerc and

Kensinger (2008, 2010), who found that when arousal levels of positive and negative stimuli were equated, all valence effects were absent. Importantly, the lack of interactions with age demonstrated an age-independent reliance on arousal in visual search performance.

Within the visual search literature, researchers usually report on whether their results show an ASE or a HSE (see Visual Search. above). In those terms, the present results demonstrate an HSE. A recent review article by Lundqvist et al. (2013b) concluded that when participants compared two facial expressions, the expression with the highest arousal ratings was detected most efficiently, regardless of whether that expression was happy or angry. The Lundqvist et al. (2013b) article may thus explain the disagreement between our findings of an HSE and previous studies' findings of an ASE. In accordance with the notion that the facial expression with the highest arousal rating is detected most efficiently, the current study showed a HSE in both arousal ratings and visual search performance. Thus, the current results help generalize the role played by arousal in visual attention to the later part of the adult life-span. In terms of behavior and related brain processes, the HSE effect is potentially associated with a more attention driven positivity bias associated with activity in the dorsolateral prefrontal cortex (Lindquist et al., 2012), a more elaborative cognitive bias associated with activity in the ventromedial prefrontal cortex (Ebner et al., 2012) and/or a more perceptually driven bias associated with activation in the occipital cortex (Lindquist et al., 2012). A recent review by Lundqvist et al. (2013b) however shows that both the HSE concept and its rivaling concept ASE may be confound by an uncontrolled influence from the arousal factor. The present data (showing overall lower scores on arousal for angry compared to happy faces indicates that the present HSE finding may well be explained by the arousal differences between the angry and happy stimuli.

Like attention processing, VSTM performance was associated with the potency ratings of stimuli, such that higher potency ratings were associated with fewer errors. This age-independent association can be seen in **Figure 4B** in the different location of younger (middle to top left area) and older adults' (middle to bottom right area) scores along the regression line. Like the emotion-attention relationship, this relationship indicate that although older adults generally have lower VSTM efficiency than younger adults, VSTM efficiency is associated with the same underlying emotional dimensions (potency and arousal) regardless of age. These findings of age-independent associations might contribute to the understanding of the preserved processing of the happy facial expression that is reported in recognition (e.g., Ruffman et al., 2008), attention (e.g., Isaacowitz et al., 2006), and memory (e.g., Mather and Carstensen, 2003). The age-related differences in emotional impression and the age-related differences in behavior were both less pronounced for happy than angry faces.

In summary, for angry faces, associations between subjective emotional impression and behavior were found in two out of three tasks. The lack of an association for happy faces are most likely due to a lower degree of variance in the processing of happy than angry faces.

POTENCY AS A PREDICTOR OF EMOTIONAL BEHAVIOR

When analyzed as univariate predictors, both high arousal and high potency ratings were associated with an increase in visual search efficiency (i.e., lower RTs). However, after adjustments for arousal and valence in Model 2 and arousal, valance, age in Model 3, only high potency ratings predicted a reduction in RT for angry faces. A likely explanation of this might be the relatively high inter-correlation between the dimensions of arousal and potency ($r = 0.539$). Thus, although arousal may in itself have an effect on visual search performance, as indicated by the results of Model 1, this effect may have been masked by the statistically stronger effect of potency. Hence, although our prediction was of an association between arousal and behavior, our finding that potency is the stronger predictor is neither controversial nor in direct disagreement with our previous results. As mentioned in the introduction, the study of emotional dimensions beyond valence and arousal has been proposed previously (Russell and Mehrabian, 1977; Fontaine et al., 2007). Given that we have found associations between potency and search efficiency in the current study and in a previous one (Lundqvist et al., 2013a)—and an additional association between potency and VSTM performance in the current study—this dimension clearly deserves to be included and investigated in future studies in this field of research.

LIMITATIONS

Using the same stimuli and the same study population across four tasks, we have consistently demonstrated a less accurate processing of angry faces in older than younger adults. Moreover, we found an association between emotional impression and emotional behavior, which indicates that subjective emotional impression influences behavior. However, some limitations are worth mentioning.

For example, the facial stimuli used all depicted younger adults. Although previous research on the recognition of facial expressions has demonstrated equal recognition processing of younger and older faces (Ebner and Johnson, 2009; Ebner et al., 2013), interactions between the age of poser and the age of participants might be present in other domains, such as those used in the present study. Thus, replication of the current study using both younger and older faces would increase the generalizability of our results.

A second potential limitation is the lack of an association between subjective emotional impression and categorical perception performance. A loss of almost 12% of the participants during the categorical perception task might have been sufficiently large to hinder the detection of such an association. The lack of an association might also be linked to nature of the task itself. Whereas the visual search task is related to response speed and the VSTM task is related to updating of information, the categorical perception task taps into categorical judgments or comparisons of two stimuli. Thus, this kind of more elaborative comparison ability might rely on a different behavior component than memory and attention processes, one that is hypothetically less affected by subjective emotional impression.

A third limitation is that because of the exploratory nature of this first study on emotional impression and behavior, we did not correct for multiple comparisons in the current

ANOVA or regression analyses. The current results must therefore be considered preliminary until they are replicated in future studies.

However, despite these potential shortcomings, our results uniquely and clearly demonstrate the importance of taking the emotional impression of the stimuli (including all three of the major emotional dimensions) into account in the study of emotional processing in general, and in aging research in particular.

ADULT AGING RESEARCH AND PROCESSING OF EMOTIONAL STIMULI

The results of the current study point to the importance of stimulus selection in studies of emotional behavior in younger and older adults. As shown in the current study, emotional faces elicit different emotional impressions in younger and older adults, and this in turn affects attention and memory processing. The present results are in line both with the memory literature, which shows that people remember material and events of emotional character better than those that are neutral (e.g., see Buchanan, 2007 for a review) and recent attention literature, which has found that arousal affects attention processing (e.g., Lundqvist et al., 2013b). Thus, a decrease in emotional impression might dampen the effect of emotion on memory performance and attention processing. By assuming that younger and older adults perceive emotional material equally in terms of the key dimensions of emotional impression, we risk misattributing age effects in emotional behavior. As our results indicate, a decrease in subjective emotional impression of angry faces was associated with poorer performance on memory and attention processing tasks. An interesting topic for future research would be to more systematically manipulate emotional impression and study subsequent emotional behavior in younger and older adults.

CONCLUSIONS

The results of all of the four tasks used in this study showed an age-related flattening of emotional impression of facial expressions that was more pronounced for angry than for happy faces. The lower level of emotional impression of angry faces in older adults was also mirrored in the two measures of emotional behavior (visual attention and VSTM) for the facial expressions. Regression analyses confirmed the association between emotional impression and behavior by showing that higher potency ratings predicted lower RTs in the visual search task and fewer errors in the VSTM task. These relationships were age-independent but statistically significant only for angry faces. The present findings of age differences in subjective emotional impression should be considered as a possible explanation of age differences in emotional effects on attention and memory in future studies.

ACKNOWLEDGMENTS

This research was conducted at the Aging Research Center, Karolinska Institutet and Stockholm University, Stockholm, Sweden, and was supported by the Bank of Sweden Tercentenary Foundation awarded to Håkan Fischer. The authors wish to thank Elsa Larsson, Karin Calissendorf, and Therese Lindström for the data collection.

REFERENCES

Beale, J. M., and Keil, F. C. (1995). Categorical effects in the perception of faces. *Cognition* 57, 217–239. doi: 10.1016/0010-0277(95)00669-X

Borg, C., Leroy, N., Favre, E., Laurent, B., and Thomas-Antérion, C. (2011). How emotional pictures influence visuospatial binding in short-term memory in ageing and Alzheimer's disease? *Brain Cogn.* 76, 20–25. doi:10.1016/j.bandc.2011.03.008

Bornstein, M. H., and Korda, N. O. (1984). Discrimination and matching within and between hues measured by reaction times: some implications for categorical perception and levels of information processing. *Psychol. Res.* 46, 207–222. doi: 10.1007/BF00308884

Buchanan, T. W. (2007). Retrieval of emotional memories. *Psychol. Bull.* 133, 761–779. doi: 10.1037/0033-2909.133.5.761

Calder, A. J., Keane, J., Manly, T., Sprengelmeyer, R., Scott, S., Nimmo-Smith, I., et al. (2003). Facial expression recognition across the adult life span. *Neuropsychologia* 41, 195–202. doi: 10.1016/S0028-3932(02)00149-5

Calder, A. J., Young, A. W., Perrett, D. I., Etcoff, N. L., and Rowland, D. (1996). Categorical perception of morphed facial expressions. *Vis. Cogn.* 3, 81–117. doi: 10.1080/713756735

Campanella, S., Quinet, P., Bruyer, R., Crommelinck, M., and Guerit, J.-M. (2002). Categorical perception of happiness and fear facial expressions: an ERP study. *J. Cogn. Neurosci.* 14, 210–227. doi:10.1162/089892902317236858

Carstensen, L. L. (2006). The influence of a sence of time on human development. *Science* 312, 1913–1915. doi: 10.1126/science.1127488

Carstensen, L. L., Isaacowitz, D. M., and Charles, S. T. (1999). Taking time seriously: a theory of socioemotional selectivity. *Am. Psychol.* 54, 165–181. doi: 10.1037/0003-066X.54.3.165

D'Argembeau, A., and van der Linden, M. (2004). Identity but not expression memory for unfamiliar faces is affected by ageing. *Memory* 12, 644–654. doi: 10.1080/09658210344000198

Ebner, N. C., and Johnson, M. K. (2009). Young and older emotional faces: are there age group differences in expression identification and memory? *Emotion* 9, 329–339. doi: 10.1037/a0015179

Ebner, N. C., Johnson, M. K., and Fischer, H. (2012). Neural mechanisms of reading facial emotions in young and older adults. *Front. Psychol.* 3:223. doi: 10.3389/fpsyg.2012.00223

Ebner, N. C., Johnson, M. R., Rieckmann, A., Durbin, K. A., Johnson, M. K., and Fischer, H. (2013). Processing own-age vs. other-age faces: neuro-behavioral correlates and effects of emotion. *Neuroimage* 78, 363–371. doi:10.1016/j.neuroimage.2013.04.029

Etcoff, N. L., and Magee, J. J. (1992). Categorical perception of facial expressions. *Cognition* 44, 227–240. doi: 10.1016/0010-0277(92)90002-Y

Folstein, M. F., Folstein, S. E., and McHugh, P. R. (1975). "Mini-mental state." A practical method for grading the cognitive state of patients for clinician. *J. Psychiatry Res.* 12, 189–198. doi: 10.1016/0022-3956(75)90026-6

Fischer, H., Nyberg, L., and Bäckman, L. (2010). Age-related differences in brain regions supporting successful encoding of emotional faces. *Cortex* 46, 490–497. doi: 10.1016/j.cortex.2009.05.011

Fontaine, J. R. J., Scherer, K. R., Roesch, E. B., and Ellsworth, P. C. (2007). The world of emotions is not two-dimensional. *Psychol. Sci.* 18, 1050–1057. doi: 10.1111/j.1467-9280.2007.02024.x

Grady, C. L., Hongwanishkul, D., Keightley, M., Lee, W., and Hasher, L. (2007). The effect of age on memory for emotional faces. *Neuropsychology* 21, 371–380. doi: 10.1037/0894-4105.21.3.371

Hahn, S., Carlson, C., Singer, S., and Gronlund, S. D. (2006). Aging and visual search: automatic and controlled attentional bias to threat faces. *Acta Psychol.* 123, 312–336. doi: 10.1016/j.actpsy.2006.01.008

Harmon-Jones, E., Gable, P., and Price, T. F. (2012). The influence of affective states varying in motivational intensity on cognitive scope. *Front. Integr. Neurosci.* 6:73. doi: 10.3389/fnint.2012.00073

Horning, S. M., Cornwell, R. E., and Davis, H. P. (2012). The recognition of facial expressions: an investigation of the influence of age and cognition. *Neuropsychol. Dev. Cogn. B Aging Neuropsychol. Cogn.* 19, 657–676. doi: 10.1080/13825585.2011.645011

Isaacowitz, D. M., Wadlinger, H. A., Goren, D., and Wilson, H. R. (2006). Is there an age-related positivity effect in visual attention? A comparison of two methodologies. *Emotion* 6, 511–516. doi: 10.1037/1528-3542.6.3.511

Jackson, M. C., Wu, C.-Y., Linden, D. E. J., and Raymond, J. E. (2009). Enhanced visual short-term memory for angry faces. *J. Exp. Psychol. Hum. Percept. Perform.* 35, 363–374. doi: 10.1037/a0013895

Keightley, M. L., Winocur, G., Burianova, H., Hongwanishkul, D., and Grady, C. L. (2006). Age effects on social cognition: faces tell a different story. *Psychol. Aging* 21, 558–572. doi: 10.1037/0882-7974.21.3.558

Kiffel, C., Campanella, S., and Bruyer, R. (2005). Categorical perception of faces and facial expressions: the age factor. *Exp. Aging Res.* 31, 119–147. doi: 10.1080/03610730590914985

Lang, P., and Bradley, M. (2010). Emotion and the motivational brain. *Biol. Psychol.* 84, 437–450. doi: 10.1016/j.biopsycho.2009.10.007

Langeslag, S. J. E., Morgan, H. M., Jackson, M. C., Linden, D. E. J., and Van Strien, J. W. (2009). Electrophysiological correlates of improved short-term memory for emotional faces. *Neuropsychologia* 47, 887–896. doi: 10.1016/j.neuropsychologia.2008.12.024

Langeslag, S. J. E., and van Strien, J. W. (2009). Aging and emotional memory: the co-occurrence of neurophysiological and behavioral positivity effects. *Emotion* 9, 369–377. doi: 10.1037/a0015356

Leclerc, C. M., and Kensinger, E. A. (2008). Effects of age on detection of emotional information. *Psychol. Aging* 23, 209–215. doi: 10.1037/0882-7974.23.1.209

Leclerc, C. M., and Kensinger, E. A. (2010). Age-related valence-based reversal in recruitment of medial prefrontal cortex on a visual search task. *Soc. Neurosci.* 5, 560–576. doi: 10.1080/17470910903512296

Liberman, A. M., Harris, K. S., Hoffman, H. S., and Griffith, B. C. (1957). The discrimination of speech sounds within and across phoneme boundaries. *J. Exp. Psychol.* 54, 358–368. doi: 10.1037/h0044417

Lindquist, K. A., Wager, T. D., Kober, H., Bliss-Moreau, E., and Barrett, L. F. (2012). The brain basis of emotion: a meta-analytic review. *Behav. Brain Sci.* 35, 121–202. doi: 10.1017/S0140525X11000446

Lindström, B. R., and Bohlin, G. (2011). Emotion processing facilitates working memory performance. *Cogn. Emot.* 25, 1196–1204. doi: 10.1080/02699931.2010.527703

Lundqvist, D., Esteves, F., and Öhman, A. (1999). The face of wrath: critical features for conveying facial threat. *Cogn. Emot.* 13, 691–711. doi: 10.1080/026999399379041

Lundqvist, D., Juth, P., and Öhman, A. (2013b). Using facial emotional stimuli in visual search experiments: the arousal factor explains contradictory results. *Cogn. Emot.* doi: 10.1080/02699931.2013.867479. [Epub ahead of print].

Lundqvist, D., and Litton, J. E. (1998). *The Averaged Karolinska Directed Emotional Faces – AKDEF.* Stockholm: CD ROM from Department of Clinical Neuroscience, Psychology section, Karolinska Institutet. ISBN: 91-630-7164-9.

Lundqvist, D., Svärd, J., and Fischer, H. (2013a). Age-related differences in sensitivity to emotional facial stimuli but age-independent association between arousal ratings and visual search efficiency. *Psychol. Topics* 22, 271–286.

Mather, M., and Carstensen, L. L. (2003). Aging and attentional biases for emotional faces. *Psychol. Sci.* 14, 409–415. doi: 10.1111/1467-9280.01455

Mather, M., and Knight, M. R. (2006). Angry faces get noticed quickly: threat detection is not impaired among older adults. *J. Gerontol. B Psychol. Sci. Soc. Sci.* 61, 54–57. doi: 10.1093/geronb/61.1.P54

Mather, M., and Sutherland, M. R. (2011). Arousal-biased competition in perception and memory. *Perspect. Psychol. Sci.* 6, 114–133. doi: 10.1177/1745691611400234

McDowell, C. L., Harrison, D. W., and Demaree, H. A. (1994). Is right hemisphere decline in the perception of emotion a function of aging? *Intern. J. Neurosci.* 79, 1–11.

Mikels, J. A., Larkin, G. R., Reuter-Lorenz, P. A., and Cartensen, L. L. (2005). Divergent trajectories in the aging mind: changes in working memory for affective versus visual information with age. *Psychol. Aging* 20, 542–553. doi: 10.1037/0882-7974.20.4.542

Osgood, C. E. (1966). Dimensionality of the semantic space for communication via facial expressions. *Scand. J. Psychol.* 7, 1–30. doi: 10.1111/j.1467-9450.1966.tb01334.x

Osgood, C. E., and Suci, G. J. (1955). Factor analysis of meaning. *J. Exp. Psychol.* 50, 325–338. doi: 10.1037/h0043965

Phelps, E. A., and LeDoux, J. E. (2005). Contributions of the amygdala to emotion processing: from animal models to human behavior. *Neuron* 48, 175–187. doi: 10.1016/j.neuron.2005.09.025

Ruffman, T., Henry, J. D., Livingstone, V., and Phillips, L. H. (2008). A meta-analytic review of emotion recognition and aging: implications for neuropsychological models of aging. *Neurosci. Biobehav. Rev.* 32, 863–881. doi: 10.1016/j.neubiorev.2008.01.001

Ruffman, T., Ng, M., and Jenkin, T. (2009). Older adults respond quickly to angry faces despite labeling difficulty. *J. Gerontol. B Psychol. Sci. Soc. Sci.* 64, 171–179. doi: 10.1093/geronb/gbn035

Russell, J. A. (2003). Core affect and the psychological construction of emotion. *Psychol. Rev.* 110, 145–172. doi: 10.1037/0033-295X.110.1.145

Russell, J. A., and Mehrabian, A. (1977). Evidence for a three-factor theory of emotions. *J. Res. Pers.* 11, 273–294. doi: 10.1016/0092-6566(77)90037-X

Spielberger, C. D., Gorsuch, R. L., and Lushene, R. E. (1988). *STAI-Manual for the State Trait Anxiety Inventory, 3rd Edn.* Palo Alto, CA: Consulting Psychological Press.

Suzuki, A., and Akiyama, H. (2013). Cognitive aging explains age-related differences in face-based recognition of basic emotions except for anger and disgust. *Neuropsychol. Dev. Cogn. B Aging Neuropsychol. Cogn.* 20, 253–270. doi: 10.1080/13825585.2012.692761

Svärd, J., Wiens, S., and Fischer, H. (2012). Superior recognition performance for happy masked and unmasked faces in both younger and older adults. *Front. Psychol.* 3:520. doi: 10.3389/fpsyg.2012.00520

Young, A. W., Rowland, D., Calder, A. J., Etcoff, N. L., Seth, A., and Perrett, D. I. (1997). Facial expression megamix: tests of dimensional and category accounts of emotion recognition. *Cognition* 63, 271–313. doi: 10.1016/S0010-0277(97)00003-6

Zigmond, A., and Snaith, R. (1983). The hospital anxiety depression scale. *Acta Psychiatr. Scand.* 67, 361–370. doi: 10.1111/j.1600-0447.1983.tb09716.x

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 16 December 2013; accepted: 22 April 2014; published online: 14 May 2014.
Citation: Svärd J, Fischer H and Lundqvist D (2014) Adult age-differences in subjective impression of emotional faces are reflected in emotion-related attention and memory tasks. Front. Psychol. ***5****:423. doi: 10.3389/fpsyg.2014.00423*
This article was submitted to Emotion Science, a section of the journal Frontiers in Psychology.

frontiers in PSYCHOLOGY

ORIGINAL RESEARCH ARTICLE
published: 25 February 2014
doi: 10.3389/fpsyg.2014.00094

Friend or foe? Decoding the facilitative and disruptive effects of emotion on working memory in younger and older adults

Linda Truong* and Lixia Yang*

Department of Psychology, Ryerson University, Toronto, ON, Canada

Edited by:
Natalie Ebner, University of Florida, USA

Reviewed by:
Hakan Fischer, Stockholm University, Sweden
Jana Nikitin, University of Zurich, Switzerland
Paul Verhaeghen, Georgia Institute of Technology, USA

***Correspondence:**
Linda Truong and Lixia Yang, Department of Psychology, Ryerson University, 350 Victoria Street, Toronto, ON M5B 2K3, Canada
e-mail: ltruong@psych.ryerson.ca; lixiay@psych.ryerson.ca

A growing body of work on emotion-cognition interactions has revealed both facilitative and disruptive effects of emotion on working memory in younger adults. These differing effects may vary by the goal relevancy of emotion within a task. Additionally, it is possible that these emotional effects would be larger for older adults, considering findings of preserved emotional processing with age. To test these hypotheses, the current study examined the effects of emotional content and aging on working memory for target information in the presence of distraction. Thirty-six younger (ages 18–29) and 36 older adults (ages 65–87) completed a delayed-response working memory task. Participants viewed two target words intermixed with two distracter words, and then judged whether a subsequently presented probe word was one of the target words. The emotional content (valence and arousal) of targets and distracters was systematically manipulated. Results indicated that emotional targets facilitated working memory in both age groups. In contrast, emotional distracters disrupted performance. Negative distracters were particularly disruptive for older adults, but younger adults did not show an emotional interference effect. These findings help clarify discrepancies in the literature and contribute to the sparse research on emotional working memory in older adults.

Keywords: aging, emotions, working memory, goal relevance, distraction, interference resolution

INTRODUCTION

The ability to successfully complete a task—such as driving—requires focused attention on task-relevant information, like traffic lights, and limited attention to task-irrelevant distraction, such as roadside advertisements. Similarly, successful working memory performance consists of briefly maintaining relevant target information while ignoring interference from irrelevant distraction. Research suggests that working memory declines with normal aging, resulting in slower and less accurate responses in older adults (e.g., Rypma and D'Esposito, 2000; Gazzaley et al., 2005). According to the inhibitory deficit theory, age-related deficits in inhibition—the ability to avoid or remove distracting information from working memory—reduces the ability to focus attention on task-relevant information, thus lowering overall working memory performance (i.e., slower and/or less accurate responses) (Hasher and Zacks, 1988). In contrast to this decline, processing of emotional information is preserved in old age (see Scheibe and Carstensen, 2010 for a review). A body of research suggests a tendency for older adults to attend to, and remember, positive information relative to neutral and negative information, termed an age-related "positivity effect" (Mather and Carstensen, 2005; see Reed and Carstensen, 2012 for a review). Several theories have been proposed to account for this age-related preference toward positive information (Murphy and Isaacowitz, 2008 for a meta-analysis that did not find evidence of this preference). According to the socioemotional selectivity theory (Carstensen et al., 1999), the preserved emotional processing and functioning in old age is due to a motivational shift toward emotional regulation goals (i.e., achieving positive affect) as a result of increasingly limited time horizons with age. The dynamic integration theory (Labouvie-Vief, 2003) proposes that older adults increasingly prefer positive over negative information, due to greater cognitive demands required to process the latter. Taken together, these findings raise an important question: how is working memory influenced by emotional information in older adults? Specifically, would older adults' preserved emotional processing lead to working memory enhancements or would it further impair performance?

Some insights into these questions can be gained from a theory about working memory and emotion interactions: the dual-competition model (DCM; Pessoa, 2008, 2009). This model states that biases toward emotional information influence the allocation of processing resources. When emotional information is relevant to a task goal, performance is facilitated due to the additional resources that are recruited for emotional processing. However, this bias toward emotional information can be impairing if it conflicts with a task goal, thus depleting resources needed for executive control processes in working memory, as in the case of task-irrelevant emotional information (e.g., emotional distracter items). Thus, DCM predicts that working memory performance will be disrupted in the face of task-irrelevant emotional information. The DCM can be used to interpret the results of studies that have examined emotional working memory in both older and younger adults. For example, one study compared maintenance of affective (emotional intensity of emotional images) vs. visual information (brightness intensity of neutral images) over a delay period with both younger and older adults (Mikels et al., 2005). Results revealed an age-related working memory deficit for visual maintenance, but no such deficit was found for maintenance of emotional intensity. Interestingly, older adults actually outperformed younger adults on trials where positive affect was maintained. In contrast, younger adults performed better on negative relative to positive trials. These results suggest that older adults' preserved emotional processing—of positive information, in particular—can offset their working memory declines, resulting in maintained or even enhanced performance. Similarly, another study by Mammarella et al. (2013a) found that age-related deficits in working memory were reduced when the task contained emotional information. This study examined performance on an operation span task in which participants maintained a set of neutral or emotional target words in working memory while performing math operations. Results indicated larger age differences for neutral words, but reduced or eliminated age differences for positive and negative words, respectively. A similar study also found better working memory performance for positive and negative words, relative to neutral words, in older adults (Mammarella et al., 2013b). Such findings also extend to paradigms using emotional pictures. Borg et al. (2011) compared performance on two working memory tasks with emotional pictures in younger and older adults. In the first task, participants were shown two negative and two neutral pictures, presented sequentially. The task was to maintain these four target pictures during a delay, after which a probe picture appeared. Participants had to indicate whether this probe was an old (i.e., from the target set) or a new picture they had not seen before. For both age groups, accuracy on this task was better when target stimuli were negative vs. neutral. Taken together, these findings showed little age differences in emotional working memory, suggesting that performance on task-relevant emotional information is relatively preserved in older adults.

It should be noted that previous studies have primarily focused on analyzing the effect of emotional task-*relevant* information—little attention has been paid to the potential effects of task-*irrelevant* emotional information. The few existing studies have been primarily conducted with younger adults. In one such study, it was found that emotional distracters presented during a delay period can impair younger adults' working memory performance for target items (e.g., Dolcos and McCarthy, 2006). It is unknown whether detrimental effects of emotion would be found or perhaps magnified for older adults. The second working memory task in Borg et al. (2011) sheds a light on this. In this task, participants were asked to bind four target pictures (negative or neutral) with their respective presentation locations and then identify whether a subsequently presented probe picture was presented in its original location. Results revealed no emotional effects on younger adults' performance. However, older adults performed worse for negative vs. neutral pictures. It was interpreted that resources devoted to processing negative information may have limited the availability of resources needed for effortful processing in working memory (i.e., binding) in older adults. Thus, the emotional aspects of the negative pictures may have diverted resources away from the primary binding task. However, another study did not find any effects of emotional pictures on a 2-back task (which consists of both target and distracter items) in older adults (Döhnel et al., 2008). Thus, it remains unclear when emotional information hinders older adults' working memory.

The current study took a novel approach to directly examine whether the effects of emotional content vary depending on the goal-relevancy of the emotional content. Examining the effect of emotional distracters is particularly important considering findings that older adults' working memory deficits are due to a specific decline in the inhibition of distracters, rather than the ability to attend to and maintain goal-relevant content (Gazzaley et al., 2005). In the current study, we modified the delayed-response working memory paradigm used by Gazzaley et al. (2005) in which both targets and distracters were presented within a memorandum set. Younger and older participants viewed four sequentially presented words: two were cued as targets and two were cued as distracters, by different colored fonts. After a delay, a probe word (could be a target, a distracter, or a new control probe) appeared. Participants' task was to indicate whether this probe was a word that was cued as a target from the current memorandum set. For some trials, targets were emotional words presented with neutral distracter words; for others, targets were neutral and distracters were emotional. These trials were compared to trials where both targets and distracters were neutral words, to evaluate the emotional effect of task-relevant (i.e., targets) vs. task-irrelevant (i.e., distracter) information. The critical manipulation was the emotional content—as indexed by both the valence (positive, negative, neutral) and arousal (high vs. low)—of targets and distracters. Arousal was manipulated in this study given the evidence of distinct neural networks involved in processing arousing vs. valenced information (Kensinger and Corkin, 2004) and differential effects of low vs. high arousal valenced information (Leclerc and Kensinger, 2008). The arousal levels of stimuli were systematically manipulated so that half of the words were high arousal and half were low arousal within each of the three valence categories. This allowed us to evaluate valence effects by controlling for the level of arousal.

This study aimed to address three questions: (1) Does emotional target information facilitate working memory? (2) Does emotional distracter information hinder working memory? (3) Do these effects change with age? Based on predictions derived from the dual-competition model (Pessoa, 2008, 2009) and the literature reviewed earlier, several hypotheses were proposed. First, it was expected that emotional content would be facilitative to working memory (i.e., faster and/or more accurate responses) for goal-relevant target information and would reduce age differences in working memory, in line with previous studies (e.g., Mikels et al., 2005; Mammarella et al., 2013a). In contrast, performance would be disrupted (i.e., slower and/or less accurate responses) by emotional distracters (e.g., Dolcos and McCarthy, 2006); we hypothesized that a detrimental effect due to emotional content would be more evident in older adults. Older adults' limited ability to inhibit distracter information (e.g., Yang and Hasher, 2007) may result in increased demand for cognitive resources to successfully resolve interference arising from these distracters. However, based on the dual-competition model, resources for interference resolution may be further limited when they are prioritized to be diverted toward the processing of emotional information (Pessoa, 2008, 2009). As such, we hypothesized that disruptive effects of emotional distracters would be more evident in older vs. younger adults. Finally, we also hypothesized that older adults would show enhanced attention to positive information, in line with findings of an age-related positivity bias (Mather and Carstensen, 2005). Specifically, we expected that this enhanced attention would result in facilitative effects of positive target information but also disruptive effects from positive distracter information.

MATERIALS AND METHODS

PARTICIPANTS

Thirty-six healthy younger adults (ages 18–29, $M = 19.69$, $SD = 2.84$; 3 males) and 36 healthy older adults (ages 65–87, $M = 73.25$, $SD = 6.37$; 6 males) participated in this study. Younger adults were recruited from the undergraduate participant pool at Ryerson University. They received course credit as compensation. Older adults were recruited from the Ryerson Senior Participant Pool at Ryerson University and received $10 per hour for participation. Four older adults were replaced: three for low accuracy in the working memory task (< 80%; see Results) and one due to computer malfunctions. All participants were tested at the Cognitive Aging Laboratory of Ryerson University and provided informed consent prior to commencing the study. All procedures in the study were conducted according to regulatory standards and were approved by the Research Ethics Board at Ryerson University.

We excluded participants who: (a) learned English after the age of 6; (b) scored less than 20 on the Shipley Institute of Living Vocabulary (Shipley, 1940); (c) scored greater than 26 on the Beck Anxiety Inventory (BAI; Beck et al., 1988), suggesting severe anxiety symptoms; (d) scored greater than 29 on the Beck Depression Inventory (BDI; Beck et al., 1996), suggesting severe depressive symptoms; (e) had previous neurological disorders (e.g., stroke, dementia, prolonged periods of unconsciousness, and head injury); or (f) uncontrolled medical conditions (e.g., diabetes, cholesterol, and cardiovascular diseases). Older adults were screened with the Short Blessed Test (SBT; Katzman et al., 1983) for dementia-related cognitive impairments and all participants in the final sample scored above the cut-off score of 6 ($M = 0.78$, $SD = 1.35$). All demographic and health information were collected through a background information questionnaire. There were age differences in several demographic and cognitive measures (see **Table 1**). Older adults had more years of education and also learned English at a younger age than did younger adults. Older adults scored higher on the Shipley Institute of Vocabulary Test and on the positive affect scale of the Positive and Negative Affect Schedule (PANAS; Watson et al., 1988), but scored lower on the BAI, the BDI, and the Digit-Symbol Substitution Task (DSST; Wechsler, 1981) than did younger adults. These age differences are typically found in research examining cognitive aging and emotion (e.g., Isaacowitz et al., 2008).

Table 1 | Participant characteristics.

Measure	Younger adults	Older adults
	***M* (*SD*)**	***M* (*SD*)**
Years of education**	13.00 (1.74)	17.53 (4.11)
Age learned english*	1.13 (1.92)	0.14 (0.83)
Digit-Symbol Substitution Task[a]**	82.86 (15.37)	68.78 (14.97)
PANAS-positive affect[b]**	27.22 (7.91)	33.83 (6.40)
PANAS-negative affect[b]	15.19 (5.48)	13.61 (4.14)
Shipley vocabulary **	27.50 (3.00)	37.36 (1.93)
Beck Anxiety Inventory**	12.67 (7.61)	6.19 (5.67)
Beck Depression Inventory**	10.83 (6.67)	5.06 (4.65)
Health rating[c]	7.79 (1.13)	8.25 (1.27)

[a] *Digit-Symbol scores were based on the number of correct solutions within a 2-min time limit;*

[b] *PANAS, the Positive and Negative Affect Schedule;*

[c] *Health ratings were self-reported based on a 1 ("poor") to 10 ("excellent") Likert-type scale;*

$^{*}p < 0.01$, $^{**}p < 0.001$.

STIMULI

All stimuli for the delayed-response working memory task in this experiment were programmed with E-prime 1.0 and presented on a 17 inch computer screen. The stimuli consisted of a total of 329 words selected from the Affective Norms of English Words (ANEW) database (Bradley and Lang, 1999). The ANEW database contains normed ratings of arousal (1 for low arousal to 9 for high arousal) and valence (1 for negative valence to 9 for positive valence). Of the 329 words selected, 240 words were used for memoranda (targets or distracters), 20 for new control words, 48 for buffer/filler trials, and 21 for practice trials.

Memoranda

A total of 240 words were selected to be targets ($N = 120$) and distracters ($N = 120$) and consisted of 48 positive words (valence $M = 7.44$, range: 6.59–8.39), 48 negative words (valence $M = 2.86$, range: 1.57–3.50), and 144 neutral words (valence $M = 4.98$, range: 4.00–6.00). Half of the words for each valence category were high in arousal (HA; arousal range: 4.51–7.45) and the other half were low in arousal (LA; arousal range: 2.39–4.48), resulting in a total of 6 word lists (one HA and one LA list for each of the three valence categories). All valence categories in the LA list were matched for arousal ($ps > 0.10$); positive and negative HA lists were matched for arousal ($p = 0.90$) and both were higher in arousal than the neutral HA list ($ps < 0.001$). Each of these six lists was then divided into two sets: one set that served as targets and one set that served as distracters. These two sets were matched on word frequency ($M = 42.21$; range 1–294) and word length (i.e., the number of letters) ($M = 6.26$; range: 3–11) ($ps > 0.21$).

Each trial consisted of a set of four memoranda: two target and two distracter words. The combination of words used in each trial varied according to trial type: (1) positive targets paired with neutral distracters (posT/neuD); (2) negative targets paired with neutral distracters (negT/neuD); (3) neutral targets paired with neutral distracters (neuT/neuD); (4) neutral targets paired with positive distracters (neuT/posD); and (5) neutral targets paired with negative distracters (neuT/negD). In each trial, one target/distracter was HA and the other target/distracter was LA. Within each trial, targets and distracters were roughly matched on arousal, frequency, and word length. For example, a neuT/negD trial consisted of one neutral HA target, one neutral LA target, one negative HA distracter, and one negative LA distracter. There were 12 trials for each trial type, resulting in a total of 60 trials. The trials were presented in a pseudorandomized order such that no more than three trials of the same trial type occurred consecutively. The sequencing of memoranda within a trial was also pseudorandomized: half of the trials combined either two targets or two distracters in a row (e.g., distracter-distracter-target-target) and the other half with intermixed targets and distracters (e.g., distracter-target-distracter-target).

Probes

After a brief delay following presentation of the memoranda, a probe word was presented. Probes belonged to one of six categories: (1) HA targets; (2) LA targets; (3) HA distracters; (4) LA distracters; (5) HA new control probes; and (6) LA new control probes. Target and distracter probes were from the current trial's memoranda set. New control probes were one of 20 additional words: 4 positive words (valence $M = 7.41$, range: 7.07–7.66), 4 negative words (valence $M = 2.80$, range: 2.73–2.90), and 12 neutral words (valence $M = 5.08$, range: 4.32–5.85), selected from ANEW (Bradley and Lang, 1999); half of the words in each valence category were HA (arousal $M = 5.70$, range: 4.66–6.41) and half were LA (arousal $M = 3.91$, range: 3.18–4.29). The new control probes matched those of the distracters on valence within a trial set (e.g., a neuT/negD trial had a new control probe that was also negative).

The six probe categories occurred equally often for each trial type. The selection of probes (i.e., which target word served as the target probe for a particular trial) was counterbalanced with a Latin Square design, resulting in six counterbalance conditions. In addition, the order within a memoranda set of targets and distracter probes was also counterbalanced such that each appeared equally often at each of the four possible positions (e.g., a HA target cue appeared in the first to fourth position equally).

PROCEDURE

Upon arrival at the laboratory, participants read and signed an informed consent, and then completed the computerized delayed-response working memory task. Participants were seated centrally in front of the computer screen at a reading distance. They were instructed to keep their eyes on the screen at all times during the working memory task. The task instructions indicated which words they should remember (i.e., targets) and which they should ignore (i.e., distracters), as cued by either blue or red font color, counterbalanced across participants. Each trial began with a fixation cross presented for 500 ms, followed by a memoranda set. Each set contained two target and two distracter words, each presented sequentially for 800 ms with an inter-stimulus interval of 200 ms. After a 500 ms delay, a probe word (in black font) was presented for 2000 ms. Participants were instructed to press a key labeled "YES" (the "/" key) if the probe was a target word from the current set. If the probe was a distracter or a new control word, participants were instructed to press the "NO" key (the "Z" key). Participants were instructed to respond as quickly and accurately as possible. Following their responses, an accuracy feedback screen ("Correct," "Incorrect," or "No response detected") was presented for 800 ms (see **Figure 1**).

The working memory task consisted of a practice block (5 trials; approximately 35 s, with an option to be repeated if needed) and an experimental block (72 trials: 60 experimental, six buffer, and six filler trials; approximately 8.5 min). Buffer trials occurred at the beginning and end of the block to reduce primacy and recency effects and filler trials were randomly intermixed with experimental ones. All buffer and filler trials consisted of target probes, requiring "yes" responses, in order to minimize response bias by balancing the number of "yes" responses with those of "no" responses to make them approximately the same (i.e., 44% "yes" responses). In addition, no more than three "yes" or "no" responses occurred in a row throughout the task.

After the working memory task, participants completed the DSST, a measure of perceptual-motor speed for 2 min. They then completed the PANAS, a self-reported assessment of positive and negative affect. At the end, participants completed a variety of paper-and-pencil tests and questionnaires, including the Shipley Institute of Vocabulary Test, the BAI, the BDI, and a background information questionnaire, to determine their eligibility. Older adults then completed the SBT. Finally, participants were

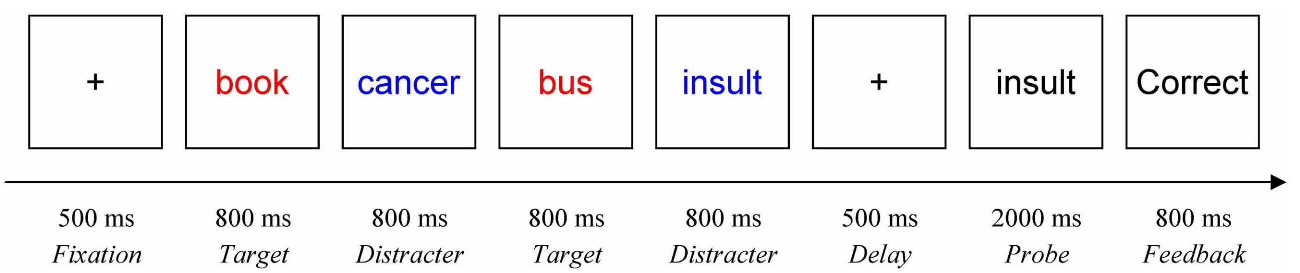

FIGURE 1 | Working memory task procedure (a neuTnegD trial with a negative distracter probe). In this example trial, the participant correctly responded "NO" to the distracter probe and received a feedback screen indicating that the response was correct.

debriefed and paid or granted course credit. The total duration of the experiment was approximately 1 h.

RESULTS

To examine differential emotional effects of goal-relevant target vs. goal-irrelevant distracting information, response times (RTs) and accuracy in the working memory task were analyzed with mixed analyses of variance (ANOVAs). These analyses were conducted separately for target probe responses (reported as target identification, requiring "yes" responses) and responses to distracter and control probes (reported as interference scores, requiring "no" responses). Only RTs for correct responses were included in the RT analyses. RTs were also trimmed by excluding those that were beyond 2.5 *SD*s away from the mean for each participant in each condition, resulting in an exclusion of 6% of data points. To ensure sufficient correct trials for meaningful RT data in each condition, we replaced three individuals with overall accuracy scores lower than 80% ($M = 74.33$, $SD = 5.69$, range: 68–79).

EFFECTS OF EMOTIONAL CONTENT ON TARGET IDENTIFICATION

To examine the effects of emotional content (i.e., arousal and valence) on the identification of target probes, a 2 × 2 × 3 mixed ANOVA with Age (younger, older) as a between-subjects variable, Arousal (high, low) and Valence (positive, negative, neutral) as within-subjects variables, was conducted on RTs and accuracy to target probes that require "yes" responses. The data for three younger and two older adults were excluded in the RT analysis because of missing data points due to RT trimming or lack of correct responses in a condition.

RT analysis

Figure 2 displays the results of the RT analysis. The mixed ANOVA revealed a main effect of Age, $F_{(1, 65)} = 11.13, p = 0.001$, $\eta_p^2 = 0.15$. Overall, younger adults ($M = 739.59$, $SD = 154.08$) were faster than older adults ($M = 875.70$, $SD = 178.61$). The main effect of Arousal was significant, $F_{(1, 65)} = 5.01, p = 0.03$, $\eta_p^2 = 0.07$. This arousal effect was qualified by an Age by Arousal interaction, $F_{(1, 65)} = 4.32$, $p = 0.04$, $\eta_p^2 = 0.06$. The arousal effect was only significant for younger, $t_{(32)} = -2.85$, $p = 0.01$, but not for older adults ($p = 0.90$). The Arousal by Valence interaction was also significant, $F_{(2, 130)} = 6.64, p = 0.002, \eta_p^2 = 0.09$, with faster RTs to high arousal than to low arousal for positive, $t_{(66)} = -4.21, p < 0.001$, but not for negative ($p = 0.70$) or neutral target probes ($p = 0.90$). This benefit of arousal for positive targets was found for both younger, $t_{(32)} = -2.54, p = 0.02$, and older, $t_{(33)} = -3.59, p = 0.001$, adults. All other effects were not significant (*F*s < 1.30, *p*s > 0.28).

Accuracy analysis

The same mixed ANOVA on accuracy revealed a main effect of Valence, $F_{(2, 140)} = 5.79, p = 0.004, \eta_p^2 = 0.08$, with lower accuracy for neutral ($M = 0.92$, $SD = 0.16$) than for both positive ($M = 0.97$, $SD = 0.08$), $t_{(71)} = 2.82$, $p = 0.006$, and negative words ($M = 0.97$, $SD = 0.11$), $t_{(71)} = 2.88, p = 0.005$; the latter two did not differ from each other, $t_{(71)} = -0.21$, $p = 0.84$. This suggested a facilitative effect of emotional valence. In addition, the main effect of Arousal was marginally significant, $F_{(1, 70)} = 3.15$, $p = 0.08$, $\eta_p^2 = 0.04$, with higher accuracy for high arousal targets ($M = 0.97$, $SD = 0.09$) than for low arousal targets ($M = 0.94$, $SD = 0.01$), suggesting a trend toward a facilitative effect of emotional arousal (**Figure 3**). All other effects were not significant (*F*s < 0.31, *p*s > 0.73).

Overall, these findings indicated age-related slowing but preserved accuracy for target identification in working memory, possibly due to age-related shifts toward prioritization of accuracy over speed (Salthouse, 1979). The results also revealed that arousal facilitated the speed in identifying positive targets and valence facilitated target identification accuracy. In summary, emotional content (arousal or valence) facilitated target identification by making responses either faster or more accurate and the effects were largely similar across the two age groups.

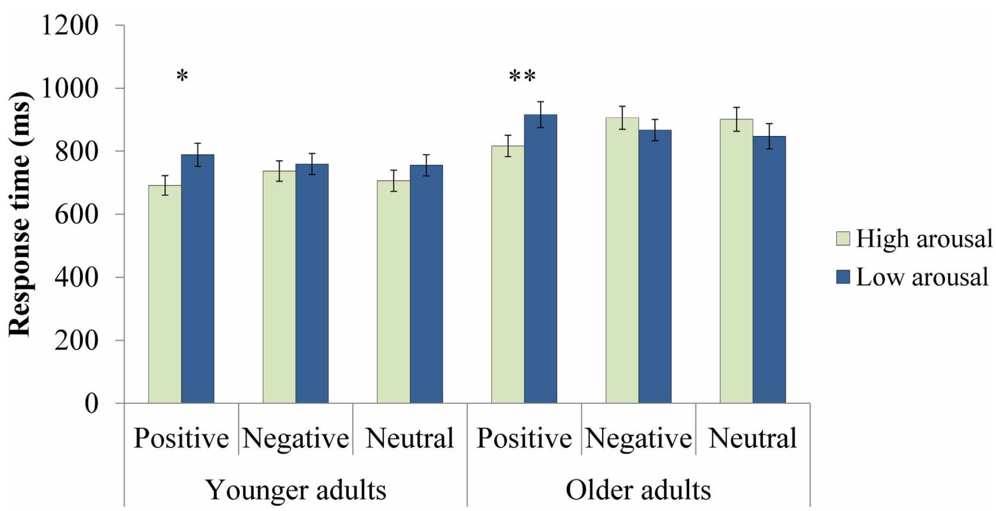

FIGURE 2 | Response times for correct target identification responses. Error bars represent standard errors. *$p < 0.05$; **$p < 0.01$.

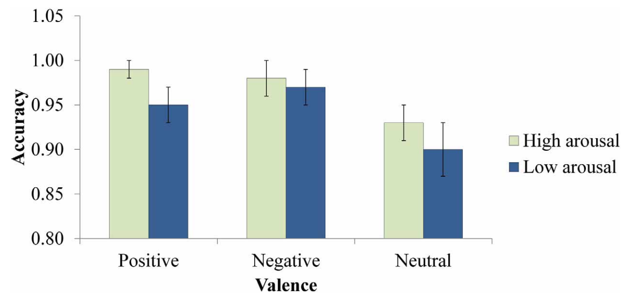

FIGURE 3 | Accuracy for target identification responses. Error bars represent standard errors.

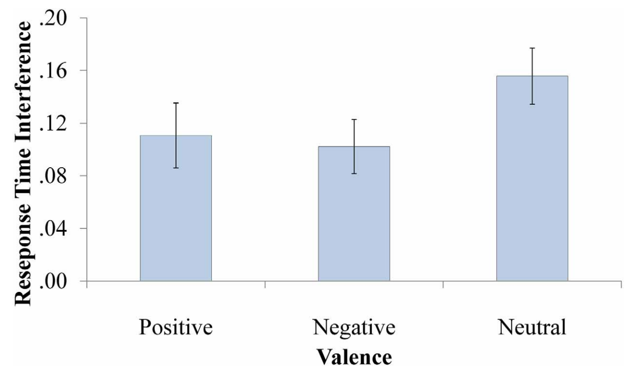

FIGURE 4 | Response time interference scores. Error bars represent standard errors.

EFFECTS OF EMOTIONAL CONTENT ON INTERFERENCE OF DISTRACTERS

Following some previous work (Yang and Hasher, 2007), interference was operationally defined as performance differences in responding to distracter vs. matched control probes. This definition is based on the assumption that both distracter and control probes require the same "no" response (i.e., correct rejection of the probe as a target). The primary difference is that distracter probes were presented earlier during encoding. If participants successfully inhibited distracters, we would expect minimal interference at retrieval/probe responding; thus, performance would be very similar to that for control probes (newly presented words). However, if participants were not efficiently inhibiting or deleting the distracter from working memory, these distracter probes may result in false alarms (i.e., incorrectly identifying a distracter as a target probe) or slower rejection responses, thus increasing the performance difference between distracter and the matched control probes.

For the RT analysis, interference was indexed with proportional RT difference scores, calculated by subtracting the RTs to control probes from RTs to the matched distracters (distracters—controls), which was then divided by the RTs to control probes. A similar calculation was applied to the accuracy data, by subtracting the accuracy to distracter probes from that to matched controls, and then divided by the accuracy to controls. Thus, larger scores in both RT and accuracy indicated greater interference. These proportional interference scores controlled for potential age-related differences in response times and accuracy. These interference scores were analyzed with 2 × 2 × 3 mixed ANOVAs with Age (younger, older) as a between-subjects variable, and Arousal (high, low) and Valence (positive, negative, neutral) as within-subjects variables. For the RT analysis only, the data for one younger and four older adults were not included due to missing data points as a result of RT trimming or lack of correct responses in a condition.

RT analysis

The mixed ANOVA revealed a marginal main effect of Valence, $F_{(2,\,130)} = 2.62$, $p = 0.08$, $\eta_p^2 = 0.04$. Follow-up paired *t*-tests indicated slightly less interference for negative ($M = 0.10$, $SD = 0.17$) vs. neutral ($M = 0.16$, $SD = 0.17$) probes, $t_{(66)} = -1.79$, $p = 0.08$. All other effects were not significant ($Fs < 2.24$, $ps > 0.14$). The RT interference scores across valence are displayed in **Figure 4**.

Accuracy analysis

Figure 5 displays the results of the accuracy analysis. The ANOVA revealed an Age by Valence interaction, $F_{(2,\,140)} = 3.89$, $p = 0.02$, $\eta_p^2 = 0.05$. There was a trend toward a main effect of Valence for older, $F_{(2,\,70)} = 2.49$, $p = 0.09$, but not for younger adults, $F_{(1.63,\,57.10)} = 0.83$, $p = 0.42$ (Greenhouse-Geisser correction). Guided by our hypotheses, we conducted planned comparisons. The results revealed that older adults experienced greater interference from negative ($M = 0.12$, $SD = 0.16$) than neutral ($M = 0.02$, $SD = 0.23$), $t_{(35)} = 2.25$,$p = 0.03$, and positive probes ($M = 0.03$, $SD = 0.23$), $t_{(35)} = -1.87$, $p = 0.07$; the latter two did not differ, $p = 0.89$. Follow-up independent samples *t*-tests for each valence also indicated age differences for negative probes only: older adults ($M = 0.12$, $SD = 0.16$) experienced greater interference from negative distracters than younger adults ($M = 0.02$, $SD = 0.12$), $t_{(64.49)} = -2.98$, $p = 0.004$. As a matter of fact, older adults experienced significant interference from negative probes, $t_{(35)} = 4.42$, $p < 0.001$, whereas younger adults did not, $t_{(35)} = 0.96$, $p = 0.35$. This age difference was not present for positive or neutral interference scores, $ts > 0.44$, $ps > 0.56$. All other effects were not significant ($Fs < 1.06$, $ps > 0.35$).

DISCUSSION

To our knowledge, this is the first study to examine how the effects of emotional content on working memory vary according to goal relevancy and age. Consistent with our hypotheses, the overall results suggest that working memory is facilitated (i.e., faster and more accurate responses) by the emotional content of goal-relevant target information. In addition, working memory can be disrupted (i.e., larger interference) by the emotional content of goal-irrelevant distraction. However, this disruptive effect appears to be limited to negatively-valenced stimuli and occurs only for older adults. These results add novel contributions to our understanding of facilitative and disruptive emotional effects on working memory by manipulating and distinguishing between goal-relevant and goal-irrelevant information.

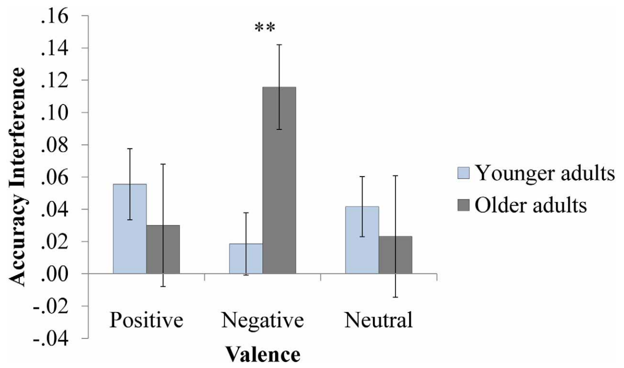

FIGURE 5 | Accuracy interference scores. Error bars represent standard errors. $^{**}p < 0.01$.

EMOTIONAL TARGET INFORMATION FACILITATES WORKING MEMORY

The dual-competition model (DCM; Pessoa, 2008, 2009) posits that emotional information receives prioritized processing, which can be beneficial when the information is relevant to current goals. Our study found support for this prediction as responses were faster or more accurate to emotional/high arousing relative to neutral/low arousing goal-relevant target words. These results are consistent with studies that have found facilitative effects of emotion on working memory (Mammarella et al., 2013a). However, the facilitative effect of arousal only occurred for response speed, and was significant only for positive, but not for negative, target words. This appears to conflict with predictions from the DCM of enhanced processing for high arousal negative information (e.g., threat-relevant stimuli). We advise caution when interpreting this result, as performance was close to ceiling for negative targets, which may have limited our ability to find differences in performance between low and high arousal negative words. However, the findings of faster responses to positive high arousal targets are consistent with another study in which high arousal positive targets were detected faster amidst an array of neutral distracters (Leclerc and Kensinger, 2008). Taken together, it appears that high arousal positive goal-relevant stimuli can receive prioritized processing in competition against neutral distracters in the current paradigm.

In addition, the results indicated higher accuracy for emotional vs. neutral target word identification for both younger and older adults. There was also a pattern toward more accurate responses for high vs. low arousal words. These results are consistent with our hypotheses and other findings of attenuation of age differences when emotional materials are used (e.g., Mikels et al., 2005; Borg et al., 2011; Mammarella et al., 2013a). However, we found less evidence of a specific advantage for positive goal-relevant information in older adults, which we hypothesized based on literature pertaining to the positivity effect. Instead, our overall results indicated that emotional content in general, regardless of valence, appears to help younger and older adults to a similar extent. Together, these results may suggest that older adults are still capable of allocating resources to prioritize processing of emotional items, and thus show no impairment on working memory accuracy for target information.

NEGATIVE DISTRACTER INFORMATION DISRUPTS WORKING MEMORY IN OLDER ADULTS

In contrast to the facilitative effects of emotion on working memory, there was some evidence supporting our hypothesis that emotional goal-irrelevant information can disrupt performance. Negative distracter stimuli caused greater interference in working memory, resulting in lower accuracy performance, but this was found for older adults only; no such effect occurred for younger adults. This finding converges, to some degree, with a large body of literature that suggests a shift toward a positivity bias in older adults vs. a negativity bias in younger adults (Reed and Carstensen, 2012). Although we hypothesized that older adults' enhanced attention to positive distracters would be detrimental to their working memory performance, our results suggested poorer performance due to negative distracters. Older adults were also less successful at resolving interference from negative distracters compared to younger adults. Poorer interference resolution involving negative distracters in older adults relative to younger adults is in line with research suggesting that younger and older adults differ in how negative information is processed, with greater attention toward negative information in younger adults and avoidance of negative information in older adults (Mather and Carstensen, 2003; Isaacowitz et al., 2006). A speculative interpretation of these findings may be derived based on the dual-competition model (DCM; Pessoa, 2008, 2009). DCM posits that task-irrelevant emotional stimuli can impair executive control by consuming resources needed for conflict resolution. If older adults have an "anti-negativity" bias, defined as avoidance of negative, relative to younger adults (e.g., Isaacowitz et al., 2006; Knight et al., 2007) or have particular difficulties processing cognitively-demanding negative information (Labouvie-Vief et al., 2010), it is possible that they did not devote sufficient resources to successfully encode negative words as distracters. This would result in a weaker representation of the negative word as a distracter item. When they encountered these words as probes during retrieval, resources may have been reallocated to prioritize the processing of these weak representations of negative information, at the expense of interference resolution. Thus, older adults' poorer performance with negative interference may be due to a "double-edged sword" of negative goal-irrelevant information, caused by both anti-negativity biases during encoding and competition between emotional information and executive control for limited resources at retrieval. In contrast, younger adults may have more resources to spare and appear to be more successful in processing negative content while simultaneously engaging in interference resolution. This is demonstrated in our study and others (Levens and Phelps, 2008) as an absence or reduction of interference arising from negative probes for younger adults.

Alternatively, disrupted performance from negative interference in older adults could also be explained as heightened attention to negative information in older adults. A negativity bias in older adults has been observed when cognitive resources are limited, often manipulated through divided or dual attention paradigms (Mather and Knight, 2005; Knight et al., 2007). Thus, it is possible that the working memory paradigm used in the current study sufficiently reduced or divided cognitive resources in older adults by requiring interference resolution, which resulted in greater attention toward negative information. This enhanced processing of negative information may have distracted older adults to a greater extent relative to positive and neutral information, resulting in increased false alarms to negative distracter probes.

FUTURE OUTLOOK

Taken together, the results from this study provide evidence suggesting that the differential effects of emotion on working memory may vary by arousal, valence, age, and goal relevancy. However, there were several limitations of the current study. First, the irrelevant information in the working memory task (i.e., distracter words) was arbitrarily and externally assigned by experimenters. Thus, this paradigm does not inform us about the interference resolution of internally generated distractions, such as in proactive interference paradigms or when there is a mismatch between task goals and emotion regulation goals. Future research could address this question by modifying the paradigm to include internally generated distracter items to measure the impact of these items on working memory. Furthermore, it could also manipulate the match/mismatch of task vs. emotional goals by implementing task instructions that explicitly direct participants to engage in emotional processing, which contrasts with the more perceptually-based processing used in the current paradigm (i.e., cuing of target vs. distracter via different colored fonts).

The second limitation is our sample. The older sample has a larger age range (i.e., 22 years) than the younger sample (i.e., 11 years). This wider range in older adults may have introduced larger performance variability (e.g., Hultsch et al., 2002). We assume that any variability in the older adult group may also be reflective of aging more generally, as studies typically find that both inter- and intra-individual variability increases with age (e.g., Nelson and Dannefer, 1992; Shammi et al., 1998). As this study was a preliminary examination of emotion on working memory and aging, to better encompass any changes that may occur in later life, we followed a common approach in cognitive aging literature and did not set an upper age limit for the older group. Additionally, the low percentage of male participants (13% of the total sample) was another limitation of this sample. In consideration of research on gender differences in emotion regulation and processing (e.g., Gur and Gur, 2002; McRae et al., 2008), our findings may not be representative of emotion processing in males. As such, future studies should aim for more balanced numbers of female and male participants.

Finally, although we expected relatively high accuracy on this task based on results from other studies (e.g., Gazzaley et al., 2005), we also expected to find some evidence of age-related working memory declines. Aside from slower target identification, which could be attributed to age-related prioritization of accuracy over speed, there were no main effects of age. The lack of age differences suggests that this paradigm may not exert high demands on working memory. This may have limited our ability to find facilitative or disruptive effects of emotion. However, the lack of age differences may also suggest that the emotional nature of the task may have helped attenuate overall age-related working memory declines, as has been found in other studies (e.g., Mikels et al., 2005). To examine this, future studies could use a working memory paradigm that is more taxing and thus more sensitive at detecting age differences. Future research could also build on the results of this study by examining the neural mechanisms that contribute to the facilitative and disruptive effects of emotion in the aging brain. Such work could be informed by research on younger adults (Dolcos et al., 2011) that have identified multiple neural connections between areas implicated in emotion processing (e.g., ventral affective system) and cognitive control (e.g., dorsal executive system).

Overall, this study provided novel evidence in support of recent frameworks that specify the competitive advantage of emotional over non-emotional information (particularly for older adults; Carstensen et al., 1999) and the role of goal relevancy (Pessoa, 2008, 2009). It contributed to the sparse, but growing, literature on the important interactions between emotion and cognitive control in older adults (e.g., Pessoa, 2008; Dolcos et al., 2011). Such work helps identify situations in which older adults' preserved emotional processing could be a helpful "friend" vs. hindering "foe" to their declines in cognitive control.

ACKNOWLEDGMENTS

We thank all research assistants involved in the completion of this project. This work was supported by a Natural Sciences and Engineering Research Council (NSERC) of Canada Discovery Grant (371762-2009) awarded to Lixia Yang.

REFERENCES

Beck, A. T., Epstein, N., Brown, G., and Steer, R. A. (1988). An inventory for measuring clinical anxiety: psychometric properties. *J. Consult. Clin. Psychol.* 56, 893–897. doi: 10.1037/0022-006X.56.6.893

Beck, A. T., Steer, R. A., and Brown, G. K. (1996) *Manual for the Beck Depression Inventory-II*. San Antonio, TX: Psychological Corporation.

Borg, C., Leroy, N., Favre, E., Laurent, B., and Thomas-Antérion, C. (2011). How emotional pictures influence visuospatial binding in short-term memory in ageing and Alzheimer's disease? *Brain Cogn.* 76, 20–25. doi: 10.1016/j.bandc.2011.03.008

Bradley, M. M., and Lang, P. J. (1999). "Affective norms for English words (ANEW): stimuli, instruction manual and affective ratings," in *Technical Report C-1* (Gainesville, FL: The Center for Research in Psychophysiology, University of Florida).

Carstensen, L. L., Isaacowitz, D. M., and Charles, S. T. (1999). Taking time seriously: a theory of socioemotional selectivity. *Am. Psychol.* 54, 165–181. doi: 10.1037/0003-066X.54.3.165

Döhnel, K., Sommer, M., Ibach, B., Rothmayr, C., Meinhardt, J., and Hajak, G. (2008). Neural correlates of emotional working memory in patients with mild cognitive impairment. *Neuropsychologia* 46, 37–48. doi: 10.1016/j.neuropsychologia.2007.08.012

Dolcos, F., Iordan, A., and Dolcos, S. (2011). Neural correlates of emotion–cognition interactions: a review of evidence from brain imaging investigations. *J. Cogn. Psychol.* 23, 669–694. doi: 10.1080/20445911.2011.594433

Dolcos, F., and McCarthy, G. (2006). Brain systems mediating cognitive interference by emotional distraction. *J. Neurosci.* 26, 2072–2079. doi: 10.1523/JNEUROSCI.5042-05.2006

Gazzaley, A., Cooney, J. W., Rissman, J., and D'Esposito, M. (2005). Top-down suppression deficit underlies working memory impairment in normal aging. *Nat. Neurosci.* 8, 1298–1300. doi: 10.1038/nn1543

Gur, R. E., and Gur, R. C. (2002). Gender differences in aging: cognition, emotions, and neuroimaging studies. *Dialogues Clin. Neurosci.* 4, 197–210.

Hasher, L., and Zacks, R. T. (1988). "Working memory, comprehension, and aging: a review and a new view," in *The Psychology of Learning and Motivation: Advances in Research and Theory,* Vol. 22, ed G. H. Bower (New York, NY: Academic Press), 193–225.

Hultsch, D. F., MacDonald, S. W. S., and Dixon, R. A. (2002). Variability in reaction time performance of younger and older adults. *J. Gerontol. B Psychol. Sci. Soc. Sci.* 57, 101–115. doi: 10.1093/geronb/57.2.P101

Isaacowitz, D. M., Toner, K., Goren, D., and Wilson, H. R. (2008). Looking while unhappy: mood-congruent gaze in young adults, positive gaze in older adults. *Psychol. Sci.* 19, 848–853. doi: 10.1111/j.1467-9280.2008.02167.x

Isaacowitz, D. M., Wadlinger, H. A., Goren, D., and Wilson, H. R. (2006). Is there an age-related positivity effect in visual attention? A comparison of two methodologies. *Emotion* 6, 511–516. doi: 10.1037/1528-3542.6.3.511

Katzman, R., Brown, T., Fuld, P., Peck, A., Schechter, R., and Schimmel, H. (1983). Validation of a short orientation-memory-concentration test of cognitive impairment. *Am. J. Psychiatry* 140, 734–739.

Kensinger, E. A., and Corkin, S. (2004). Two routes to emotional memory: distinct neural processes for valence and arousal. *Proc. Natl. Acad. Sci. U.S.A.* 101, 3310–3315. doi: 10.1073/pnas.0306408101

Knight, M., Seymour, T. L., Gaunt, J. T., Baker, C., Nesmith, K., and Mather, M. (2007). Aging and goal-directed emotional attention: distraction reverses emotional biases. *Emotion* 7, 705–714. doi: 10.1037/1528-3542.7.4.705

Labouvie-Vief, G. (2003). Dynamic integration: affect, cognition, and the self in adulthood. *Curr. Dir. Psychol. Sci.* 12, 201–206. doi: 10.1046/j.0963-7214.2003.01262.x

Labouvie-Vief, G., Grühn, D., and Studer, J. (2010). "Dynamic integration of emotion and cognition: equilibrium regulation in development and aging," in *The Handbook of Lifespan Development*, eds R. M. Lerner, M. E. Lamb, and A. M. Freund (Hoboken: John Wiley and Sons, Inc.), 79–115.

Leclerc, C. M., and Kensinger, E. A. (2008). Effects of age on detection of emotional information. *Psychol. Aging* 23, 209–215. doi: 10.1037/0882-7974.23.1.209

Levens, S. M., and Phelps, E. A. (2008). Emotion processing effects on interference resolution in working memory. *Emotion* 8, 267–280. doi: 10.1037/1528-3542.8.2.267

Mammarella, N., Borella, E., Carretti, B., Leonardi, G., and Fairfield, B. (2013a). Examining an emotion enhancement effect in working memory: evidence from age-related differences. *Neuropsychol. Rehabil.* 23, 416–428. doi: 10.1080/09602011.2013.775065

Mammarella, N., Fairfield, B., Di Domenico, A., Borella, E., and Carretti, B. (2013b). Is working memory affective in dementia of alzheimer's type? *Neurosci. Discov.* 1, 1–4. doi: 10.7243/2052-6946-1-4

Mather, M., and Carstensen, L. L. (2003). Aging and attentional biases for emotional faces. *Psychol. Sci.* 14, 409–415. doi: 10.1111/1467-9280.01455

Mather, M., and Carstensen, L. L. (2005). Aging and motivated cognition: the positivity effect in attention and memory. *Trends Cogn. Sci.* 9, 496–502. doi: 10.1016/j.tics.2005.08.005

Mather, M., and Knight, M. (2005). Goal-directed memory: the role of cognitive control in older adults' emotional memory. *Psychol. Aging* 20, 554–570. doi: 10.1037/0882-7974.20.4.554

McRae, K., Ochsner, K. N., Mauss, I. B., Gabrieli, J. J. D., and Gross, J. J. (2008). Gender differences in emotion regulation: an fMRI Study of cognitive reappraisal. *Gr. Process. Intergr. Relat.* 11, 143–162. doi: 10.1177/1368430207088035

Mikels, J. A., Larkin, G. R., Reuter-Lorenz, P. A., and Cartensen, L. L. (2005). Divergent trajectories in the aging mind: changes in working memory for affective versus visual information with age. *Psychol. Aging* 20, 542–553. doi: 10.1037/0882-7974.20.4.542

Murphy, N. A., and Isaacowitz, D. M. (2008). Preferences for emotional information in older and younger adults: a meta-analysis of memory and attention tasks. *Psychol. Aging* 23, 263–286. doi: 10.1037/0882-7974.23.2.263

Nelson, E. A., and Dannefer, D. (1992). Aged heterogeneity: fact or fiction? the fate of diversity in gerontological research. *Gerontologist* 32, 17–23. doi: 10.1093/geront/32.1.17

Pessoa, L. (2008). On the relationship between emotion and cognition. *Nat. Rev. Neurosci.* 9, 148–158. doi: 10.1038/nrn2317

Pessoa, L. (2009). How do emotion and motivation direct executive control? *Trends Cogn. Sci.* 13, 160–166. doi: 10.1016/j.tics.2009.01.006

Reed, A. E., and Carstensen, L. L. (2012). The theory behind the age-related positivity effect. *Front. Psychol.* 3:339. doi: 10.3389/fpsyg.2012.00339

Rypma, B., and D'Esposito, M. (2000). Isolating the neural mechanisms of age-related changes in human working memory. *Nat. Neurosci.* 3, 509–515. doi: 10.1038/74889

Salthouse, T. A. (1979). Adult age and the speed-accuracy trade-off. *Ergonomics* 22, 811–821. doi: 10.1080/00140137908924659

Scheibe, S., and Carstensen, L. L. (2010). Emotional aging: recent findings and future trends. *J. Gerontol. Psychol. Sci.* 65B, 135–144. doi: 10.1093/geronb/gbp132

Shammi, P., Bosman, E., and Stuss, D. T. (1998). Aging and variability in performance. *Aging Neuropsychol. Cogn.* 5, 1–13. doi: 10.1076/anec.5.1.1.23

Shipley, W. C. (1940). A self-administering scale for measuring intellectual impairment and deterioration. *J. Psychol. Interdiscip. Appl.* 9, 371–337. doi: 10.1080/00223980.1940.9917704

Watson, D., Clark, L. A., and Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: the PANAS scales. *J. Pers. Soc. Psychol.* 54, 1063–1070. doi: 10.1037/0022-3514.54.6.1063

Wechsler, D. (1981). *Manual for the Wechsler Adult Intelligence Scale-Revised*. New York, NY: Psychological Corporation.

Yang, L., and Hasher, L. (2007). The enhanced effects of pictorial distraction in older adults. *J. Gerontol. B. Psychol. Sci. Soc. Sci.* 62, 230–233. doi: 10.1093/geronb/62.4.P230

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 25 October 2013; accepted: 23 January 2014; published online: 25 February 2014.

Citation: Truong L and Yang L (2014) Friend or foe? Decoding the facilitative and disruptive effects of emotion on working memory in younger and older adults. Front. Psychol. ***5****:94. doi: 10.3389/fpsyg.2014.00094*

This article was submitted to Emotion Science, a section of the journal Frontiers in Psychology.

ORIGINAL RESEARCH ARTICLE
published: 21 April 2014
doi: 10.3389/fpsyg.2014.00253

The ties to unbind: age-related differences in feature (un)binding in working memory for emotional faces

Didem Pehlivanoglu*, Shivangi Jain, Robert Ariel and Paul Verhaeghen

School of Psychology, Georgia Institute of Technology, Atlanta, GA, USA

Edited by:
Natalie Ebner, University of Florida, USA

Reviewed by:
Natalie Ebner, University of Florida, USA
Carla Marie Strickland-Hughes, University of Florida, USA
Christina M. Leclerc, State University of New York at Oswego, USA
Lixia Yang, Ryerson University, Canada

****Correspondence:***
Didem Pehlivanoglu, School of Psychology, Georgia Institute of Technology, J. S. Coon Building, 654 Cherry Street, Atlanta, GA 30332, USA
e-mail: dpehlivanoglu3@gatech.edu

In the present study, we investigated age-related differences in the processing of emotional stimuli. Specifically, we were interested in whether older adults would show deficits in unbinding emotional expression (i.e., either no emotion, happiness, anger, or disgust) from bound stimuli (i.e., photographs of faces expressing these emotions), as a hyper-binding account of age-related differences in working memory would predict. Younger and older adults completed different *N*-Back tasks (side-by-side 0-Back, 1-Back, 2-Back) under three conditions: match/mismatch judgments based on either the identity of the face (identity condition), the face's emotional expression (expression condition), or both identity and expression of the face (both condition). The two age groups performed more slowly and with lower accuracy in the expression condition than in the both condition, indicating the presence of an unbinding process. This unbinding effect was more pronounced in older adults than in younger adults, but only in the 2-Back task. Thus, older adults seemed to have a specific deficit in unbinding in working memory. Additionally, no age-related differences were found in accuracy in the 0-Back task, but such differences emerged in the 1-Back task, and were further magnified in the 2-Back task, indicating independent age-related differences in attention/STM and working memory. Pupil dilation data confirmed that the attention/STM version of the task (1-Back) is more effortful for older adults than younger adults.

Keywords: hyper-binding, memory binding, working memory, aging, pupillary response, emotion

INTRODUCTION

Working memory is the workspace of the mind, where passive storage and active manipulation/transformation of information engage in dynamic interplay (Baddeley and Hitch, 1974; Miyake and Shah, 1999; Kane et al., 2001). An effective working memory system is crucial for high-level performance in a multitude of cognitive tasks, perhaps because an effective working memory system depends on the efficient implementation of a host of basic cognitive control operations that are likely involved in most, if not all aspects of the cognitive system. For instance, significant relations have been demonstrated between fluid intelligence and working memory capacity, and between spatial and language abilities and working memory (e.g., Kyllonen, 1996; Engle et al., 1999; Conway et al., 2002; Kemper et al., 2003).

Given the centrality of the working memory construct, it is not surprising that there is a growing literature on the effects of aging on its capacity and dynamics. The brunt of the research shows that working memory capacity declines with advancing adult age. Small age differences are already found in the performance of short-term memory (STM) tasks that do not require much cognitive control or attentional resources, such as digit span tasks, but age-related deficits in working memory, as measured by tasks such as reading span, listening span, or operation span, are demonstrably larger. In a meta-analysis compiling a total of 123 studies from 104 papers, Bopp and Verhaeghen (2007) found that older adults' capacity in simple STM span tasks was 92% that of the capacity of younger adults; their capacity on true working memory tasks, however, was only 74% that of younger adults. This decline in working memory capacity has consequences for complex aspects of cognition: on average, working memory capacity explains 52% of the age-related variance in episodic memory performance, 63% of the age-related variance in spatial abilities, and 72% of the age-related variance in reasoning abilities; STM, in contrast, explains 9% or less of the age-related variance (Verhaeghen, 2014).

One particular determinant of working memory capacity that has consistently been found to be age-sensitive is the availability of information that has left focus of attention and needs to be retrieved after a bout of intermittent processing. Our lab and others have studied this topic using variations on the *N*-Back task – the task we will also use here (e.g., Oberauer, 2002; Verhaeghen and Basak, 2005; Chen and Li, 2007; Vaughan et al., 2008; Verhaeghen, 2012; Zhang et al., 2012). In an *N*-Back task, subjects indicate whether the stimulus currently on the screen matches the stimulus presented *N* positions back. The typical finding in our experiments (but see Kirchner, 1958; Dobbs and Rule, 1989) is that older and younger adults are equally (and highly) accurate in the 1-Back version of the task, but that age differences in accuracy consistently emerge when $N > 1$. We would argue that 1-Back tasks primarily reflect the workings of attention, with a possible STM component as well (i.e., subjects have to retain information passively over a very brief duration – 2 s in our experiment). A 2-Back version adds a true working memory component to the task, in the form of intervening items that need to be processed.

The finding then echoes other reports (e.g., Bopp and Verhaeghen, 2007) that older adults show small or not deficits in STM tasks, but substantial deficits in working memory tasks. Additionally, in the present study, we will include a 0-Back condition where two stimuli are shown side-by-side, to test and/or control for perceptual deficiencies in older adults.

The finding of an age-related deficit in the working memory component, but not the attentional/STM component of working memory leads to an obvious question: can this result be reduced to a deeper deficit in a known process, or is this aspect of working memory – retrieval of items stored outside immediate attention – a cognitive primitive that is especially age-sensitive? This is the research question we will address in the present paper. To foreshadow: the cognitive primitive we will investigate is association, more precisely, the binding of features into objects and the concomitant unbinding of objects into features; the objects we will use, for reasons explained below, are faces displaying emotional expressions (presenting emotion and identity into a compound percept). Additionally, we will use a physiological measure (pupil dilation) to independently verify the commitment of attentional resources throughout the task. As a side effect, the use of emotional stimuli will allow us to investigate the claims of an age-related positivity effect in a domain where such effects have rarely been investigated, namely that of working memory.

One popular hypothesis to explain age-related differences in working memory functioning is the hypothesis of an age-related associative deficit. The claim is that older adults fail to efficiently and/or effectively link individual features of a learning episode together; one consequence is a particular difficulty in forming or retrieving the associations or bindings between the features of objects, compared to maintaining the single features in memory (Chalfonte and Johnson, 1996; Naveh-Benjamin et al., 2004; Cowan et al., 2006). The associative-binding theory has fared extremely well in the domain of episodic memory (e.g., Old and Naveh-Benjamin, 2008), but evidence from the domain of working memory have been decidedly mixed.

In support of the associative-deficit hypothesis, Cowan et al. (2006), in a delayed match-to-sample task, did indeed find evidence that older adults were especially poor at detecting binding changes. Importantly, this deficit was not due to age-related differences in attentional resources per se, because the decline was evident even when the set size of the array was reduced to be well below capacity limits. Other researchers, in contrast, have failed to discover evidence for an associative deficit in working memory, concluding instead that aging is governed by a rather general deficit in working memory functioning. For instance, in three change-detection experiments, Brockmole et al. (2008) found overall lower working memory performance in older adults, but no specific age-related deficit emerged in a feature-binding condition. Importantly, in this study, older adults were more affected by increases in set size than younger adults were, suggesting that the age-related decline in working memory performance is tied to a fundamental change in capacity rather than to associative deficits. With a very different task – a repetition-detection paradigm – Bopp and Verhaeghen (2009) found, in line with the Brockmole et al. (2008) findings, that the necessity to bind content to context decreased performance in both age groups to the same degree.

In the present paper, we approach the binding problem from a different angle, inspired by a recent study that found evidence – in episodic memory – of the existence of the third possible empirical outcome, namely that older adults are better at associative binding than younger adults. That is, Campbell et al. (2010) found that when to-be-remembered stimuli (in this case: line drawings) were paired with stimuli explicitly labeled as irrelevant (in this case: words) older participants showed better memory for the drawing–word conjunction than younger adults did. The authors labeled this phenomenon hyper-binding, and see it as predicated on deficient inhibitory functioning. Under this hypothesis, older adults are unable to inhibit the irrelevant information, which therefore gets encoded (and maintained) along with the relevant information. The net result is a functional shrinkage in the capacity of working memory.

So far, age-related hyper-binding has not been demonstrated in working memory. Clearly, the three papers cited above report either no evidence for a binding deficit in old age, or the opposite of hyper-binding, that is, a binding deficit. It is also clear, however, that the standard set-up of experiments into the associative deficit hypothesis might not be easily conducive to elicit the phenomenon of age-related hyper-binding. One potential issue is that in classical association experiments (which often use artificial compound stimuli composed of random combinations of abstract features, e.g., Wheeler and Treisman, 2002) feature binding typically comes at a cost: remembering the compound object is more difficult than remembering the individual features. Working memory experiments reporting age-related binding deficits as evidenced by age by condition interactions could then simply be instantiations of a complexity or difficulty effect: age differences are "naturally" larger in tasks yielding lower performance, that is, in this case, the both condition (e.g., Cerella, 1985).

In the present study, we reversed this situation by using naturally occurring and ecologically valid compound objects that, by all accounts, are easier to remember than at least some of their constituent features. More specifically, we capitalized on an interesting finding in the face recognition literature, namely that when participants are confronted with a face showing a natural emotion, recognition of facial identity (i.e., who is this person?) typically occurs faster and with higher accuracy than recognition of the emotional expression (e.g., Ganel and Goshen-Gottstein, 2004; Martens et al., 2010). At the same time, matching on both identity and emotional expression typically occurs no faster or more accurately than matching on identity alone (e.g., Soto and Wasserman, 2011). These findings suggest that identity of faces is processed easily, maybe even automatically, whereas extraction of emotional expression is a much slower, potentially effortful process. (Note that there is some controversy over whether these two types of judgments – identity or emotional expression – are independent; Bruce and Young, 1986; or interrelated; e.g., Ganel and Goshen-Gottstein, 2004. This question, however, is irrelevant to our current study, which concerns only the relative efficiency of these processes.) This particular quirk of the cognitive system makes emotional face recognition particularly well suited to investigate the hyper-binding hypothesis. If older adults indeed encode more of the stimulus than strictly needed for the task, the age-related deficit in performance would be larger in conditions in which only the emotional expression (a single feature) needs to be remembered compared to memory for the whole stimulus (i.e., identity bound with emotional expression), because older adults would be less inclined or less capable to extract and remember only the relevant feature. (Note that the age-related deficit for memory for facial identity (another single feature) should likely match that for memory of the whole stimulus, given that identity extraction typically comes at no cost.)

One added advantage of these stimuli lies in their emotional nature: it has often been claimed that the valence of emotions inherent in experimental stimuli moderates age-related differences in cognition. Our study allows us to investigate some of these claims explicitly, in a domain where these have been rarely researched. For instance, socioemotional selectivity theory (Carstensen et al., 1999) states that a shrinking time perspective leads older adults to focus on positive information rather than negative information – the so-called positivity bias. There are only a few studies that investigated the impact of emotional stimuli on working memory performance, but their usefulness for the present questions is limited: these studies included either only younger adults or negative stimuli (Kensinger and Corkin, 2003) or examined the effect of arousal but not emotion (Wurm et al., 2004). The literature on attention and the positivity bias suggests that the pattern may be complicated. For instance, Allard and Isaacowitz (2008) found that older adults fixated their gaze more on positive and neutral images compared to negative images, regardless of whether the images were presented in full or divided attention conditions; additionally, older adults' secondary task performance was as good as that of younger adults. This finding strongly suggests that processing positive emotional material does not require full attention. Other studies, however, have found that the presence of a distractor task leads older adults to remember proportionally more negative images than positive images (Mather and Knight, 2005) and to exhibit an attentional preference for negative images relative to positive images (Knight et al., 2007). This set of findings then indicates that processing positive emotional material does require attention, and that the age-related positivity bias may disappear or reverse under conditions of high cognitive load. Our study could shed further light on this controversy. That is, if the cognitive or memory load explanation has any validity, we would expect an age-related positivity effect for the *N*-Back conditions with low cognitive load (i.e., 0-Back or 1-Back), but a reversal of the effect for the 2-Back version, which has an added memory component which has been shown to increase response time (RT) and decrease accuracy (e.g., Verhaeghen and Basak, 2005).

We additionally recorded changes in participants' pupil diameter during stimulus processing. The aim was to investigate how this response changes with age and/or as a function of processing demands and emotional content of the stimuli. Pupil dilations have long been thought to reflect a brain activity during perceptual and cognitive processing (Kahneman and Beatty, 1966). Task-evoked pupillary responses occur during the processing of stimuli and have been interpreted as indicators of cognitive effort and emotional arousal (for a review, see Beatty, 1982; Goldinger and Papesh, 2012). In line with this reasoning, pupil diameter typically increases as task demand increases (e.g., Karatekin et al., 2007; Van Gerven et al., 2004; Heitz et al., 2008) and as task/response interference increases (e.g., Porter et al., 2007; Laeng et al., 2011). Pupils also dilate during emotional processing, with larger pupil dilations occurring in response to positively valenced images (Hess, 1965), sexually arousing stimuli (Hicks et al., 1967), and positively and negatively arousing sounds (Partala and Surakka, 2003).

Surprisingly, few studies have investigated the joint influence of processing demands and emotional content on task-evoked pupillary responses. One exception is Stanners et al. (1979) who manipulated both processing demands (difficulty level of an arithmetic task) and arousal (threat of shock) or only arousal without processing demands. They found that pupillary responses increased with the difficulty of the arithmetic problems regardless of threat of shock, suggesting that pupillary responses are influenced mainly by cognitive demands of the task regardless of emotional arousal. In the low-difficulty task, however, arousal did influence pupil dilations. The two results combined suggest that arousal influences pupillary responses in low-demand situations, but that high cognitive demand may override the arousal-related response.

Based on this literature, we propose that pupil dilation during stimulus processing (relative to a baseline pupil measurement) could provide an independent, physiological indication of age-related differences in the effects of working memory demands (by comparing responses in the 2-Back task with responses in the 0-Back and 1-Back tasks) and potentially also of age-related differences in phasic changes due to emotion-specific arousal; the latter effect will likely only be observable in the low-demand conditions (i.e., 0-Back and 1-Back), as observed by Stanners et al. (1979).

To summarize, in the present study, we investigate one potential source of the oft-noted age-related differences in working memory performance, namely the possibility that older adults are less flexible than younger adults in unbinding information in working memory when representing the bound object is unnecessary – the so-called hyper-binding hypothesis. To maximize the chances of hyper-binding, we used emotional faces as stimuli; it has been shown that extracting the emotion content from such faces is an effortful process. The task is a subject-paced *N*-Back task. In its side-by-side 0-Back form, this task measures perceptual discrimination; its 1-Back version adds an attentional/STM requirement; the 2-Back version adds a working memory component. If older adults do hyper-bind, they would need more time and/or be less accurate in unbinding a stimulus into its features. As a consequence, we would expect larger age differences in the condition in which subjects respond only to the emotional expression. Additionally, we investigated the role of emotional valence on age differences in perception, attention, and memory, expecting, from the one extant study (Knight et al., 2007), a positivity bias in perception and attention (i.e., in 0-Back and 1-Back) and a negativity bias in working memory (i.e., in 2-Back), possibly (Knight et al., 2007) modulated by task difficulty such that the positivity bias would only show in the simpler tasks (i.e., 0-Back or 1-Back). Pupil dilation data will provide information as to the resource investment in each of the conditions. Given previous reports of age differences in performance in *N*-Back tasks, we expect that older adults would show a higher investment of resources in this task than younger adults.

The present work breaks modest new ground in at least two aspects. First, as far as we know, although emotional faces have been used extensively in perceptual paradigms such as stimulus discrimination or classification, there are fewer data on how working memory handles this class of stimuli (for one exception, see Kensinger and Corkin, 2003), and none in the field of aging. Second, as far as we know, we are the first research team to employ a physiological measure, pupil dilation, as independent verification of adult age-related differences in the task difficulty presumably involved in working memory encoding and/or retrieval and in the processing of emotional content.

MATERIALS AND METHODS

PARTICIPANTS

Twenty-one younger (67% female) and 21 older (71% female) adults participated in this experiment. Older participants were recruited from the community; they received cash payment ($10/hour) as compensation for participation. Younger adults were students at Georgia Institute of Technology; they were given either course credit or cash payment ($10/hour) for participation.

One older adult whose data could not be recorded due to technical problems was excluded from the analyses. The mean age of the remaining 20 older adults was 70.55 ($SD = 4.3$); mean age of younger adults was 20.33 ($SD = 1.62$). Older adults ($M = 16.7$, $SD = 3.16$) had completed more years of education than younger adults ($M = 14.21$, $SD = 1.49$), $t(39) = 3.25$, $p = 0.002$. Younger adults ($M = 62.9$, $SD = 8.04$) performed significantly better than older adults ($M = 45.65$, $SD = 8.57$) on a symbol digit test, $t(39) = 6.65$, $p < 0.001$. On the other hand, older adults' performance ($M = 34.1$, $SD = 4.51$) on the Shipley Vocabulary test was significantly higher than performance of younger adults ($M = 31.33$, $SD = 3.61$), $t(39) = 2.18$, $p = 0.04$.

MATERIALS

Faces

Forty-eight faces were selected from the FACES database (Ebner et al., 2010), with 12 different young-female actors portraying either angry, happy, neutral, or disgusted expressions. One of the faces, showing all these emotions is presented in **Figure 1A**. To keep the number of to-be-analyzed variables manageable we included only young and female faces in the study. Previous research has shown effects of age (young vs. old) and sex (female vs. male) of face stimuli on attention and memory performance of younger and older adults (for a meta-analytic review, see Rhodes and Anastasi, 2012); however, investigation of the effect of these variables is out of the scope of the current study.

Our choice of emotional expressions was guided by previous findings concerning age-related differences in emotion processing; the aim was to bias the results toward observing age by condition interactions. We included happy and angry faces specifically because older adults have been shown to show high recognition accuracy for happy stimuli (e.g., Carstensen et al., 1999) while younger adults tend to show a memory bias for angry faces (Mikels et al., 2005). Additionally, we included disgust to see whether recognition of disgust appears to be relatively preserved in old age as shown in a couple of studies (e.g., Calder et al., 2003).

We selected a subset of 12 young-female faces with happy, angry, neutral, and disgusted expressions from the FACES database based on correct identification of these facial expressions by younger-female, younger-male, older-female, and older-male raters in the norming study (Ebner et al., 2010)[1]. Given that we were interested in the effects of emotion alone, arousal level of the stimuli is a potential confound. Since arousal ratings are not available in FACES database, we conducted a separate study including 42 young adults (55% female) recruited from the Georgia Institute of Technology (mean age 19.81, $SD = 2.12$). Participants provided arousal ratings for each face on a 9-point Likert scale (1 – *not arousing at all*, 9 – *highly arousing*) using the Self-Assessment Manikin (Bradley and Lang, 1994). As expected, participants rated neutral faces ($M = 3.13$, $SD = 1.42$) as less arousing than happy ($M = 5.26$, $SD = 1.56$), disgusted ($M = 6.00$, $SD = 1.73$), or angry faces ($M = 5.56$, $SD = 1.53$), all $ts(41) > 6.35$, $ps < 0.001$. Although the perceived arousal level of individual face pictures in each emotion category varied, disgusted and angry faces were on average not more arousing than happy faces. The only significant difference was between angry and disgusted faces, $t(41) = 4.41$, $p < 0.001$.

Apparatus

Pupil data were recorded binocularly using a head-mounted SR Inc. Eyelink II eyetracker with a 500-Hz sample rate. To obtain baseline pupil estimates, an 8,000 ms fixation cross was presented at the beginning of each block. For each block, the average pupil size recorded during this 8,000 ms period served as the baseline pupil estimate for that block. Peak pupil sizes were recorded during presentation of the face photos and during the interstimulus interval. For the analyses, the peak pupil size value during stimulus presentation and the interstimulus interval for each trial was determined. The percentage change was calculated as max pupil size at each trial minus the baseline pupil value divided by the baseline, thus scaling responses as a function of each individual subject's baseline (e.g., Iqbal et al., 2004).

All tasks were prepared and presented by E-Prime 2.2. Stimuli were presented on a 14-inch computer screen (resolution 1024 × 768 pixel) over a gray background (RGB: 150, 150, 150) as bitmap images (231 × 185 pixels). The face stimuli subtended

[1] In the norm study (Ebner et al., 2010), for our subset of the stimuli, the mean accuracy of emotional expression identification by younger women was 93.15 ($SD = 11.31$), by younger men was 90.56 ($SD = 10.91$), by older women was 86.42 ($SD = 15.17$), and by older men was 83.67 ($SD = 16.42$).

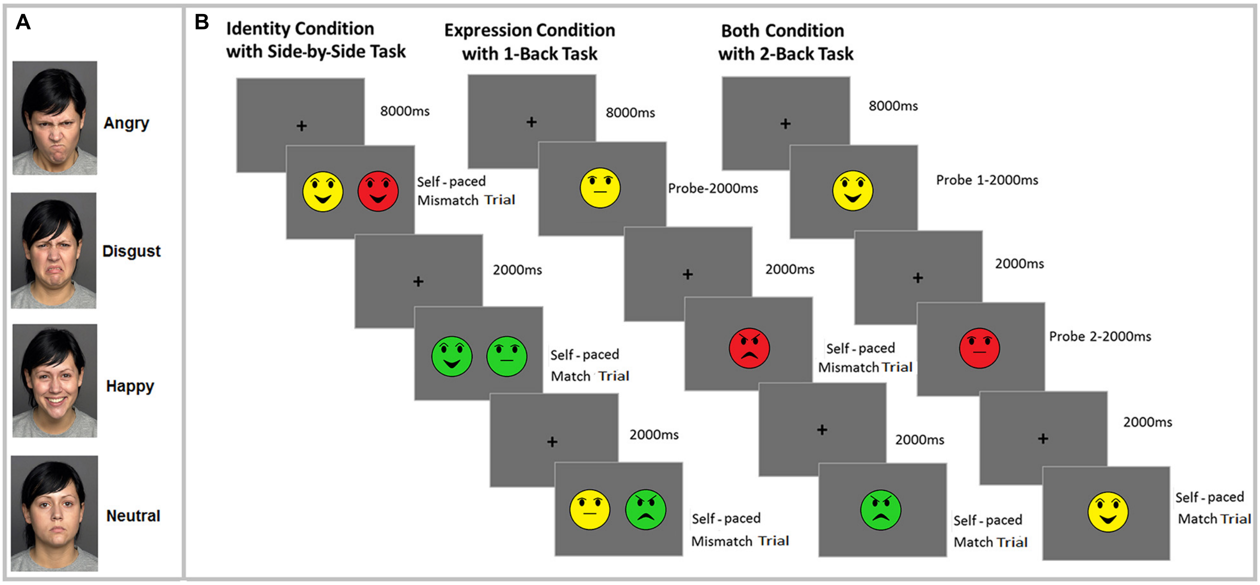

FIGURE 1 | Illustration of the one of the faces with all emotional expressions (angry, disgust, happy, neutral) used in the study (A) and the experimental procedure, with a sample *N*-Back task for each of the three conditions: identity (side-by-side 0-Back task), expression (1-Back task) and both (2-Back task) (B). Note that different colors represent different individual faces.

a horizontal visual angle of 7.5° and a vertical visual angle of 6.6°.

Task design

The experiment consisted of identity, expression, and both conditions with three *N*-Back tasks (side-by-side 0-Back, 1-Back, and 2-Back). The task design for each condition is illustrated in **Figure 1B**[2]. Each condition involved making match/mismatch judgments based on either the identity of the face (identity condition), the face's emotional expression (expression condition), or joint identity and expression of the faces (both condition). Each condition consisted of two blocks of 48 trials of each *N*-Back task. Since we had three different *N*-Back tasks, there were a total of 288 trials in each of the three conditions (identity, expression, both). The number of match and mismatch trials was equally distributed across the 48 trials within each block. Furthermore, different trials included equal number of difficult and easy lures in each *N*-Back tasks. For instance, when participants were shown the face of person "A" with happy facial expression in the identity condition, the face of person "B" with happy facial expression was considered a difficult lure, whereas the face of person "B" with angry facial expression was an easy lure. Within each condition and task, the same set of face stimuli were used. This was done to ensure that performance differences between the different tasks and conditions could not be attributable to the stimuli. Emotional expressions and facial identity were pseudo-randomized so that each face and emotional expression was presented an equal number of times within each *N*-Back task. Conditions were blocked. The order of presentation of *N*-Back tasks and conditions was counterbalanced using a Latin square design. There was no effect of counterbalancing on performance.

Side-by-side 0-Back task

For the side-by-side 0-Back task, two face pictures were presented side-by-side on the screen and participants decided whether the two pictures were identical or not in terms of either identity or emotional expression, or of both identity and emotional expression, depending on condition. The purpose of the side-by-side task was to evaluate potential age differences in perceptual discrimination of facial identity, emotional expression, and their conjunction. Note that this side-by-side comparison likely involves saccadic eye movements, making it likely that the RTs for the 0-Back task will be larger than those of the 1-Back and 2-Back tasks.

1-Back and 2-Back tasks

In these tasks, participants were asked to compare either identity, emotional expression, or joint identity and emotional expression of a face with the face presented one position back (1-Back) or two positions back (2-Back task).

PROCEDURE

Participants were tested individually. Before the experiment, each participant signed a consent form. Each condition began with 12 practice trials. During the study, the eye tracker was calibrated before each block in each condition to establish a map between each participant's gaze position and the eye tracker. Each block began with an 8,000 ms presentation of a fixation cross that served to collect the baseline pupil measurement. Next, participants were presented with a probe face (1-Back) or two probe faces (2-Back) for 2,000 ms each, or no probe (side-by-side 0-Back

[2]Since the FACES database agreement provides only one young-female face to use in scientific publications, it was not possible to demonstrate the tasks we used in this study using the real stimuli. Thus, for the purposes of task design illustration, we used emoticons in **Figure 1B**.

task). Following probe trials, participants completed 48 self-paced trials. In each trial, a single face (1-Back and 2-Back conditions) or two side-by-side faces (0-Back condition) were presented; subjects indicated whether the relevant feature(s) of the presented face matched the relevant feature(s) of the face presented one face back (1-Back condition), two faces back (2-Back condition), or whether the relevant feature(s) of the two side-by-side faces matched (0-Back). Because face trials were self-paced and peak pupil dilation typically occurs 1,800–2,000 ms post-stimulus onset (Beatty, 1982), each face trial was followed by a 2,000 ms interstimulus interval to allow sufficient time for the pupil to reach peak dilation. After 48 trials, a new block began. Pupil dilation was continuously recorded throughout the task. The total duration of the experiment was approximately 120 min.

RESULTS

CORRECTED RECOGNITION RATES

Corrected recognition rates (proportion of hit rates minus false alarm rates) were calculated for each participant and entered in a three-way mixed analysis of variance (ANOVA): 2 (Age: young, old) × 3 (Condition: identity, expression, both) × 3 (*N*-Back: side-by-side 0-Back, 1-Back, 2-Back). The data for younger and older adults are presented in **Figures 2A,B**, respectively. Younger adults ($M = 0.87$, $SD = 0.08$) performed significantly better than older participants ($M = 0.77$, $SD = 0.08$), $F(1,39) = 18.74$, $MSE = 0.05$, $p < 0.001$, $\eta_p^2 = 0.33$. There was a main effect of condition [$F(2,78) = 9.87$, $MSE = 0.02$, $p < 0.001$, $\eta_p^2 = 0.2$] showing that participants performed better in the both ($M = 0.86$, $SD = 0.11$) than in the expression condition ($M = 0.79$, $SD = 0.10$), $t(40) = 4.44$, $p < 0.001$. Performance in the identity condition ($M = 0.82$, $SD = 0.12$) was not significantly different from performance in the expression and both conditions (all ps > 0.10). The main effect of *N*-Back task [$F(2,78) = 134.58$, $MSE = 0.01$, $p < 0.001$, $\eta_p^2 = 0.78$] revealed that participants had higher corrected recognition responses in the side-by-side 0-Back task ($M = 0.89$, $SD = 0.07$) than in the 1-Back task ($M = 0.86$, $SD = 0.09$), $t(40) = 2.9$, $p = 0.006$, and 2-Back task ($M = 0.71$, $SD = 0.15$), $t(40) = 9.22$, $p < 0.001$. Performance was higher in the 1-Back task than 2-Back task, $t(40) = 9.89$, $p < 0.001$.

Additionally, the ANOVA revealed a significant Age × *N*-Back interaction [$F(2,78) = 27.65$, $MSE = 0.01$, $p < 0.001$, $\eta_p^2 = 0.42$]. Follow-up analyses indicated that there was no age difference in the side-by-side task. Older adults performed significantly worse than younger adults in the 1-Back [$t(39) = 2.79$, $p = 0.008$] and 2-Back tasks [$t(39) = 5.89$, $p < 0.001$]. Moreover, while both age groups performed poorer in the 2-Back task than in the 1-Back and 0-Back versions, only older adults showed significantly poorer performance in the 1-Back compared to the 0-Back version [$t(19) = 3.02$, $p = 0.007$]. To examine the unbinding cost directly, a separate ANOVA: 2 (Age: young, old) × 2 (Condition: expression, both) × 3 (*N*-Back: side-by-side 0-Back, 1-Back, 2-Back) showed a significant Condition × *N*-Back × Age interaction [$F(2,78) = 4.34$, $MSE = 0.01$, $p = 0.016$, $\eta_p^2 = 0.10$][3]. In the side-by-side 0-Back task, there was no age difference in the expression and both conditions. With regard to 1-Back task, there was no age difference in the both condition, but older adults performed worse than younger adults in the expression condition [$t(39) = 2.59$, $p < 0.05$]. For 2-Back task, older adults performed worse than younger adults in the expression [$t(39) = 4.99$, $p < 0.001$] and both [$t(39) = 4.12$, $p < 0.001$] conditions. More importantly, within the 2-Back task, older adults' performance in the both condition exceeded that in the expression condition [$t(19) = 3.25$, $p = 0.004$]. However, younger adults did not show such difficulty in the expression condition compared to the both condition in the 2-Back task. For younger adults, the only difference between expression and both condition was within the side-by-side 0-Back task [$t(20) = 3.09$, $p = 0.006$]; their side-by-side 0-Back task performance was better in the both condition than the performance in the expression condition.

RESPONSE TIMES

Any RTs 3 *SD* above or below the group mean values were excluded from the analyses. To eliminate the effect of age-related slowing in age by condition interaction analyses (Faust et al., 1999), a logarithmic transformation was applied on the RT data prior to analysis. Only hit trials were included in RT data analyses. The data for younger and older adults are presented in **Figures 2C,D**, respectively. A three-way mixed ANOVA on log transformed RTs showed that younger participants ($M = 787.37$, $SD = 172.69$) had faster reaction times than older participants ($M = 1359.93$, $SD = 348.34$), $F(1,39) = 114.79$, $MSE = 0.22$, $p < 0.001$, $\eta_p^2 = 0.75$. There was a main effect of task [$F(2,78) = 122.66$, $MSE = 0.03$, $p < 0.001$, $\eta_p^2 = 0.76$]. Participants had significantly longer RTs in side-by-side 0-Back task ($M = 1194.7$, $SD = 296.13$) than they had in 1-Back ($M = 884.02$, $SD = 219.95$), $t(40) = 15.86$, $p < 0.001$ and 2-Back tasks ($M = 1142.22$, $SD = 265.45$), $t(40) = 3.72$, $p = 0.001$. RTs were longer in 2-Back task than in 1-Back task [$t(40) = 11.76$, $p < 0.001$]. Longer RTs in the side-by-side task are consistent with participants' verbal reports that they looked for differences in fine details between the two pictures; it is also likely that this RT included saccadic eye movements. ANOVA revealed a significant main effect of condition, $F(2,78) = 17.58$, $MSE = 0.05$, $p < 0.001$, $\eta_p^2 = 0.31$. Participants had longer RTs in the expression ($M = 1176.93$, $SD = 250.89$) condition than in the identity [$M = 1022.43$, $SD = 237.28$; $t(40) > 6.26$, $p < 0.001$] and both conditions [$M = 1021.58$, $SD = 293.37$; $t(40) = 5.01$, $p < 0.001$].

INFLUENCE OF EMOTION ON ACCURACY

The analysis of the effect of emotional expression was restricted to the 1-Back and 2-Back tasks (the side-by-side comparison in the 0-Back task makes it impossible to assess which of the emotional expressions influenced performance), and to the expression and both conditions (in the identity condition, participants were supposed to disregard emotional information, and therefore any calculation of accuracy for expression is not meaningful in this condition).

A four-way mixed ANOVA: 2 (Age: young, old) × 2 (Condition: expression, both) × 2 (*N*-Back: 1-Back, 2-Back) × 4

[3]When we conducted a separate ANOVA: 2 (Age: young, old) × 2 (Condition: identity, both) × 3 (*N*-Back: side-by-side 0-Back, 1-Back, 2-Back) to see whether age-related unbinding cost would occur for identity task, the Condition × *N*-Back × Age interaction was not significant, indicating no differential cost of unbinding for older adults in the identity condition.

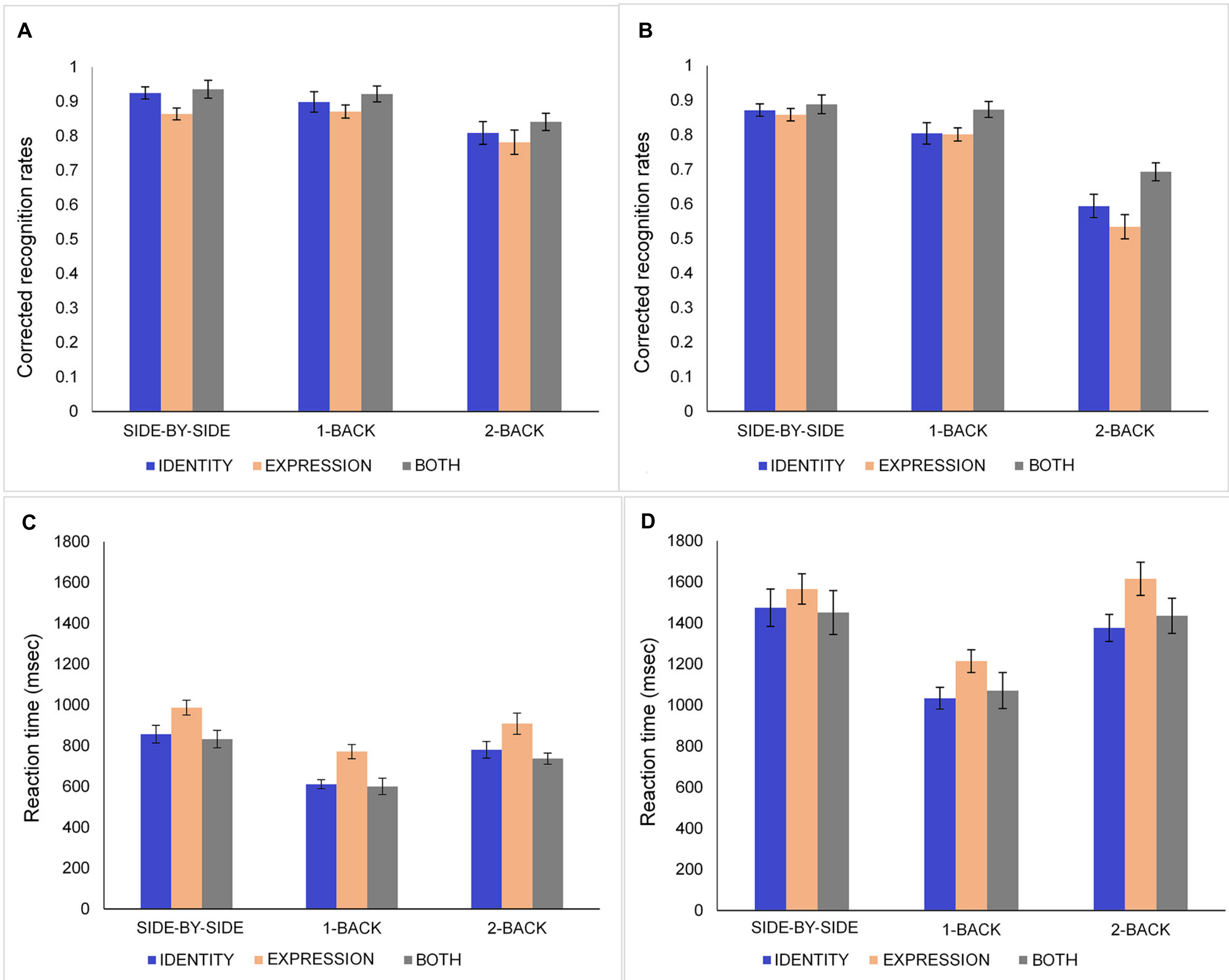

FIGURE 2 | Corrected recognition rates (proportion of hits minus false alarms) and response times of younger (A,C) and older (B,D) adults in the identity, expression, and both conditions for side-by-side 0-Back, 1-Back, and 2-Back tasks. Error bars denote standard error.

(Emotion: happy, angry, neutral, disgust) was performed on corrected recognition rates (proportion of hit minus false alarm rates) for each emotional expression. The data for younger and older adults are represented in **Figures 3A,B**, respectively. The main effect of emotion [$F(3,117) = 18.87$, $MSE = 0.02$, $p < 0.001$, $\eta_p^2 = 0.33$] showed that happy ($M = 0.83$, $SD = 0.09$) and neutral ($M = 0.81$, $SD = 0.12$) faces were recognized better than angry faces ($M = 0.73$, $SD = 0.11$) [happy vs. angry, $t(40) = 6.86$, $p < 0.001$; neutral vs. angry, $t(40) = 5.82$, $p < 0.001$]. Additionally, disgusted faces ($M = 0.76$, $SD = 0.13$) were recognized significantly worse than happy [$t(40) = 3.93$, $p < 0.001$], and neutral faces [$t(40) = 3.21$, $p = 0.003$]. There was no significant difference between angry and disgusted faces [$t(40) = 2.04$, $p = 0.048$] and between happy and neutral faces [$t(40) = 0.99$, $p > 0.10$]. Furthermore, the Condition by Emotion interaction [$F(3,117) = 17.85$, $MSE = 0.02$, $p < 0.001$, $\eta_p^2 = 0.32$] was significant. Follow-up analyses showed that in the expression condition, happy faces were recognized better than angry [$t(40) = 8.39$, $p < 0.001$], disgusted [$t(40) = 5.62$, $p < 0.001$] and, neutral faces [$t(40) = 3.21$, $p = 0.003$] while there was no difference in recognition of the faces in the both condition [all $ts(40) < 2.05$, $ps > 0.09$]. Additionally, participants performed better in the both condition than in the expression condition for angry [$t(40) = 6.3$, $p < 0.001$], and disgusted [$t(40) = 4.48$, $p < 0.001$] faces. There was no age-related recognition bias for the specific type of emotional stimuli shown, as indexed by a non-significant interaction between age and emotion [$F(3,117) = 1.83$, $MSE = 0.02$, $p > 0.10$, $\eta_p^2 = 0.05$].

INFLUENCE OF EMOTION ON RESPONSE TIMES

The data for younger and older adults are shown in **Figures 3C,D**, respectively. The main effect of emotion was significant [$F(3,117) = 15.79$, $MSE = 0.09$, $p < 0.001$, $\eta_p^2 = 0.29$]. Participants' RTs were significantly faster for happy ($M = 937.87$, $SD = 55.67$) faces than for angry [$M = 1112.47$, $SD = 59.21$; $t(40) = 6.58$, $p < 0.001$], disgusted [$M = 1080.38$, $SD = 55.35$; $t(40) = 4.36$, $p < 0.001$], or neutral faces [$M = 1027.71$,

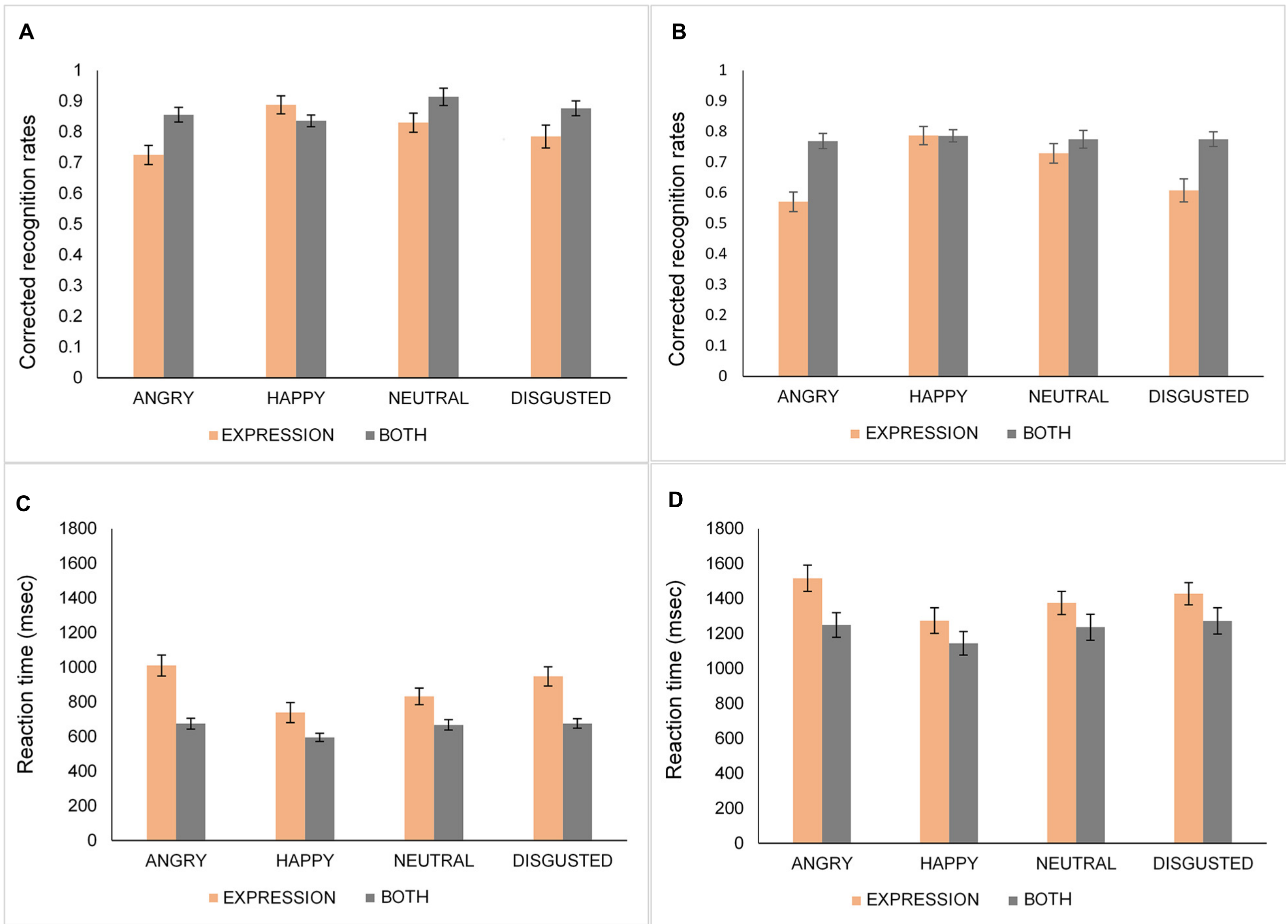

FIGURE 3 | Corrected recognition rates (proportion of hits minus false alarms) and response times of younger (A,C) and older (B,D) adults for angry, happy, neutral, and disgusted faces in the identity, expression, and both conditions. Error bars denote standard error.

SD = 54.6; $t(40) = 3.52$, $p = 0.001$]. In addition, neutral faces were detected faster than angry faces [$t(40) > 3.9$, $p < 0.001$]. Moreover, the Condition × Emotion interaction was significant [$F(3,117) = 3.72$, $MSE = 0.07$, $p = 0.01$, $\eta_p^2 = 0.09$]. Follow-up analyses showed that in the expression condition, happy faces were recognized faster than angry [$t(40) = 7.55$, $p < 0.001$], disgusted [$t(40) = 4.73$, $p < 0.001$], or neutral faces [$t(40) = 4.58$, $p < 0.001$]. Additionally, neutral faces were recognized faster than angry faces [$t(40) = 4.73$, $p < 0.001$]. For happy faces, there was no RT difference between conditions whereas the expression condition yielded slower RTs than the both condition for angry [$t(40) = 6.94$, $p < 0.001$], neutral [$t(40) = 3.46$, $p = 0.001$], and disgusted faces [$t(40) = 4.22$, $p < 0.001$]. Consistent with the accuracy data, a non-significant Age × Emotion interaction [$F(3,117) = 1.94$, $MSE = 0.09$, $p > 0.10$, $\eta_p^2 = 0.05$] reflects an absence of age-related speed bias for any type of emotional expression.

INFLUENCE OF EMOTION AND COGNITIVE LOAD ON PUPIL RESPONSES

Prior to analysis, pupil data with missing observations due to eyeblinks or signal loss were discarded. Additionally, pupil values above 2.5 *SD* from the average of their 10 immediate neighbors were removed within each individual and replaced by linear interpolation, in accordance with guidelines by Goldinger et al. (2009). This procedure resulted in fewer than 4% corrected trials per participant. For the analyses, the max peak pupil size value during stimulus presentation and the inter-stimulus interval for each trial was determined. The percentage change was calculated as max pupil size at each trial minus the baseline pupil value divided by the baseline (e.g., Iqbal et al., 2004). Baseline pupil size was the average pupil size recorded during this 8,000 ms fixation cross presented at the beginning of each block. Only hit responses were included in the analyses.

To understand the joint effects of emotion and cognitive task on pupil size, average percentage change in pupil size was calculated for each emotional expression within the 1-Back and 2-Back versions of the task. As in the previous analyses focusing on emotion, side-by-side tasks in each condition and identity condition as a whole were not included. A four-way mixed ANOVA: 2 (Age: young, old) × 2 (Condition: expression, both) × 2 (*N*-Back: 1-Back, 2-Back) × 4 (Emotion: angry, happy, neutral, disgust) was performed on average percentage change in pupil size. Only hit trials were considered. The data for younger and older adults are presented in **Figures 4A,B**, respectively.

There was a main effect of emotion [$F(3,117) = 6.77$, $MSE = 0.00$, $p < 0.001$, $\eta_p^2 = 0.15$) with larger pupil dilation for disgusted and angry faces than neutral faces [disgusted vs. neutral faces, $t(40) = 3.46$, $p = 0.001$; angry vs. neutral faces $t(40) = 3.37$, $p = 0.001$]. More importantly, we obtained a significant N-Back × Emotion × Age interaction [$F(3,117) = 3.55$, $MSE = 0.00$, $p = 0.02$, $\eta_p^2 = 0.08$]. To follow-up, we ran separate ANOVAs on *N*-Back and Emotion within the groups of younger and older adults. Younger adults' pupil dilation was larger in 2-Back task than 1-Back task [$F(1,20) = 9.32$, $MSE = 0.00$, $p = 0.006$, $\eta_p^2 = 0.32$] while older adults did not show a significant main effect of *N*-Back task [$F(1,19) = 0.22$, $MSE = 0.00$, $p > 0.10$, $\eta_p^2 = 0.01$]. For younger adults, pupil dilation was larger for angry and disgusted faces than neutral and happy faces in 1-Back task [angry vs. neutral, $t(20) = 3.56$, $p = 0.002$; disgust vs. neutral, $t(20) = 3.33$, $p = 0.003$; disgust vs. happy, $t(20) = 3.28$, $p = 0.004$]. However, there was no differential effect of any emotion on pupil dilation in 2-Back task for younger adults. These findings indicated that the effect of emotion on pupil dilation was evident only under low cognitive demand condition (in 1-Back task) for younger adults. On the other hand, the *N*-Back × Emotion interaction was not significant for older adults, showing that older adults' pupil dilation was not different for the faces across *N*-Back tasks.

DISCUSSION

Before we discuss the age-related effects in the data, we first turn to the general-psychological findings.

First, we indeed obtained the predicted difficulty effects for our *N*-Back tasks. Crucial for our main investigation, we found that the 1-Back task, which involves sequential comparisons between two stimuli, and is thus primarily a measure of attention and STM, is easier (i.e., it leads to higher accuracy and faster RT) than the 2-Back task, which involves retrieving a memory presentation stored outside the immediate focus of attention, and is thus primarily a measure of working memory performance. In older adults, the 0-Back task, which involves a side-by-side comparison and is thus primarily a measure of perceptual discrimination, was also easier (i.e., it led to higher accuracy) than the 1-Back task; younger adults showed statistically indistinguishable accuracy for the two tasks. Note that RT for the 0-Back task is much higher than for the other tasks. This is probably due to the peculiarity of our set-up: the two stimuli are presented side-by-side, likely prompting saccadic eye movements during the comparison process.

Second, our results concerning binding and unbinding of identity and emotion in the face stimuli are in line with expectations as well. Analysis of RTs showed that the identity condition (where only the identity of the face needed to be matched) and the both condition (where both identity and emotional expression needed to be matched) were statistically indistinguishable, and that they were performed on average about 150 ms faster than the expression condition (where only the emotional expression of the face needed to be matched). These results are in line with the literature on perceptual discrimination for emotional faces, where extraction of identity appears to happen relatively automatically, but extraction of emotional expression is an effortful, time-demanding process (e.g., Ganel and Goshen-Gottstein, 2004). The accuracy analyses added a subtle twist to these findings: subjects were more accurate in the both condition than in the expression condition, with the identity condition situated in between (and not significantly different from either). For younger adults (we will return to the older-adults data below), this effect is already present in the side-by-side 0-Back condition, and is simply carried over to the 1-Back and 2-Back versions of the task. This suggests that for younger adults the effect operates at the perceptual stage only – it is not further exacerbated by the attentional/STM requirement in the 1-Back, or the working memory requirement in the 2-Back task. In sum, the accuracy findings reaffirm that expression extraction is an added, effortful process, leading to lower accuracy, and suggest that identity extraction may come at a

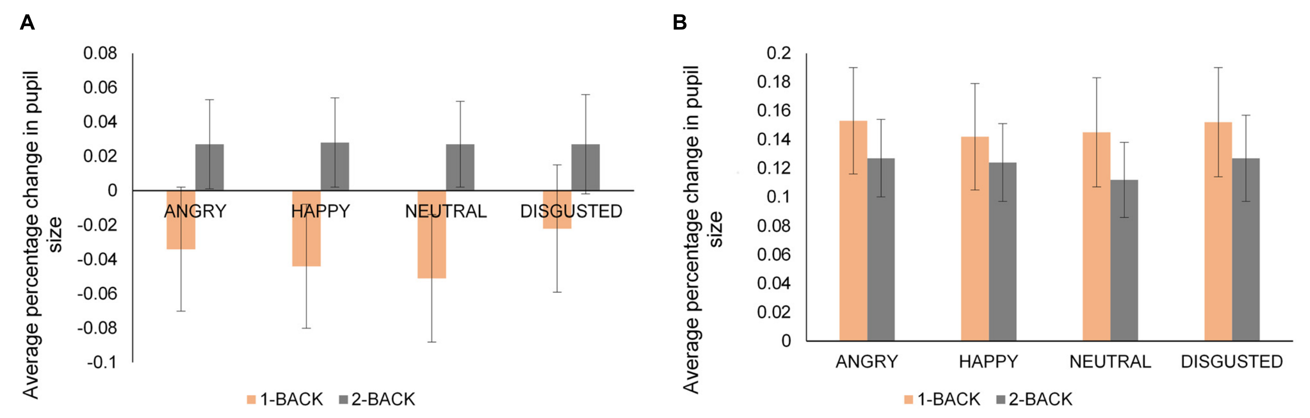

FIGURE 4 | Average percentage change in pupil size from a fixation-cross baseline for younger (A) and older (B) adults for angry, happy, neutral, and disgusted faces in 1-Back and 2-Back tasks. Error bars denote standard error. Note the different scale of the vertical axis for younger and older adults.

small (and, in the present study, not significant) cost in error rates.

The third set of findings concerns the effects of particular emotions on performance. This analysis was restricted to the 1-Back and 2-Back versions of the task (in mismatch stimuli in the 0-Back task, it is impossible to ascertain which of the two emotions displayed drives the effect); the analysis was also restricted to the two conditions were the emotional expressions were explicitly part of the decision process – the both condition and the expression condition. Overall, the evidence points at a positivity effect: happy and neutral faces yielded higher accuracy than angry and disgusted faces. This effect, however, only operated in the expression condition, not in the both condition, where no significant difference between accuracy for the different emotions was observed. RT data largely confirm this picture, with the exception of a less flat profile for the both condition, where happy faces were responded to faster than any other emotion. We note that the positivity effect in accuracy and RT may be due to the valence of the emotion, but it could also partially related to perceptual factors specific to happy faces, which tend to display more perceptually distinct features (i.e., open mouth, visible teeth) than negative and neutral faces. RTs in the both condition, with happy faces being the only stand-out (and being responded to fastest), lend some credence to the perceptual-distinctiveness hypothesis. Additionally, we showed that disgusted and angry emotions were more easily recognized in the both condition than in the expression condition. More accurate recognition of negative and potentially threatening emotions in the condition in which faces are processed as a whole may have its origin in the evolutionary survival value of swift action in the face of such emotions (e.g., Ackerman et al., 2006).

The final set of general findings pertains to pupil dilation. We highlight two results. First, for younger adults, we found evidence for a separation between the 1-Back task, which did not lead to larger pupil dilation compared to baseline, and the 2-Back task, which did. This finding is clearly in line with previous work showing that pupil dilation indexes cognitive resources (e.g., Granholm et al., 1996; Van Gerven et al., 2004; Goldinger and Papesh, 2012). Second, also for younger adults, but only for the 1-Back condition, we found a differential effect for emotion, with disgusted faces showing the highest amount of dilation, and angry the second highest. One observation here is that the emotions that yielded the lowest accuracy also elicit the largest pupil dilation, suggesting that higher effort (as evidenced by pupil dilation) is associated with more difficulties in maintaining attention across sequential presentation of stimuli. It also suggests that the recognition and reaction time advantage for happy faces is not due to attentional biases: one would expect that higher attentional effort would lead to better recognition and faster decisions, and therefore larger pupil dilation would be observed for happy faces. However, the opposite was true. We can solve this apparent puzzle if we assume that in the present case, pupil dilation does not index effort, but arousal (e.g., Stanners et al., 1979). In the separate study we conducted to assess arousal value of the stimuli (see Materials and Methods), the rank ordering of arousal values (from lowest to highest: neutral, happy, angry, disgusted) nicely tracks the pupil dilation date in the 1-Back condition for younger adults. We note that this differential effect of emotion disappeared in the 2-Back condition. The reason for this may be a functional ceiling in pupil dilation, in which the larger dilation associated with cognitive effort masks or trumps the arousal-related changes visible under conditions of low effort.

One goal of our study was to investigate age-related changes in the efficiency and/or efficacy of binding of information in working memory. Recall that binding emotional expressions to the identity of faces seems to be the default, and that abstracting emotional expressions from faces is effortful, as exemplified in higher accuracy and faster RTs for emotional faces than for the emotional expression on its own. Also recall that in younger adults, this effect operates at the perceptual stage, simply carrying over into the attentional/STM and working memory stages of processing (i.e., in the 1-Back and 2-Back task, respectively). The picture is different for older adults: age-related unbinding problems (operationalized as the difference between the expression condition and the both condition) become apparent in the 2-Back version of the task. Thus, older adults are as good (or as bad) as younger adults in unbinding the emotional feature from the compound stimulus in the perceptual and attentional/STM stages of the task; an added working memory component, however, widens the observed age difference. This suggests that older adults have a specific deficit, at least in this task, either with keeping unbound, feature-level information active and/or retrievable in memory, or with keeping the bound representation that is stored in working memory sufficiently detailed to easily abstract the emotional content from it. Further research is necessary to more precisely pinpoint the locus of or mechanism behind the effect. The result does not suggest a specific age-related problem of hyper-binding in the sense that older adults would keep the representation bound and younger adults do not: both age groups incur an unbinding cost in both accuracy and RT in the expression condition.

There is another possibility as well – an age-related deficit in flexible strategy use. Note that conditions were blocked, so that participants could freely apply strategic processing to the task, such as extraction of the relevant feature at the encoding stage rather than from a retrieved memory representation. If this strategy was used at all, the results suggest it was used more often, or with greater efficacy, by younger adults. In sum, the evidence points at the existence of hyper-binding in working memory in older adults, at least in this task, where the default modus operandi is to process stimuli in a bound state.

A second results concerns the emergence of age-related differences in the 1-Back task. In our previous work using the *N*-Back task (e.g., Verhaeghen et al., 2004; Vaughan et al., 2008), we consistently observed age-related differences in 2-Back tasks, but not in 1-Back tasks. The present experiment is the first where we do obtain age-related deficits in a 1-Back task. We can see at least two possible reasons for this difference. First, in our previous work, we used digits; the present study uses faces. Faces contain much more detail than digits, and so it is possible that this result signifies that older adults are less able to keep informational detail alive than younger adults do, even in the simple 1-Back task (for a related theoretical argument, see Myerson et al., 1990). The second possible reason is related to the brief interstimulus interval – 2,000 ms – built into the present, but not previous studies.

The interpretation would then be that older adults lose informational detail at a faster clip than younger adults do. We are not aware of relevant data in visual working memory, but decay rates in verbal working memory are indeed faster in older than younger adults – the half-life of older adults' STM representations is about 70% shorter than that of younger adults (Verhaeghen, 2014). Further research is necessary to assess to what degree each of those potential mechanisms operates to create the effect. We do know that this age-related deficit in attentional/STM processing cannot be due to perceptual deficits – younger and older adults performed equally well in the side-by-side comparison task.

Whatever the mechanism, it seems quite counterintuitive that age differences would appear with so minimal a cognitive load: all that is required of the subject in the 1-Back task is to retain an image of a face for 2 s, with no additional requirements. The pupil data confirm, however, that what one might consider a minimal load is far from minimal for older adults. First, older adults had elevated pupil dilations compared to younger adults in the 1-Back task, indicating that the 1-Back task is more effortful for older than for younger adults. Second, while we observed a clear separation between the 1-Back and the 2-Back version of the task in younger adults, older adults showed only nominally smaller pupil dilation for 1-Back that for 2-Back. This finding suggests that for older adults the cognitive load of passively maintaining a representation in the focus of attention is about as large as that for maintaining a representation in working memory while performing a concurrent task. One possible complication with the interpretation of this second finding is that there might be a functional ceiling for pupil dilation, and that statistical identity of 1-Back and 2-Back performance can therefore not directly equated with equal effort. Even under this interpretation, however, it is clear that the 1-Back task does not require attentional resources in younger adults, as testified by the lack of pupil dilation compared to baseline, whereas it clearly does in older adults.

A third age-related result concerns the differential effect of the emotion content of the stimuli. In general, and perhaps surprisingly, we observed a positivity effect, where happy and neutral faces were generally responded to faster and more accurately than angry and disgusted faces. Socioemotional selectivity theory (Carstensen et al., 1999) would predict this effect to be larger in older adults. One recent refinement of the theory (Mather and Knight, 2005) claimed that processing positive emotional material does require attention, and that the age-related positivity bias should then disappear or reverse under conditions of high cognitive load, as in our 2-Back task. We did not find any evidence for either hypothesis: no age by emotion interactions were observed in either accuracy or RTs, thus suggesting both an absence of an age-specific positivity effect and the absence of an effect of load on age-related difference in emotion-specific processing. Thus, the impact of the type of emotion was identical across age groups, regardless of processing stage (perceptual, attentional/STM, or memory) or cognitive load. This result runs counter socioemotional selectivity theory (including modifications of this theory that take cognitive load into account; e.g., Knight et al., 2007), but is in line with the one extant meta-analysis (Murphy and Isaacowitz, 2008) which found no significant difference in the preference for positive emotional stimuli of younger and older adults in either memory or attention studies.

Summarized, our results indicate that older adults do have more difficulty unbinding a bound stimulus than younger adults do, and that this difficulty is restricted to a working memory condition (2-Back); tasks primarily measuring perceptual clarity and attention/STM do not show age-related hyper-binding. Additionally, we found that, in general, older adults show deficits in attentional/STM processing (1-Back) as well as working memory processing; pupil dilation data suggest that attentional processing mobilizes and possibly requires more cognitive resources in older adults compared to younger adults. Finally, and importantly, our study adds to the body of literature suggesting a lack of age sensitivity in differential effects of different emotional stimuli on perception, attention, and working memory, counter the so-called positivity effect posited by socioemotional selectivity theory.

We note some important limitations of our study. One potential issue concerns the stimulus set: we used only young, female (and white) faces. Given the potential for own-age biases in attention and/or memory (Rhodes and Anastasi, 2012), it might be advisable to replicate this work using older-adult faces as well. We reiterative that same-age biases in face discrimination or face memory would influence mean levels of accuracy, but there is no reason to expect that that would influence interactions involving age.

Likewise, we obtained arousal data for these stimuli only from younger adults. Given that our study included both younger and older adults, arousal ratings from a sample of older adults would have been useful to ensure that older adults did not perceive the emotional faces differently than younger adults. Although some face databases (e.g., The Karolinska Directed Emotional Faces by Goeleven et al., 2008) measured perceived arousal level of the emotional face stimuli in the norming study, to our knowledge none of the databases included older adults as raters in their norming studies. When we look at non-face stimuli, Grühn and Scheibe (2008) investigated age-related differences in perceived levels of IAPS pictures and found that older adults perceived negative pictures as being more arousing and positive pictures as being less arousing than young adults did. If this result were to generalize to faces, we would expect larger pupil dilation for angry and disgusted faces in older adults compared to younger adults, and perhaps pupil contraction for happy faces. This is not what was found. We do note that this limitation is likely moot in the present study: only younger adults showed modulation of their pupil responses that could be interpreted as arousal-mediated, and then only in the 1-Back condition. Older adults, as well as younger adults in the more demanding condition (2-Back), showed elevated pupil dilation and no modulation by emotion, suggesting that the cognitive demands of the task wiped out any arousal-based effects on pupil dilation. Of course, it remains theoretically possible that older adults perceived all faces as much more arousing than younger adults did, thereby in effect attenuating all differential effects of emotion on pupil dilation.

A third limitation is that we scaled our pupillometry data as percentage of baseline; recent work (unknown to us when we were designing the experiment) has used a different approach, scaling pupil size as a function of maximum possible pupil change (Piquado et al., 2010). We cannot retroactively apply this metric to our data, but this rescaling would have been useful to see if older adults' asymptoting of pupil size in the 1-Back condition reflects a limit on the deployment of attentional/STM resources or a physiological limit on pupil size.

Many questions remain. For instance, it is not clear whether the unbinding deficit in old age is a specific deficit, or merely an instantiation of the complexity effect – age differences in perception and attention are magnified in memory tasks, with the larger age differences then observed in the more difficult task. Under most circumstances, binding would be more difficult (a finding in line with the results on associative deficits summarized in the Introduction), but in the present study, unbinding was more difficult, and hence we found evidence for hyper-binding in older adults. Likewise, it is unclear what exactly makes the 1-Back, attention-centered condition so hard and effortful for older adults: information detail, the 2-s delay, or some other mechanism. It would also be worthwhile to get neuroimaging data on the brain locus of this effect, and see whether it (as one would expect) originates in parts of the control network.

ACKNOWLEDGMENT

This research was supported by the grant AG-16201 of National Institute of Health, USA.

REFERENCES

Ackerman, J. M., Shapiro, J. R., Neuberg, S. L., Kenrick, D. T., Becker, D. V., Griskevicius, V., et al. (2006). They all look the same to me (unless they're angry): from out-group homogeneity to outgroup heterogeneity. *Psychol. Sci.* 17, 836–840. doi: 10.1111/j.1467-9280.2006.01790.x

Allard, E. S., and Isaacowitz, D. M. (2008). Are preferences in emotional processing affected by distraction? Examining the age-related positivity effect in visual fixation within a dual-task paradigm. *Aging Neuropsychol. Cogn.* 15, 725–743. doi: 10.1080/13825580802348562

Baddeley, A. D., and Hitch, G. J. (1974). "Working memory," in *The Psychology of Learning and Motivation*, eds G. H. Bower (New York: Academic Press), 47–89.

Beatty, J. (1982). Task-evoked pupillary responses, processing load, and the structure of processing resources. *Psychol. Bull.* 91, 276–292. doi: 10.1037/0033-2909.91.2.276

Bopp, K. L., and Verhaeghen, P. (2007). Age-related differences in control processes in verbal and visuo-spatial working memory: storage, transformation, supervision, and coordination. *J. Gerontol. B Psychol. Sci. Soc. Sci.* 62, 239–246. doi: 10.1093/geronb/62.5.P239

Bopp, K. L., and Verhaeghen, P. (2009). Working memory and aging: separating the effects of content and context. *Psychol. Aging* 24, 968–980. doi: 10.1037/a0017731

Bradley, M. M., and Lang, P. J. (1994). Measuring emotion: the self-assessment manikin and the semantic differential. *J. Behav. Ther. Exp. Psychiatry* 25, 49–59. doi: 10.1016/0005-7916(94)90063-9

Brockmole, J. R., Parra, M. A., Della Sala, S., and Logie, R. H. (2008). Do binding deficits account for age-related decline in visual working memory? *Psychon. Bull. Rev.* 15, 543–547. doi: 10.3758/PBR.15.3.543

Bruce, V., and Young, A. W. (1986). Understanding face recognition. *Br. J. Psychol.* 77, 305–327. doi: 10.1111/j.2044-8295.1986.tb02199.x

Calder, A. J., Keane, J., Manly, T., Sprengelmeyer, R., Scott, S., Nimmo-Smith, I., et al. (2003). Facial expression recognition across the adult life span. *Neuropsychologia* 41, 195–202. doi: 10.1016/S0028-3932(02)00149-5

Campbell, K. L., Hasher, L., and Thomas, R. C. (2010). Hyper-binding: a unique age effect. *Psychol. Sci.* 21, 399–405. doi: 10.1177/0956797609359910

Carstensen, L. L., Isaacowitz, D., and Charles, S. T. (1999). Taking time seriously: a theory of socioemotional selectivity. *Am. Psychol.* 54, 165–181. doi: 10.1037/0003-066X.54.3.165

Cerella, J. (1985). Information processing rates in the elderly. *Psychol. Bull.* 98, 67–83. doi: 10.1037/0033-2909.98.1.67

Chalfonte, B. L., and Johnson, M. K. (1996). Feature memory and binding in young and older adults. *Mem. Cogn.* 24, 403–416. doi: 10.3758/BF03200930

Chen, T., and Li, D. (2007). The roles of working memory updating and processing speed in mediating age-related differences in fluid intelligence. *Neuropsychol. Dev. Cogn. B Aging Neuropsychol. Cogn.* 14, 631–646. doi: 10.1080/13825580600987660

Conway, A. R. A., Cowan, N., Bunting, M. F., Therriault, D. J., and Minkoff, S. R. B. (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, and general fluid intelligence. *Intelligence* 30, 163–183. doi: 10.1016/S0160-2896(01)00096-4

Cowan, N., Naveh-Benjamin, M., Kilb, A., and Saults, J. S. (2006). Life-span development of visual working memory: when is feature binding difficult? *Dev. Psychol.* 42, 1089–1102. doi: 10.1037/0012-1649.42.6.1089

Dobbs, A. R., and Rule, B. G. (1989). Adult age differences in working memory. *Psychol. Aging* 4, 500–503. doi: 10.1037/0882-7974.4.4.500

Ebner, N., Riediger, M., and Lindenberger, U. (2010). FACES – a database of facial expressions in young, middle-aged, and older women and men: development and validation. *Behav. Res. Methods* 42, 351–362. doi: 10.3758/BRM.42.1.351

Engle, R. W., Kane, M. J., and Tuholski, S. W. (1999). "Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence and functions of the prefrontal cortex," in *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control*, eds A. Miyake and P. Shah (London: Cambridge University Press), 102–134.

Faust, M. E., Balota, D. A., Spieler, D. H., and Ferraro, F. R. (1999). Individual differences in information-processing rate and amount: implications for group differences in response latency. *Psychol. Bull.* 125, 777–799. doi: 10.1037/0033-2909.125.6.777

Ganel, T., and Goshen-Gottstein, Y. (2004). Effects of familiarity on the perceptual integrality of the identity and expression of faces: the parallel-route hypothesis revisited. *J. Exp. Psychol. Hum. Percept. Perform.* 30, 583–597. doi: 10.1037/0096-1523.30.3.583

Goeleven, E., Raedt, R., Leyman, L., and Verschuere, B. (2008). The Karolinska directed emotional faces: a validation study. *Cogn. Emot.* 22, 1094–1118. doi: 10.1080/02699930701626582

Goldinger, S. D., and Papesh, M. H. (2012). Pupil dilation reflects the creation and retrieval of memories. *Curr. Dir. Psychol. Sci.* 21, 90–95. doi: 10.1177/0963721412436811

Goldinger, S. D., He, Y., and Papesh, M. (2009). Deficits in cross-race face learning: insights from eye-movements and pupillometry. *J. Exp. Psychol. Learn. Mem. Cogn.* 35, 1105–1122. doi: 10.1037/a0016548

Granholm, E., Asarnow, R. F., Sarkin, A. J., and Dykes, K. L. (1996). Pupillary responses index cognitive resource limitations. *Psychophysiology* 33, 457–461. doi: 10.1111/j.1469-8986.1996.tb01071.x

Grühn, D., and Scheibe, S. (2008). Age-related differences in valence and arousal ratings of pictures from the International Affective Picture System (IAPS): do ratings become more extreme with age? *Behav. Res. Methods* 40, 512–521. doi: 10.3758/BRM.40.2.512

Heitz, R. P., Schrock, J. C., Payne, T. W., and Engle, R. W. (2008). Effect of incentive on working memory capacity: behavioral and pupillometric data. *Psychophysiology* 45, 119–129. doi: 10.1111/j.1469-8986.2007.00605.x

Hess, E. H. (1965). Attitude and pupil size. *Sci. Am.* 212, 46–54. doi: 10.1038/scientificamerican0465-46

Hicks, R. A., Reaney, T., and Hill, L. (1967). Effects of pupil size and facial angle on preference for photographs of a young woman. *Percept. Mot. Skills* 24, 388–390. doi: 10.2466/pms.1967.24.2.388

Iqbal, S. T., Zheng, X. S., and Bailey, B. P. (2004). "Task-evoked pupillary response to mental workload in human-computer interaction," in *Proceedings of the Conference on Human Factors in Computing Systems*, Vienna, Austria, 2004, 1477–1480. doi: 10.1145/985921.986094

Kahneman, D., and Beatty, J. (1966). Pupil diameter and load on memory. *Science* 154, 1583–1585. doi: 10.1126/science.154.3756.1583

Kane, M. J., Bleckley, M. K., Conway, A. R. A., and Engle, R. W. (2001). A controlled-attention view of working memory capacity: individual differences in memory span and the control of visual orienting. *J. Exp. Psychol. Gen.* 130, 169–183. doi: 10.1037/0096-3445.130.2.169

Karatekin, C., Marcus, D. J., and Couperus, J. W. (2007). Regulation of cognitive resources during sustained attention and working memory in 10-year-olds and adults. *Psychophysiology* 44, 128–144. doi: 10.1111/j.1469-8986.2006.00477.x

Kemper, S., Herman, R. E., and Lian, C. H. T. (2003). The costs of doing two things at once for young and older adults: talking while walking, finger tapping, and ignoring speech or noise. *Psychol. Aging* 18, 181–192. doi: 10.1037/0882-7974.18.2.181

Kensinger, E. A., and Corkin, S. (2003). Effects of negative emotional content on working memory and long-term memory. *Emotion* 3, 378–393. doi: 10.1037/1528-3542.3.4.378

Kirchner, W. K. (1958). Age differences in short-term retention of rapidly changing information. *J. Exp. Psychol.* 55, 352–358. doi: 10.1037/h0043688

Knight, M., Seymour, T. L., Gaunt, J. T., Baker, C., Nesmith, K., and Mather, M. (2007). Aging and goal directed emotional attention: distraction reverses emotional biases. *Emotion* 7, 705–714. doi: 10.1037/1528-3542.7.4.705

Kyllonen, P. C. (1996). "Is working memory capacity Spearman's g?," in *Human Abilities: Their Nature and Measurement*, eds I. Dennis and P. Tapsfield (Mahwah, NJ: Erlbaum), 49–75.

Laeng, B., Ørbo, M., Holmlund, T., and Miozzo, M. (2011). Pupillary Stroop effects. *Cogn. Process.* 12, 13–21. doi: 10.1007/s10339-010-0370-z

Martens, U., Leuthold, H., and Schweinberger, S. R. (2010). On the temporal organization of facial identity and expression analysis: inferences from event-related brain potentials. *Cogn. Affect. Behav. Neurosci.* 10, 505–522. doi: 10.3758/CABN.10.4.505

Mather, M., and Knight, M. (2005). Goal-directed memory: the role of cognitive control in older adults' emotional memory. *Psychol. Aging* 20, 554–570. doi: 10.1037/0882-7974.20.4.554

Mikels, J. A., Larkin, G. R., Reuter-Lorenz, P. A., and Cartensen, L. L. (2005). Divergent trajectories in the aging mind: changes in working memory for affective versus visual information with age. *Psychol. Aging.* 20, 542–553. doi: 10.1037/0882-7974.20.4.542

Miyake, A., and Shah, P. (1999). "Toward unified theories of working memory: emerging general consensus, unresolved theoretical issues, and future research directions," in *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control*, eds A. Miyake and P. Shah (Cambridge: Cambridge University Press), 442–481. doi: 10.1017/CBO9781139174909

Murphy, N. A., and Isaacowitz, D. M. (2008). Preferences for emotional information in older adults: a meta-analysis of memory and attention studies. *Psychol. Aging* 23, 263–286. doi: 10.1037/0882-7974.23.2.263

Myerson, J., Hale, S., Wagstaff, D., Poon, L. W., and Smith, G. A. (1990). The information-loss model: A mathematical theory of age-related cognitive slowing. *Psychol. Rev.* 97, 475–487. doi: 10.1037/0033-295X.97.4.475

Naveh-Benjamin, M., Guez, J., Kilb, A., and Reedy, S. (2004). The associative deficit of older adults: further support using face-name associations. *Psychol. Aging* 19, 541–546. doi: 10.1037/0882-7974.19.3.541

Oberauer, K. (2002). Access to information in working memory: exploring the focus of attention. *J. Exp. Psychol. Learn. Mem. Cogn.* 28, 411–421. doi: 10.1037/0278-7393.28.3.411

Old, S., and Naveh-Benjamin, M. (2008). Differential effects of age on item and associative measures of memory: a meta-analysis. *Psychol. Aging* 23, 104–118. doi: 10.1037/0882-7974.23.1.104

Partala, T., and Surakka, V. (2003). Pupil size variation as an indication of affective processing. *Int. J. Hum. Comput. Stud.* 59, 185–198. doi: 10.1016/S1071-5819(03)00017.x

Piquado, T., Isaacowitz, D. M., and Wingfield, A. (2010). Pupillometry as a measure of cognitive effort in younger and older adults. *Psychophysiology* 47, 560–569. doi: 10.1111/j.1469-8986.2009.00947.x

Porter, G., Troscianko, T., and Gilchrist, I. D. (2007). Effort during visual search and counting: insights from pupillometry. *Q. J. Exp. Psychol.* 60, 211–229. doi: 10.1080/17470210600673818

Rhodes, M. G., and Anastasi, J. S. (2012). The own-age bias in face recognition: a meta-analytic and theoretical review. *Psychol. Bull.* 138, 146–174. doi: 10.1037/a0025750

Soto, F. A., and Wasserman, E. A. (2011). Asymmetrical interactions in the perception of face identity and emotional expression are not unique to the primate visual system. *J. Vis.* 11:24. doi: 10.1167/11.3.24

Stanners, R., Coulter, M., Sweet, A., and Murphy, P. (1979). The pupillary response as an indicator of arousal and cognition. *Motiv. Emot.* 3, 319–340. doi: 10.1007/BF00994048

Van Gerven, P. W. M., Paas, F., Van Merriënboer, J. J. G., and Schmidt, H. G. (2004). Memory load and the cognitive pupillary response in aging. *Psychophysiology* 41, 167–174. doi: 10.1111/j.1469-8986.2003.00148.x

Vaughan, L., Basak, C., Hartman, M., and Verhaeghen, P. (2008). Aging and working memory inside and outside the focus of attention: dissociations of availability and accessibility. *Aging Neuropsychol. Cogn.* 15, 1–22. doi: 10.1080/13825580802061645

Verhaeghen, P. (2012). "Working memory still working: age-related differences in working memory and executive control," in *Memory and Aging*, eds N. Ohta and M. Naveh-Benjamin (New York: Psychology Press), 3–30.

Verhaeghen, P. (2014). *The Elements of Cognitive Aging: Meta-Analyses of Age-Related Differences in Processing Speed and Their Consequences.* New York, NY: Oxford University Press.

Verhaeghen, P., and Basak, C. (2005). Aging and switching of the focus of attention in working memory: results from a modified *N*-Back task. *Q. J. Exp. Psychol. A* 58, 134–154. doi: 10.1080/02724980443000241

Verhaeghen, P., Cerella, J., and Basak, C. (2004). A working memory workout: how to change to size of the focus of attention from one to four in ten hours or less. *J. Exp. Psychol. Learn. Mem. Cogn.* 30, 1322–1337. doi: 10.1037/0278-7393.30.6.1322

Wheeler, M. E., and Treisman, A. M. (2002). Binding in short-term visual memory. *J. Exp. Psychol. Gen.* 131, 48–64. doi: 10.1037/0096-3445.131.1.48

Wurm, L. H., Labouvie-Vief, G., Aycock, J., Rebucal, K. A., and Koch, H. E. (2004). Performance in auditory and visual emotional Stroop tasks: a comparison of older and younger adults. *Psychol. Aging* 19, 523–535. doi: 10.1037/0882-7974.19.3.523

Zhang, Y., Verhaeghen, P., and Cerella, J. (2012). Working memory at work: how the updating process alters the nature of memory encoding. *Acta Psychol.* 139, 77–83. doi: 10.1016/j.actpsy.2011.10.012

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 22 November 2013; accepted: 07 March 2014; published online: 21 April 2014.

Citation: Pehlivanoglu D, Jain S, Ariel R and Verhaeghen P (2014) The ties to unbind: age-related differences in feature (un)binding in working memory for emotional faces. Front. Psychol. ***5****:253. doi: 10.3389/fpsyg.2014.00253*

This article was submitted to Emotion Science, a section of the journal Frontiers in Psychology.

frontiers in PSYCHOLOGY

ORIGINAL RESEARCH ARTICLE
published: 07 February 2014
doi: 10.3389/fpsyg.2014.00087

Age differences in medial prefrontal activity for subsequent memory of truth value

Brittany S. Cassidy[1]*, Trey Hedden[2], Carolyn Yoon[3] and Angela H. Gutchess[1]

[1] Department of Psychology, Brandeis University, Waltham, MA, USA
[2] Athinoula A. Martinos Center for Biomedical Imaging, Massachusetts General Hospital, Boston, MA, USA
[3] University of Michigan, Ann Arbor, MI, USA

Edited by:
Natalie Ebner, University of Florida, USA

Reviewed by:
Hakan Fischer, Stockholm University, Sweden
Eric S. Allard, Boston College, USA
Kyungmi Kim, Yale University, USA

****Correspondence:***
Brittany S. Cassidy, Department of Psychology, Brandeis University, 415 South St., MS 062, Waltham, MA 02454, USA
e-mail: bcassidy@brandeis.edu

Much research has demonstrated that aging is marked by decreased source memory relative to young adults, yet a smaller body of work has demonstrated that increasing the socioemotional content of source information may be one way to reduce age-related performance differences. Although dorsomedial prefrontal cortex (dmPFC) activity may support source memory among young and older adults, the extent to which one activates dorsal vs. ventral mPFC may reflect one's personal connection with incoming information. Because truth value may be one salient marker that impacts one's connection with information and allocation of attention toward incoming material, we investigated whether the perceived truth value of information differently impacts differences in mPFC activity associated with encoding source information, particularly with age. Twelve young (18–23 years) and 12 older adults (63–80 years) encoded true and false statements. Behavioral results showed similar memory performance between the age groups. With respect to neural activity associated with subsequent memory, young adults, relative to older adults, exhibited greater activity in dmPFC while older adults displayed enhanced ventromedial prefrontal cortex (vmPFC) and insula engagement relative to young. These results may potentially indicate that young adults focus on a general knowledge acquisition goal, while older adults focus on emotionally relevant aspects of the material. The findings demonstrate that age-related differences in recruitment of mPFC associated with encoding source information may in some circumstances underlie age-equivalent behavioral performance.

Keywords: medial prefrontal cortex, truth value, aging, encoding, insula

INTRODUCTION

In addition to remembering the information itself, some of the most important choices in life require consideration of the context related to incoming information, often referred to as source memory (Johnson and Raye, 1981; Johnson et al., 1993). For example, the reliability of a source may be crucial when evaluating health claims (e.g., should you believe an endorsement that a dietary supplement can increase longevity if the endorser helped develop the supplement?). A small body of behavioral evidence shows that increasing task salience, or the degree of importance of a task to an individual, may reduce age differences in source memory (e.g., Rahhal et al., 2002; but see Siedlecki et al., 2005), in contrast with the age-related source memory impairments shown for tasks across several domains of stimuli that utilize less salient (e.g., focusing on perceptual information, as in Rahhal et al., 2002) and non-social material (e.g., Spencer and Raz, 1995). This suggests that for salient information (e.g., using affective or value-based information, as in Rahhal et al., 2002), older adults may not show the same pattern of age-related impairment that is typically found in tasks involving less salient information.

Purported truth might be one salient factor driving prioritization of information at encoding, and may reduce age differences in source memory, given the inherent value of knowing whether information is true. For instance, while both the *National Enquirer* and *The New York Times* are sources of information, people may perceive non-tabloid journalism as more truthful, and more deeply encode this information. These decisions occur in the interpersonal realm as well. You might, for example, learn the same piece of information from a gossiping coworker known to spread rumors, or from a trusted friend; you may allocate more attention to your friend due to the perceived reliability of that source. This prioritization in encoding strategies suggests that source memory, or remembering the context in which information was presented, may directly relate to how we process information obtained from our daily interactions.

It is possible that the neural activity supporting age-equivalent source memory for socially salient material involves the interaction of cortical systems with the medial temporal lobe (MTL) that are distinct from the cortical-MTL interactions underlying non-social sources, which undergo age-related decline. Processing socially meaningful vs. non-social information recruits a reliable network of brain regions (Mitchell et al., 2002, 2005), and the engagement of medial prefrontal cortex (mPFC) in particular has been documented in a range of tasks involving socioemotional processing (Van Overwalle, 2009), including memory for information encoded during a social vs. a non-social orienting task (e.g., Mitchell et al., 2004).

Work exploring potential age differences in mPFC function during social tasks shows evidence for equivalent engagement for young and older adults (Gutchess et al., 2007; Beadle et al., 2012; Cassidy et al., 2012) as well as evidence for decreased activity with age (Moran et al., 2012). The diverging patterns of age effects on dorsomedial prefrontal cortex (dmPFC), however, may reflect when information is personally salient (Beadle et al., 2012; Cassidy et al., 2012) vs. when it is not (Moran et al., 2012). For instance, for the socially salient task involving self-referencing, young and older adults similarly recruit dmPFC for the processing of self- vs. other-related information (Gutchess et al., 2007) and for successful encoding of source materials presented in a self- vs. other-referential way (Leshikar and Duarte, 2013). However, older adults may not activate dmPFC to the level of young (e.g., Moran et al., 2012) unless a task explicitly involves socially and personally salient information.

Age-equivalent mPFC activity in personally salient social tasks may be concordant with behavioral data showing that socioemotional or value-rich materials reduce age-related performance differences (Fung and Carstensen, 2003; Carstensen and Mikels, 2005; Mather and Carstensen, 2005; May et al., 2005; Cassidy and Gutchess, 2012). Because older adults place higher priorities than young adults on value-rich, affective information (Fredrickson and Carstensen, 1990), they may perform as well as young adults on source memory tasks with value-rich material. For instance, although young adults recall perceptual and conceptual source information better than older adults, this age difference disappears when using sources relevant to emotional information (May et al., 2005) or truth value (Rahhal et al., 2002).

Recruitment of dmPFC for social tasks may also depend on one's orientation to the task, regardless of age. For instance, young adults show a dissociation in mPFC activity when thinking about similar or dissimilar others, such that dmPFC is engaged when abstractly thinking about a dissimilar other, while ventromedial prefrontal cortex (vmPFC) is recruited for thinking about self-similar others and emotional states (Mitchell et al., 2006a). This raises the possibility that age differences in mPFC activity may in part be due to differences in how young and older adults naturally orient to social tasks (e.g., they approach the learning of social information in an abstract way largely devoid of personal involvement, or with more of an emotional orientation). Supporting the idea of task orientation influencing mPFC activity, recent work has demonstrated that age differences in mPFC engagement toward processing valenced social material are driven by dmPFC in young adults, and by vmPFC in older adults (Cassidy et al., 2013). It is unknown, however, whether young and older adults display overall differences in neural activity, and specifically dissociations in dorsal and ventral mPFC activity, for salient tasks that are not overtly positive or negative.

A tendency to focus on value-rich and emotional information with age is reflective of Socioemotional Selectivity Theory, which posits that older adults tend to focus on processing information with enhanced value and socioemotional meaning due to the feeling that time in one's life is limited (Carstensen et al., 1999). In contrast, young adults are proposed to have a more general focus on acquiring knowledge. Illustrating this concept, older adults have been shown to remember more advertisements featuring emotionally meaningful messages, whereas young adults do not display a bias based on the type of presented material (Fung and Carstensen, 2003). If older adults approach tasks involving value-rich stimuli with an emotional orientation, then more vmPFC activity rather than dmPFC activity might be expected in older vs. young for such tasks. This is because ventral subregions of mPFC have been implicated in affective processing (Davidson and Irwin, 1999), including subsequent memory for emotional material (Dolcos et al., 2004), and for affective components, as opposed to cognitive components, in theory of mind tasks (Shamay-Tsoory and Aharon-Peretz, 2007). In contrast, dmPFC has been implicated in more complex cognitive operations (e.g., see Saxe, 2006).

Another distinction in dorsal and ventral mPFC activity involves the extent of their engagement during controlled and automatic processing tasks (Satpute and Lieberman, 2006; Lieberman, 2007). For instance, automatic processing has been likened to reflexive processing and with vmPFC activity during the formation of intuitions (Bechara et al., 1997). In contrast, controlled processing has been likened to reflective processing, and has been linked with increased dmPFC activity when using reappraisal to reduce emotional response to negative scenes (Ochsner et al., 2002). Older adults have larger memory deficits on tasks involving controlled processing, relative to automatic processing (Hasher and Zacks, 1979), perhaps because many tasks do not motivate older adults to access controlled processing resources (Germain and Hess, 2007). When motivated by socioemotional goals, however, older adults may be more likely to allocate the cognitive resources necessary for controlled processing toward their goal, as in the case of emotion regulation (Carstensen et al., 2003). Thus, in the case of a context where information is value-rich, but the task itself is not necessarily emotionally meaningful, we might expect young, but not older, adults to use controlled processing to encode information even if they are not instructed to do so, in the service of knowledge acquisition goals. In contrast, older adults may employ automatic processing during similar tasks. For a task involving value-rich stimuli, this might be reflected in enhanced vmPFC activity among older adults relative to young adults.

The present study explored whether young and older adults differentially engage dmPFC and vmPFC for the value-rich task of encoding truth value, be it inferred from a social source or explicitly stated. Our task involved learning the purported truth value of health-related statements, which provides a unique opportunity to appeal to the processing strategies of both young and older adults. Because health-related statements may hold particular importance for older adults, age differences in behavioral source memory for truth value may be reduced compared to the typical finding of deficits with age. Given previous findings of age differences in dmPFC and vmPFC activity as a function of the content of incoming salient information (Leclerc and Kensinger, 2008, 2010; Cassidy et al., 2013), we expected that young adults would show enhanced dmPFC activity relative to older adults for subsequent memory based on the idea that learning true and false statements might signal an inherent knowledge acquisition focus in the young. In contrast, we expected that older adults would exhibit increased vmPFC activity relative to young adults for subsequent memory, given that the more value-based aspects of health-related statements to older adults may make them more likely to approach the task with a socioemotional orientation. Given a potential socioemotional orientation among older adults, the insula, due to its broad role in emotional processing, was another neural region where increased activity might be expected in older vs. young adults for the encoding of truth value (Adolphs et al., 2000; Phan et al., 2002; Sanfey et al., 2003; Barrett et al., 2004; Craig, 2009; Wiech et al., 2010; Zaki et al., 2012). Insofar as the insula is engaged when making decisions in an emotional context (Sanfey et al., 2003), greater insula recruitment might be expected among individuals who orient to material in an emotional way (e.g., older adults) relative to those less likely to do so (e.g., young adults).

METHODS

PARTICIPANTS

Twelve right-handed University of Michigan students (18–23 years old, $M = 20.5$, $SD = 1.2$, 58% female) and twelve right-handed community dwelling older adults (63–80 years old, $M = 71.1$, $SD = 5.5$, 66% female) were recruited for the study. Older adults were screened for abnormal orientation scores (<27) using the Mini-Mental State Examination ($M = 28.7$, $SD = 1.1$), and had marginally more years of education ($M = 15.4$ years, $SD = 2.7$) than young adults ($M = 13.6$ years, $SD = 1.7$), $t_{(22)} = 1.95$, $p = 0.06$. To ensure the samples' comparability with those in the prior literature, participants completed a vocabulary measure (Shipley, 1986), digit and pattern comparison tasks (Salthouse and Babcock, 1991), forward and backward digit span measures (Wechsler, 1981), and a letter-number sequencing measure (Wechsler, 1997). Results are summarized in **Table 1**. Participants reported no history of psychiatric or neurological disorders and no history of drug or alcohol abuse at the time of testing. The University of Michigan Institutional Review Board approved the study, and written informed consent was obtained from all participants.

STIMULI

The stimuli consisted of 240 true statements regarding health-related information for which participants were unlikely to have prior knowledge (e.g., "Women's hearts beat faster than men's"). Altering words in each true statement created factually untrue statements (e.g., "Men blink nearly twice as much as women"). After creating a factually untrue version of each statement, each statement was randomly assigned to one of two sets (Set A and Set B). For half of the participants, Set A consisted of true versions and Set B of false. For the other half of participants, Set A consisted of false versions and Set B of true. Thus, whether each participant saw a true or false version of any given statement was fully counterbalanced across participants. The order of statements from each set was randomly drawn for each participant. These statements have been used in prior aging research (Skurnik et al., 2005) and are available upon request. All stimuli were programmed and presented using E-Prime software (Psychological Software Tools, Pittsburgh, PA) and IFIS 9.0 (MRI Devices, Waukesha, WI).

Table 1 | Means (*SD*) for cognitive measures.

Measure	Young adults	Older adults	*t*	*p*-value
Shipley vocabulary	31.1 (3.6)	37.3 (2.9)	−4.37	<0.001
Digit comparison	28.6 (2.8)	22.2 (4.0)	4.10	0.001
Pattern comparison	24.2 (2.3)	16.2 (4.7)	4.70	<0.001
Forward digit span	8.2 (1.3)	7.9 (1.2)	0.55	0.60
Backward digit span	6.4 (1.1)	5.8 (1.7)	0.78	0.45
Letter-number sequencing	5.4 (1.0)	5.1 (0.9)	0.86	0.40

TRUTH JUDGMENT TASK

Participants were told they would see statements coupled with an indication of truth value, and would later be asked to remember if each statement was true or false. The task comprised a 2 (Truth Value: True/False) × 2 (Source Type: Inferred/Stated) design, in which source memory for different types of information was compared across age groups. Some statements were stated to be true or false (stated: "TRUE" or "FALSE"), without referencing a social source. Other statements were inferred to be true or false, based on the source (inferred: "PAT says:" or "CHRIS says:"). Prior to encoding, participants were introduced to two hypothetical individuals, Pat and Chris. One individual was described as being honest and trustworthy, and participants were told to assume that every statement obtained from this person was true. The other individual was described as very dishonest and untrustworthy, and participants were told to assume this person only made false statements. Half of the statements were true and the other half false, and each of these were randomly assigned to each participant for the corresponding inferred or stated source. Participants practiced the task and received feedback on their responses before completing the full encoding task in the scanner.

Statements and truth value indications were presented on the screen concurrently for 6 s (see **Figure 1**). Participants selected whether presented information was true or false via button press. Responses were monitored during scanning to ensure that participants were accurately reporting the truth status of statements. No participant exhibited difficulty with this aspect of the task. Each run contained 60 statements, pseudorandomly distributed among baseline periods of fixation ranging from 2 to 12 s. Condition order and baseline periods were determined using Optseq2 (http://surfer.nmr.mgh.harvard.edu/optseq).

Participants completed the source memory task outside the scanner approximately 15–20 min after structural scans and four encoding runs. Participants were reminded of the truth values associated with each person (e.g., "If you remember that Pat said it, it must be true; if Chris said it, it must be false."), were informed that they had seen all statements previously in the scanner, and were told that half the statements were true and half false. During the source memory task, participants saw each of the 240 statements displayed during encoding, with no indication of truth value. Participants indicated whether they were confident a statement was true, guessing that it was true, guessing

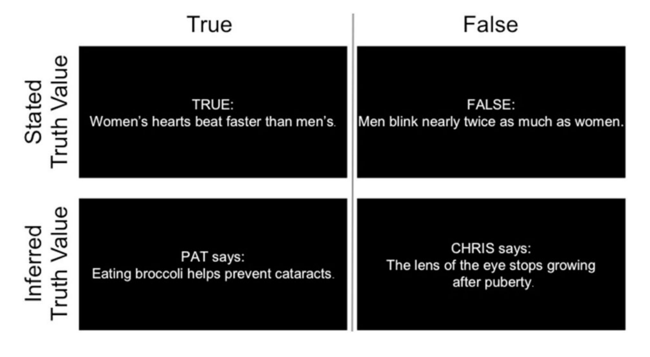

FIGURE 1 | Examples of encoding stimuli used in each condition.

it was false, or confident it was false, via a four-choice button press.

IMAGE ACQUISITION

Data were acquired using a 3T GE LX MR scanner (GE Signa 9.0 VH3 software, General Electric, Milwaukee, WI) paired with a whole-head coil. Two hundred and seventy volumes were obtained in each of four functional runs, using a gradient-echo spiral acquisition sequence to measure blood oxygen level-dependent (BOLD) effects ($TR = 2000$ ms, $TE = 25$ ms, flip angle = 80, 64 × 64 matrix, FOV = 200 mm). Dummy scans were also acquired, but discarded for analyses. Thirty-two contiguous oblique slices were acquired parallel to the AC/PC line. T1 Structural images were acquired using a Spoiled GRASS sequence (FOV = 24 mm, 256 × 192 matrix), of 120 sagittal slices (0.9373 mm in-plane resolution) of 1.5 mm thickness.

DATA ANALYSIS

Behavioral data

Behavioral data were analyzed using an alpha level of 0.05. Responses to a statement involving a confident correct truth value attribution were classified as correct source memory for that statement. Guessing responses and incorrect attributions were classified as incorrect source memory for that statement, in keeping with prior research (Otten et al., 2001).

fMRI data

Functional volumes were slice time corrected with an 8-point Hanning windowed sinc interpolation implemented in C++. Subject motion correction was performed using AIR 3.08 (Woods et al., 1992). Remaining analyses were performed using SPM2 (Wellcome Department of Cognitive Neurology, London, UK) and programs from the Gablab Toolbox (Massachusetts Institute of Technology, Cambridge, MA). The anatomical image was coregistered to the fifth functional volume and normalized to MNI space using a standard T1 template image with 2 mm^3 voxels. Normalization parameters determined from the anatomy were applied to functional volumes, which were then smoothed with a 6 mm isotropic Gaussian kernel. Effects for the eight stimulus conditions [i.e., 2 (Truth Value: True/False) × 2 (Source Type: Inferred/Stated) × 2 (Subsequent Memory: Correct/Incorrect)] were estimated using event-related regressors convolved with a canonical hemodynamic response function.

Results reported are from group-level, random effects analyses using an uncorrected threshold of $p = 0.005$ with a cluster size of $k > 11$, chosen to ensure that activations spanned at least two acquired contiguous voxels. Although we used a fairly liberal threshold, we took a whole-brain rather than a region of interest approach because relatively little prior work on this topic made it desirable to test a wider array of regions showing age-related changes in subsequent source memory in order to inform future work. Functional images from encoding were back-sorted for further analyses according to whether truth value was subsequently remembered (correct: high confidence correct responses only) or forgotten (incorrect: summing across guess responses and confident incorrect attributions). Subsequent memory contrasts (young > old, correct > incorrect source memory; old > young, correct > incorrect source memory) were used to initially analyze functional data and to identify regions demonstrating age differences where correct source memory produced increased engagement over incorrect source memory. The correct > incorrect source memory contrast was defined at the subject-level individually, and then entered in a group-level analysis for simple one-way group-wise differences. Locations of peak activation on the cortical surface were identified using SPM2, and Brodmann areas were obtained with MRIcron (Rorden and Brett, 2000). To characterize age differences in subsequent source memory from our whole-brain analysis, parameter estimates for each condition from each participant were extracted from the peak voxels of our a priori regions of interest (dmPFC, vmPFC, and insula) where significant activations emerged in the correct > incorrect source memory contrast.

RESULTS

BEHAVIORAL RESULTS

Proportions of recognition responses in each category (confident true, guessing true, guessing false, confident false) are shown in **Table 2**. From these responses, two behavioral measures were computed to assess memory performance. First, the proportion of correct source memory judgments (confident correct attributions; e.g., confident true when the statement was true) was calculated. Second, the false alarm rate was calculated as the proportion of statements incorrectly assigned a confident attribution (e.g., confident true when the statement was false). We analyzed these measures separately as dependent variables using a 2 (Age Group: young, old) × 2 (Source Type: inferred, stated) × 2 (Truth Value: true, false) mixed ANOVA.

For correct source memory judgments, there was a main effect of Truth Value, $F_{(1, 22)} = 45.84$, $p < 0.001$, $\eta_p^2 = 0.68$, such that participants correctly identified more true ($M = 0.71$, $SD = 0.18$) than false ($M = 0.53$, $SD = 0.20$) statements. There were no main effects of Age Group or Source Type. There was also a significant interaction between Source Type and Truth Value, $F_{(1, 22)} = 9.42$, $p < 0.01$, $\eta_p^2 = 0.30$. Contrasts showed that true statements coming from a stated source ($M = 0.73$, $SD = 0.19$) were better remembered than true statements coming from a inferred source ($M = 0.68$, $SD = 0.17$), $F_{(1, 22)} = 7.69$, $p < 0.01$, $\eta_p^2 = 0.26$. In contrast, accuracy in identifying false statements from inferred ($M = 0.54$, $SD = 0.20$) and stated

Table 2 | Behavioral source memory performance [*M*, (*SD*)] for young (YA) and older (OA) adults.

	Confident true		Guessing true		Guessing false		Confident false	
	True	**False**	**True**	**False**	**True**	**False**	**True**	**False**
SOCIAL SOURCE								
YA	0.70 (0.19)	0.13 (0.06)	0.15 (0.14)	0.12 (0.11)	0.10 (0.06)	0.19 (0.09)	0.06 (0.03)	0.56 (0.16)
OA	0.67 (0.16)	0.13 (0.10)	0.15 (0.12)	0.12 (0.11)	0.09 (0.06)	0.21 (0.14)	0.09 (0.07)	0.53 (0.25)
NON-SOCIAL SOURCE								
YA	0.73 (0.22)	0.13 (0.08)	0.14 (0.12)	0.14 (0.11)	0.07 (0.09)	0.20 (0.13)	0.06 (0.07)	0.54 (0.18)
OA	0.73 (0.16)	0.15 (0.12)	0.13 (0.11)	0.13 (0.11)	0.08 (0.05)	0.23 (0.12)	0.06 (0.06)	0.50 (0.22)

Correct source memory is the same as confident responses for the correct truth value (e.g., confident true for true statements). Incorrect source memory is the sum of guessing (true and false) and confident incorrect source attributions. No age group differences were significant in any condition.

($M = 0.52, SD = 0.20$) sources did not differ, $F_{(1, 22)} = 1.33, p = 0.26, \eta_p^2 = 0.06$. No other interactions approached significance.

For false alarm rates, there was a main effect of Truth Value, $F_{(1, 22)} = 15.46$, $p < 0.001$, $\eta_p^2 = 0.41$. Participants were more likely to confidently remember an originally false statement as true than an originally true statement as false. No other effects approached significance.

The absence of behavioral interactions involving Source Type and Age Group suggests that source memory in aging does not depend on whether information was inferred via a person's reliability or explicitly stated. However, prior fMRI results have suggested that social information processing is neurally distinct from processing other types of information (Mitchell et al., 2002, 2004; Van Overwalle, 2009). We accordingly characterized our imaging data to determine if the processing mechanisms involved in encoding inferred vs. stated truth value were similarly distinct, and how aging might modulate the engagement of these regions.

fMRI RESULTS

We identified brain regions showing age differences in response to overall subsequent memory, given the relatively low number of participants in this study (Ns = 12 for each age group) (correct > incorrect memory; see **Table 3**). This contrast captures regions that differ across age groups, but is conservative with respect to the source and truth of each statement. Parameter estimates from the peak voxel of these functionally defined regions were probed to characterize whether age differences in activity was driven by Source Type or Truth Value (**Figure 1**). However, specific contrasts involving these factors were not conducted due to low power and the lack of behavioral evidence for source memory differences with age depending on Source Type or Truth Value.

In a whole-brain analysis, this subsequent memory contrast yielded brain regions contributing to age differences in correct subsequent memory for source (**Table 2**). To probe the expected age differences related to socioemotional processing in the dmPFC, vmPFC, and insula, we focused on these regions. Parameter estimates of activation attributable to each condition were then extracted and compared in 2 (Age Group: young, old) × 2 (Source Type: inferred, stated) × 2 (Truth Value: true, false) mixed ANOVAs.

As defined by the contrast, young adults had increased activation compared to older adults in two regions of left dmPFC [**Figure 2A**; BA 6: $F_{(1, 22)} = 9.43$, $p < 0.01$, $\eta_p^2 = 0.30$; BA 8: $F_{(1, 22)} = 16.48, p < 0.001, \eta_p^2 = 0.43$]. Characterizing this effect further (and probing effects unrelated to the region-defining contrast), there were marginal Age Group by Truth Value interactions in both regions of dmPFC [BA 6: $F_{(1, 22)} = 3.01, p = 0.097, \eta_p^2 = 0.12$; BA 8: $F_{(1, 22)} = 3.43$, $p = 0.08$, $\eta_p^2 = 0.14$]. Pairwise comparisons showed that in both dmPFC regions, this interaction appeared to be driven by enhanced activity in young relative to older adults when successfully encoding true (BA6: $p = 0.002$, BA 8: $p = 0.004$) vs. false (BA 6: $p = 0.40$, BA 8: $p = 0.70$) statements.

As defined by the contrast, older adults had increased vmPFC engagement compared to young adults in a region of left vmPFC [**Figure 2B**; $F_{(1, 22)} = 3.43$, $p = 0.002$, $\eta_p^2 = 0.35$]. Examination of parameter estimates for effects unrelated to the region-defining contrast showed that unlike the marginal Age Group by Truth Value interactions in dmPFC activity, vmPFC showed a marginal Age Group by Source Type interaction, $F_{(1, 22)} = 3.46, p = 0.08$, $\eta_p^2 = 0.14$. Young adults engaged vmPFC more for the successful encoding of truth value from stated vs. socially-inferred sources, $F_{(1, 11)} = 4.35$, $p = 0.06$, $\eta_p^2 = 0.28$, while older adults, showed no such difference, $F < 1$, $p = 0.93$. There was also a marginal main effect of Source Type, such that all participants tended to recruit vmPFC for the successful encoding of stated vs. inferred truth value, $F_{(1, 22)} = 3.11$, $p = 0.09$, $\eta_p^2 = 0.12$. Finally, older adults had increased neural activity relative to young adults (as defined by the contrast) in the right insula (**Figure 2C**), $F_{(1, 22)} = 9.55$, $p < 0.01$, $\eta_p^2 = 0.30$, for the successful encoding of truth value. Unlike the marginal Truth Value by Age Group interactions in dmPFC and Source Type by Age Group interaction exhibited in vmPFC during the task, no interactions were present in insula recruitment.

DISCUSSION

Previous research on source memory and aging has detailed decreases in older adults' behavioral performance (Chalfonte and Johnson, 1996), and neural activity (Mitchell et al., 2006b; Dennis et al., 2008) when compared to a young cohort, indicating overall age-related decline in encoding source information. However, a smaller body of behavioral work suggests that

Table 3 | Age differences in brain activity for correct > incorrect source memory.

Region	*BA*	*k*	Activation Peak *(x, y, z)*			*t*
(A) YOUNG > OLD, CORRECT > INCORRECT SOURCE MEMORY						
L dorsomedial prefrontal cortex	6/8	68	−14	32	54	5.70
L dorsomedial prefrontal cortex	6	33	−14	12	66	3.60
R amygdala		28	20	−2	−24	3.87
R superior frontal gyrus	6	14	14	−16	78	3.52
L precuneus	19	15	−30	−72	32	3.25
L inferior frontal gyrus	9	14	−52	20	24	3.08
(B) OLD > YOUNG, CORRECT > INCORRECT SOURCE MEMORY						
L ventromedial prefrontal cortex	10/11	66	−16	56	−2	4.01
L medial prefrontal cortex	10		−8	52	−4	3.16
L anterior cingulate gyrus	32		−14	46	−4	3.08
R insula		37	44	−6	−2	3.26
R precuneus	7	224	16	−66	52	5.81
L dorsolateral prefrontal cortex	9/46	75	−40	36	36	5.36
L middle frontal gyrus	46		−46	36	24	4.10
L precentral gyrus	4	50	−52	−16	28	4.69
R middle frontal gyrus	8	180	26	36	40	4.69
R cingulate gyrus	32		18	22	36	3.43
L cingulate gyrus	31	25	−20	−28	40	4.48
L insula		12	−28	−22	24	4.08
R inferior parietal lobule	40	64	68	−26	26	3.77
R superior parietal lobe	5	40	20	−52	58	3.66
R thalamus		19	10	−38	10	3.59
R middle frontal gyrus	6	13	26	4	42	3.58
L inferior parietal lobule	40	20	−34	−42	48	3.57
R inferior frontal gyrus	47	27	36	36	2	3.56
L superior parietal lobule	5	12	−22	−46	68	3.53
R posterior cingulate gyrus	29	18	6	−50	4	3.53
R superior frontal gyrus	6	20	8	−10	70	3.52
R insula		15	38	22	6	3.45
R inferior temporal gyrus	20	24	50	−34	−14	3.41
R fusiform gyrus	37	12	−12	58	20	3.26
L postcentral gyrus	40	15	−54	−22	14	3.26
R middle frontal gyrus	10	28	32	56	22	3.24
R superior frontal gyrus	10		22	62	24	3.05
R superior frontal gyrus	9	11	10	56	30	3.06

The data show regions emerging in the contrast with an overall threshold of $p < 0.005$ and an extent threshold of 11 voxels. Regions listed without a cluster size are subsumed by the larger cluster listed directly above. A priori regions of interest are listed first. Other regions are listed from highest to lowest t-value. L, Left; R, right; k, cluster size.

increasing the salience of stimuli can reduce age-related source memory impairments (Rahhal et al., 2002; May et al., 2005), and that older adults' memory may be enhanced when information is initially encoded in a salient way (Cassidy and Gutchess, 2012). The current study extended this idea by asking if the value-rich task of encoding truth value would be represented by differential activation of mPFC with age, despite potential age-equivalent memory performance. If young adults rely more on knowledge acquisition goals when learning salient information, greater activity in *dorsal* mPFC would be expected, whereas greater activity in *ventral* mPFC and in the insula would be expected for older adults, representing an approach to the task that reflects more socioemotional processing. Our findings are consistent with these expectations, suggesting that in these circumstances, age-equivalent performance may be supported by differential neural recruitment.

The demonstrated dorsal-ventral shift in encoding-related activity with age could also be reflective of overall changes in processing focus, as posited by Socioemotional Selectivity Theory (Carstensen et al., 1999). This theory puts forth the idea that with increasing age, people shift from a focus on acquiring knowledge to a focus on enhancing the emotional meaning in one's life. Thus, a changing focus in older adults toward material with enhanced emotional meaning might be reflected in enhanced activity in regions supporting affective processing (i.e., vmPFC) relative to young. In contrast, regions implicated in the encoding

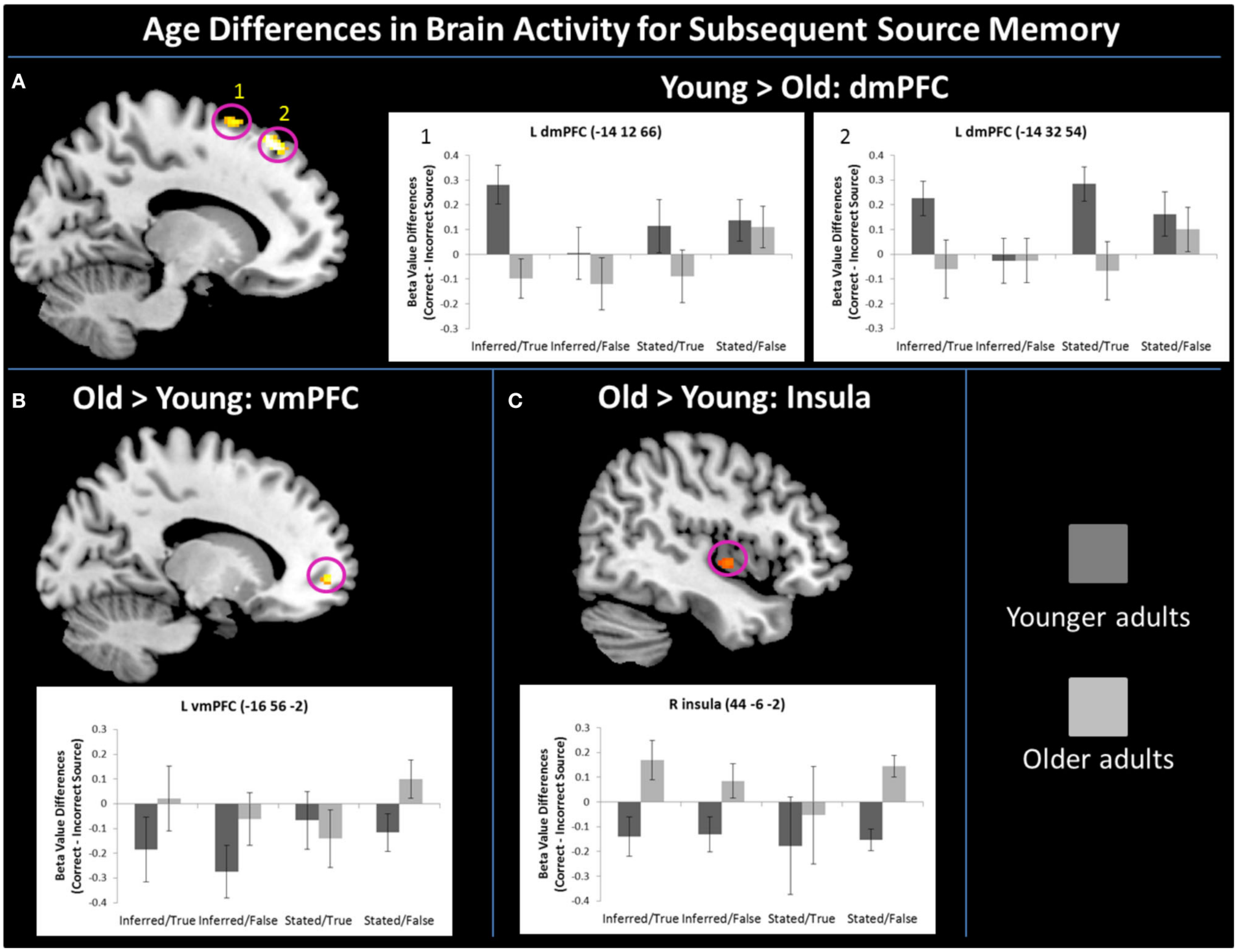

FIGURE 2 | Age differences for correct—incorrect source memory for truth value existed in mPFC, such that young adults had enhanced activity over older adults in two regions of left dmPFC (A), while older adults had increased recruitment over young in left vmPFC (B). Older adults also had enhanced activity relative to young adults for subsequent memory of truth value in the right insula **(C)**. Error bars represent standard error of the mean.

of value-rich information (i.e., dmPFC) may be more active in young than older adults, as young adults may try to optimize their likelihood of acquiring knowledge.

The current findings revealed enhanced overall dmPFC activity in young relative to older adults. While older adults have shown dmPFC activity similar to young adults during socially self-relevant processing (Gutchess et al., 2007; Beadle et al., 2012; Cassidy et al., 2012), age-related decreases have been observed in tasks involving social, but not-explicitly self-related, material (Moran et al., 2012). Given that the current task did not place older adults within such a social task, we might not expect them to activate dmPFC to the same extent as young. Increased dmPFC processing among young compared to older adults may also indicate the use of relatively more controlled processing to encode information. Additional research is needed to clarify this possibility.

Exploratory analyses provided further insight into whether stated or inferred truth value, or the truth value of information itself, drove age differences in dmPFC activity. An exploratory characterization of the greater activity in dmPFC among young adults revealed a trend toward increased activity among young over older adults during encoding of veridical, but not false, information regardless of the source. Albeit speculative, such an interaction might be expected for this task because being told that information is true might trigger allocation of attention for prioritized encoding. Enhanced dmPFC activity in young over older adults, especially for encoding true statements, may therefore reflect the overall knowledge acquisition focus among young adults posited by Socioemotional Selectivity Theory (Carstensen et al., 1999).

Older adults, in contrast, tend toward an enhanced focus on salient and emotionally meaningful material (Fredrickson and Carstensen, 1990; Carstensen and Turk-Charles, 1994; Fung et al., 1999; Carstensen et al., 2000; Carstensen and Mikels, 2005), which we suggest may be reflected in their recruitment of vmPFC and insula for subsequent memory relative to young adults. If older adults approach a task involving salient material with a focus, conscious or not, on the personally relevant or emotional aspects of the presented information, then we might expect increased engagement of vmPFC (e.g., Mitchell et al., 2006a). Previous work with young adults has shown that vmPFC is more active for tasks involving more self-similar, and thereby potentially more personally salient, information, vs. self-dissimilar social material, and work in aging has also shown that age-related biases toward positively valenced social information might be primarily reflected in vmPFC (Cassidy et al., 2013), rather than dmPFC activity. Thus, a tendency to focus on salient socioemotional material with age may result in more activation of neural regions sensitive to emotional processing during tasks that involve the encoding of value-rich material, such as truth value. Age-related increases in vmPFC engagement may also reflect the idea that, with age, enhanced focus on value-rich material may result in the recruitment of brain regions supporting more affective vs. cognitive processing.

Our findings are consistent with a growing body of work showing that for young adults (Mitchell et al., 2004; Gilron and Gutchess, 2012), and healthy older adults (Leshikar and Duarte, 2013), mPFC engagement may underlie subsequent memory for value-rich information. This is in contrast to prior literature on the encoding of non-social source material, which shows that age-related impairments in encoding source information stem from MTL dysfunction, particularly in the hippocampus (Mitchell et al., 2000; Dennis et al., 2008). Notably, we did not find age differences in hippocampal function for the task in the present study. However, our results are *consistent* with a recent study on source memory in aging that also utilized socially relevant stimuli (Leshikar and Duarte, 2013), and with work suggesting that face-trait associations are preserved in individuals with substantial hippocampal damage (Todorov and Olson, 2008). A critical follow-up to the present experiment would be to compare directly, memory for socially salient with non-social source information collected within the same task. Such a task could provide evidence that different cortical networks may interact with MTL memory systems for social vs. non-social information across age.

Importantly, the demonstrated age differences in how young and older adults recruit mPFC for encoding truth value may reflect how such information was presented to them. Although Pat and Chris were presented as sources of information, participants never learned additional behavioral information about Pat and Chris aside from learning that one was more trustworthy than the other. Speculatively, in aging, explicit person representations and comparisons may drive dmPFC activity in socially salient tasks. It could be that a lack of explicit person representation involved in assessing abstract factual statements may explain why young adults had enhanced dmPFC activity compared to older adults for the encoding of truth value. Thus, we might expect to see interactions with age in dmPFC activity for source memory related to people, but not for more abstract material. At the same time, a focus on the emotional value of health information, something that might have increased salience with age, may have led to the demonstrated age difference in vmPFC activity seen in the current task. These ideas could be further tested in future work that directly compares neural responses to both abstract and concrete social and non-social sources.

Also consistent with age differences in socioemotional orientation to the task, older adults had increased insula activity relative to young adults. However, our exploratory analysis of parameter estimates showed that enhanced activation of the right insula was not characterized specifically by the truth value of information or by the social source. Speculatively, enhanced insula activity in older relative to young adults for subsequent memory for truth value may be indicative of more emotional initial responses to incoming information (Critchley et al., 2004; Tsakiris et al., 2007; Craig, 2009; Zaki et al., 2012) rather than treating incoming material as facts that must be acquired for the pursuit of knowledge.

Limitations of the present work include the sample sizes of the young and older adult cohorts as well as the threshold for fMRI analyses. Although exploring memory for truth value from the lens of aging is an important topic with both social and public health implications, the limited statistical power due to small sample sizes restricted the present analyses from utilizing direct contrasts of potential interactions (e.g., a direct contrast exploring brain regions that might be differentially engaged with age based on whether truth value was inferred or stated), and thus the reported marginal interactions between conditions as well as null results must be interpreted with caution. Although we investigated this in an exploratory way by characterizing our regions of interest for potential differences in activity by truth value and source type, we recognize that future work should test this in a direct manner. Nonetheless, the marginal interactions we report could be fruitful for the generation of future hypotheses, and the reported effect sizes for these interactions suggest a potentially significant effect if larger sample sizes were to be employed. Moreover, the small sample sizes used here could have masked potential age differences in our behavioral data, which in turn could have guided analyses of the imaging data. Because other studies found similar behavioral performance among young and older adults for socioemotionally salient material (e.g., May et al., 2005), it is unclear whether increasing our sample size would yield age differences in memory, particularly as our means were quite similar across the age groups.

Another potential limitation of the current work involved the different age ranges of our young (5 year span) compared to older (17 year span) adult samples. This could be problematic insofar as it could have led to more age-related variance in the older vs. young adults. This notable limitation is indicative of recruitment difficulties in aging research, as fewer older adults volunteer for fMRI studies than young. Moreover, the older adults who volunteer for fMRI studies tend to be active and highly educated, allowing for the possibility that more sedentary older adults may show different patterns of brain activation. Incorporating a wider range of ages in a lifespan sample could be helpful to address these issues in future work.

Studying how young and older adults subsequently remember truth value and its underlying neural mechanism may help to clarify a public health issue of critical importance. Older adults have increased vulnerability to fraud compared to young adults (Lormel, 2001; Telemarketing fraud against older Americans, 2007; Ruffman et al., 2012). Deficits in source memory processes may in part contribute to this enhanced vulnerability because in order to successfully navigate through one's environment, one must not only consider and remember snippets of information, but also *where* the information came from. That is, failing to remember that a "fact" came from an unreliable source may lead to suboptimal decision making. For instance, one may make a bad financial investment after being given information from an untrustworthy source, or may adopt a political opinion while forgetting to consider that a biased source was reporting the information in the first place. The observed age differences in mPFC activity in response to encoding truth value may indicate that approaching the learning of social source information with a goal of acquiring knowledge could be a strategy more typical of young adults that combats against fraud vulnerability, as opposed to encoding incoming information in a more emotional way, a strategy more typical of older adults.

In summary, the current work demonstrated that for the salient task of encoding truth value of health statements, young and older adults show differential recruitment of dmPFC and vmPFC, despite showing similar behavioral performance. It would be worthwhile for future work to test explicitly how age differences in information processing styles may be associated with age-related increases in vulnerability to fraud and deception.

ACKNOWLEDGMENTS

We thank Cory Crane for assistance in data collection. Research funding was provided by the Stephen M. Ross School of Business at the University of Michigan, and NIH grant K01 AG040197 (supporting Trey Hedden).

REFERENCES

Adolphs, R., Damasio, H., Tranel, D., Cooper, G., and Damasio, A. (2000). A role for somatosensory cortices in the visual recognition of emotion as revealed by three-dimensional lesion mapping. *J. Neurosci.* 20, 2683–2690.

Barrett, L., Quigley, K., Bliss-Moreau, E., and Aronson, K. (2004). Interoceptive sensitivity and self-reports of emotional experience. *J. Pers. Soc. Psychol.* 87, 684–697. doi: 10.1037/0022-3514.87.5.684

Beadle, J., Yoon, C., and Gutchess, A. (2012). Age-related neural differences in affiliation and isolation. *Cogn. Affect. Behav. Neurosci.* 12, 269–279. doi: 10.3758/s13415-012-0085-y

Bechara, A., Damasio, H., Tranel, D., and Damasio, A. (1997). Deciding advantageously before knowing the advantageous strategy. *Science* 275, 1293–1294. doi: 10.1126/science.275.5304.1293

Carstensen, L., Fung, H., and Charles, S. (2003). Socioemotional selectivity theory and the regulation of emotion in the second half of life. *Motiv. Emot.* 27, 103–123. doi: 10.1023/A:1024569803230

Carstensen, L., Isaacowitz, D., and Charles, S. (1999). Taking time seriously: a theory of socioemotional selectivity. *Am. Psychol.* 54, 165–181. doi: 10.1037/0003-066X.54.3.165

Carstensen, L., and Mikels, J. (2005). At the intersection of emotion and cognition. *Curr. Dir. Psychol. Sci.* 14, 117–121. doi: 10.1111/j.0963-7214.2005.00348.x

Carstensen, L., Pasupathi, M., Mayr, U., and Nesselroade, J. (2000). Emotional experience in everyday life across the adult lifespan. *J. Pers. Soc. Psychol.* 79, 644–655. doi: 10.1037/0022-3514.79.4.644

Carstensen, L., and Turk-Charles, S. (1994). The salience of emotion across the adult life span. *Psychol. Aging* 9, 259–264. doi: 10.1037/0882-7974.9.2.259

Cassidy, B., and Gutchess, A. (2012). Social relevance enhances memory for impressions in older adults. *Memory* 20, 332–345. doi: 10.1080/09658211.2012.660956

Cassidy, B., Leshikar, E., Shih, J., Aizenman, A., and Gutchess, A. (2013). Valence-based age differences in medial prefrontal activity during impression formation. *Soc. Neurosci.* 8, 462–473. doi: 10.1080/17470919.2013.832373

Cassidy, B., Shih, J., and Gutchess, A. (2012). Age-related changes to the neural correlates of social evaluation. *Soc. Neurosci.* 7, 552–564. doi: 10.1080/17470919.2012.674057

Chalfonte, B., and Johnson, M. (1996). Feature memory and binding in young and older adults. *Mem. Cogn.* 24, 403–416. doi: 10.3758/BF03200930

Craig, A. (2009). How do you feel–now? The anterior insula and human awareness. *Nat. Rev. Neurosci.* 10, 59–70. doi: 10.1038/nrn2555

Critchley, H., Wiens, S., Rotshtein, P., Ohman, A., and Dolan, R. (2004). Neural systems supporting interoceptive awareness. *Nat. Neurosci.* 7, 189–195. doi: 10.1038/nn1176

Davidson, R., and Irwin, W. (1999). The functional neuroanatomy of emotion and affective style. *Trends Cogn. Sci.* 3, 11–21. doi: 10.1016/S1364-6613(98)01265-0

Dennis, N., Hayes, S., Prince, S., Madden, D., Huettel, S., and Cabeza, R. (2008). Effects of aging on the neural correlates of successful item and source memory encoding. *J. Exp. Psychol. Learn. Mem. Cogn.* 34, 791–808. doi: 10.1037/0278-7393.34.4.791

Dolcos, F., LaBar, K., and Cabeza, R. (2004). Dissociable effects of arousal and valence on prefrontal activity indexing emotional evaluation and subsequent memory: an event-related fMRI study. *Neuroimage* 23, 64–74. doi: 10.1016/j.neuroimage.2004.05.015

Fredrickson, B., and Carstensen, L. (1990). Choosing social partners: how old age and anticipated endings make people more selective. *Psychol. Aging* 5, 335–347. doi: 10.1037/0882-7974.5.3.335

Fung, H., and Carstensen, L. (2003). Sending memorable messages to the old: age differences in preferences and memory for advertisements. *J. Pers. Soc. Psychol.* 85, 163–178. doi: 10.1037/0022-3514.85.1.163

Fung, H., Carstensen, L., and Lutz, A. (1999). Influence of time on social preferences: implications for lifespan development. *Psychol. Aging* 14, 595–604. doi: 10.1037/0882-7974.14.4.595

Germain, C. M., and Hess, T. M. (2007). Motivational influences on controlled processing: moderating distractibility in older adults. *Neuropsychol. Dev. Cogn. B Aging Neuropsychol. Cogn.* 14, 462–486. doi: 10.1080/13825580600611302

Gilron, R., and Gutchess, A. (2012). Remembering first impressions: effects of intentionality and diagnosticity of subsequent memory. *Cogn. Affect. Behav. Neurosci.* 12, 85–98. doi: 10.3758/s13415-011-0074-6

Gutchess, A., Kensinger, E., and Schacter, D. (2007). Aging, self-referencing, and medial prefrontal cortex. *Soc. Neurosci.* 2, 117–133. doi: 10.1080/17470910701399029

Hasher, L., and Zacks, R. (1979). Automatic and effortful processes in memory. *J. Exp. Psychol. Gen.* 108, 356–388. doi: 10.1037/0096-3445.108.3.356

Johnson, M., Hashtroudi, S., and Lindsay, D. (1993). Source monitoring. *Psychol. Bull.* 114, 3–28. doi: 10.1037/0033-2909.114.1.3

Johnson, M., and Raye, C. (1981). Reality monitoring. *Psychol. Rev.* 88, 67–85. doi: 10.1037/0033-295X.88.1.67

Leclerc, C., and Kensinger, E. (2008). Age-related differences in medial prefrontal activation in response to emotional images. *Cogn. Affect. Behav. Neurosci.* 8, 153–164. doi: 10.3758/CABN.8.2.153

Leclerc, C., and Kensinger, E. (2010). Age-related valence-based reversal in recruitment of medial prefrontal cortex on a visual search task. *Soc. Neurosci.* 5, 560–576. doi: 10.1080/17470910903512296

Leshikar, E., and Duarte, A. (2013). Medial prefrontal cortex supports subsequent memory for self-referenced materials in young and older adults. *Cogn. Affect. Behav. Neurosci.* 1–17. doi: 10.3758/s13415-013-0198-y. [Epub ahead of print].

Lieberman, M. (2007). Social cognitive neuroscience: a review of core processes. *Annu. Rev. Psychol.* 58, 259–289. doi: 10.1146/annurev.psych.58.110405.085654

Lormel, D. (2001). *Fraud Against the Elderly*. *Federal Bureau of Investigation*. Available online at: http://www.fbi.gov/news/testimony/fraud-against-the-elderly

Mather, M., and Carstensen, L. (2005). Aging and motivated cognition: the positivity effect in attention and memory. *Trends Cogn. Sci.* 9, 496–502. doi: 10.1016/j.tics.2005.08.005

May, C., Rahhal, T., Berry, E., and Leighton, E. (2005). Aging, source memory, and emotion. *Psychol. Aging* 20, 571–578. doi: 10.1037/0882-7974.20.4.571

Mitchell, J., Heatherton, T., and Macrae, C. (2002). Distinct neural systems subserve person and object knowledge. *Proc. Natl. Acad. Sci. U.S.A.* 99, 15238–15243. doi: 10.1073/pnas.232395699

Mitchell, J., Macrae, C., and Banaji, M. (2004). Encoding-specific effects of social cognition on the neural correlates of subsequent memory. *J. Neurosci.* 24, 4912–4917. doi: 10.1523/JNEUROSCI.0481-04.2004

Mitchell, J., Macrae, C., and Banaji, M. (2005). Forming impressions of people versus inanimate objects: social-cognitive processing in the medial prefrontal cortex. *Neuroimage* 26, 251–257. doi: 10.1016/j.neuroimage.2005.01.031

Mitchell, J., Macrae, C. N., and Banaji, M. R. (2006a). Dissociable medial prefrontal contributions to judgments of similar and dissimilar others. *Neuron* 50, 655–663. doi: 10.1016/j.neuron.2006.03.040

Mitchell, K., Raye, C., Johnson, M., and Greene, E. (2006b). An fMRI investigation of short-term source memory in young and older adults. *Neuroimage* 30, 627–633. doi: 10.1016/j.neuroimage.2005.09.039

Mitchell, K., Johnson, M., Raye, C., and D'Esposito, M. (2000). fMRI evidence of age-related hippocampal dysfunction in feature binding in working memory. *Brain Res. Cogn. Brain Res.* 10, 197–206. doi: 10.1016/S0926-6410(00)00029-X

Moran, J., Jolly, E., and Mitchell, J. (2012). Social-cognitive deficits in normal aging. *J. Neurosci.* 32, 5553–5561. doi: 10.1523/JNEUROSCI.5511-11.2012

Ochsner, K., Bunge, S., Gross, J., and Gabrieli, J. (2002). Rethinking feelings: an fMRI study of the cognitive regulation of emotion. *J. Cogn. Neurosci.* 14, 1215–1229. doi: 10.1162/089892902760807212

Otten, L., Henson, R., and Rugg, M. (2001). Depth of processing effects on neural correlates of memory encoding: relationship between findings from across- and within-task comparisons. *Brain* 124, 399–412. doi: 10.1093/brain/124.2.399

Phan, K., Wager, T., Taylor, S., and Liberzon, I. (2002). Functional neuroanatomy of emotion: a meta-analysis of emotion activation studies in PET and fMRI. *Neuroimage* 16, 331–348. doi: 10.1006/nimg.2002.1087

Rahhal, T., May, C., and Hasher, L. (2002). Truth and character: sources that older adults can remember. *Psychol. Sci.* 13, 101–105. doi: 10.1111/1467-9280.00419

Rorden, C., and Brett, M. (2000). Stereotaxic display of brain lesions. *Behav. Neurol.* 12, 191–200. doi: 10.1155/2000/421719

Ruffman, T., Murray, J., Halberstadt, J., and Vater, T. (2012). Age-related differences in deception. *Psychol. Aging* 27, 543–549. doi: 10.1037/a0023380

Salthouse, T., and Babcock, R. (1991). Decomposing adult age differences in working memory. *Dev. Psychol.* 27, 763–776. doi: 10.1037/0012-1649.27.5.763

Sanfey, A., Rilling, J., Aronson, J., Nystrom, L., and Cohen, J. (2003). The neural basis of economic decision-making in the ultimatum game. *Science* 300, 1755–1758. doi: 10.1126/science.1082976

Satpute, A., and Lieberman, M. (2006). Integrating automatic and controlled processes into neurocognitive models of social cognition. *Brain Res.* 1079, 86–97. doi: 10.1016/j.brainres.2006.01.005

Saxe, R. (2006). Uniquely human social cognition. *Curr. Opin. Neurobiol.* 16, 235–239. doi: 10.1016/j.conb.2006.03.001

Shamay-Tsoory, S., and Aharon-Peretz, J. (2007). Dissociable prefrontal networks for cognitive and affective theory of mind: a lesion study. *Neuropsychologia* 45, 3054–3067. doi: 10.1016/j.neuropsychologia.2007.05.021

Shipley, W. (1986). *Shipley Institute of Living Scale*. Los Angeles, CA: Western Psychological Services.

Siedlecki, K., Salthouse, T., and Berish, D. (2005). Is there anything special about the aging of source memory? *Psychol. Aging* 20, 19–32. doi: 10.1037/0882-7974.20.1.19

Skurnik, I., Yoon, C., Park, D., and Schwarz, N. (2005). How warnings about false claims become recommendations. *J. Consum. Res.* 31, 713–724. doi: 10.1086/426605

Spencer, W., and Raz, N. (1995). Differential effects of aging on memory for content and context: a meta-analysis. *Psychol. Aging* 10, 527–539. doi: 10.1037/0882-7974.10.4.527

Telemarketing fraud against older Americans. (2007). *Federal Trade Commission.* Available online at: http://www.ftc.gov/reports/Fraud/fraudcon.shtm

Todorov, A., and Olson, I. (2008). Robust learning of affective trait associations with faces when the hippocampus is damaged, but not when the amygdala and temporal pole are damaged. *Soc. Cogn. Affect. Neurosci.* 3, 195–203. doi: 10.1093/scan/nsn013

Tsakiris, M., Hesse, M., Boy, C., Haggard, P., and Fink, G. (2007). Neural signatures of body ownership: a sensory network for bodily self-consciousness. *Cereb. Cortex* 17, 2235–2244. doi: 10.1093/cercor/bhl131

Van Overwalle, F. (2009). Social cognition and the brain: a meta-analysis. *Hum. Brain Mapp.* 30, 829–858. doi: 10.1002/hbm.20547

Wechsler, D. (1981). *Wechsler Adult Intelligence Scale–Revised Manual*. New York, NY: Psychological Corporation.

Wechsler, D. (1997). *Wechsler Memory Scale, 3rd Edn.* San Antonio, TX: The Psychological Corporation.

Wiech, K., Lin, C., Brodersen, K., Bingel, U., Ploner, M., and Tracey, I. (2010). Anterior insula integrates information about salience into perceptual decisions about pain. *J. Neurosci.* 30, 16324–16331. doi: 10.1523/JNEUROSCI.2087-10.2010

Woods, R., Cherry, S., and Mazziotta, J. (1992). Rapid automated algorithm for aligning and reslicing PET images. *J. Comput. Assist. Tomogr.* 16, 620–633. doi: 10.1097/00004728-199207000-00024

Zaki, J., Davis, J., and Ochsner, K. (2012). Overlapping activity in anterior insula during interoception and emotional experience. *Neuroimage* 62, 493–499. doi: 10.1016/j.neuroimage.2012.05.012

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 14 November 2013; accepted: 22 January 2014; published online: 07 February 2014.

Citation: Cassidy BS, Hedden T, Yoon C and Gutchess AH (2014) Age differences in medial prefrontal activity for subsequent memory of truth value. Front. Psychol. ***5****:87. doi: 10.3389/fpsyg.2014.00087*

This article was submitted to Emotion Science, a section of the journal Frontiers in Psychology.

frontiers in PSYCHOLOGY

PERSPECTIVE ARTICLE
published: 06 May 2014
doi: 10.3389/fpsyg.2014.00380

Emotional aging: a discrete emotions perspective

Ute Kunzmann[1], Cathleen Kappes[1] and Carsten Wrosch[2]*

[1] Institute of Psychology, University of Leipzig, Leipzig, Germany
[2] Department of Psychology, Concordia University, Montreal, QC, Canada

Edited by:
Natalie Ebner, University of Florida, USA

Reviewed by:
Natalie Ebner, University of Florida, USA
Manuel C. Voelkle, Max Planck Institute for Human Development, Germany
Andrew Mienaltowski, Western Kentucky University, USA

****Correspondence:***
Ute Kunzmann, Institute of Psychology, University of Leipzig, Seeburgstrasse 14-20, Leipzig 04103, Germany
e-mail: kunzmann@uni-leipzig.de

Perhaps the most important single finding in the field of emotional aging has been that the overall quality of affective experience steadily improves during adulthood and can be maintained into old age. Recent lifespan developmental theories have provided motivation- and experience-based explanations for this phenomenon. These theories suggest that, as individuals grow older, they become increasingly motivated and able to regulate their emotions, which could result in reduced negativity and enhanced positivity. The objective of this paper is to expand existing theories and empirical research on emotional aging by presenting a discrete emotions perspective. To illustrate the usefulness of this approach, we focus on a discussion of the literature examining age differences in anger and sadness. These two negative emotions have typically been subsumed under the singular concept of negative affect. From a discrete emotions perspective, however, they are highly distinct and show multidirectional age differences. We propose that such contrasting age differences in specific negative emotions have important implications for our understanding of long-term patterns of affective well-being across the adult lifespan.

Keywords: emotional aging, adult lifespan, anger, sadness, affective well-being

The single most important finding in the field of emotional aging is perhaps that affective well-being does not decline during most of the adult lifespan (e.g., Charles and Carstensen, 2007; Scheibe and Carstensen, 2010; Isaacowitz and Blanchard-Fields, 2012). Research based on the most prominent life-span theories of developmental regulation and emotional aging have provided different explanations for this phenomenon by examining broad dimensions of emotions (i.e., negative affect and positive affect; e.g., Baltes and Baltes, 1990; Brandtstädter and Greve, 1994; Heckhausen, 1997; Carstensen, 2006). Complementing these theories, we present a discrete emotions perspective, that considers specific positive and negative emotions. To illustrate the usefulness of this approach, we focus on a discussion of age differences in the experience of anger and sadness. These two negative emotions have typically been subsumed under the singular concept of negative affect. From a discrete emotions perspective, however, they are highly distinct and show multidirectional age differences. We propose that such contrasting age differences in specific emotions have important implications for understanding long-term patterns of affective well-being across the adult lifespan.

LIFE-SPAN THEORIES OF DEVELOPMENTAL REGULATION AND EMOTIONAL AGING

Prominent theories of developmental regulation postulate that individuals can avoid the adverse emotional effects of life's challenges, threats, and losses if they engage in effective self-regulatory strategies (e.g., Baltes and Baltes, 1990; Brandtstädter and Renner, 1990; Heckhausen et al., 2010). Although the nature of strategies has been defined and labeled differently by different theories, the various strategies seem to cluster according to whether they refer to continued engagement in attaining goals or to disengagement from unattainable goals (Haase et al., 2013). Further, the extent to which these two higher-order categories of developmental regulation protect affective well-being is thought to differ as a function of an individual's place in the life-cycle, which can be considered a proxy for individual differences in control opportunities and constraints. Given that individuals' capacity to influence their environment is relatively high in young adulthood and often declines in old age, processes of goal engagement should be used more frequently and adaptive in young adulthood. Processes of goal disengagement, by contrast, should become increasingly salient and adaptive in older adulthood. A large number of longitudinal and intervention studies have supported these propositions (reviews: Wrosch et al., 2006; Heckhausen et al., 2010).

Socioemotional Selectivity Theory (SST; Carstensen, 2006; Scheibe and Carstensen, 2010; Reed and Carstensen, 2012), a prominent theory of emotional aging, explains the maintenance of affective well-being in old age by focusing on future-related expectations, particularly older individuals' estimations of their remaining life-time. According to SST, because advancing age is naturally associated with endings and a limited lifetime, older adults prioritize social and emotional goals related to the optimization of immediate affective well-being over longer-term knowledge-related goals aimed at optimizing future resources (Carstensen et al., 1999). In support of SST's main predictions, a large body of evidence suggests that, in comparison with their younger counterparts, older adults are more selective in their choice of social partners and make their social interactions more emotionally satisfying (reviews: Carstensen et al., 1999; Fingerman and Charles, 2010). There is also substantial evidence for systematic age differences in basic affective information processing. Older adults appear to be generally more sensitive to positive information and less sensitive to negative information than young adults, a phenomenon termed the "positivity effect" (Carstensen and Mikels, 2005). SST states that this positivity effect is the result of an age-related increase in the allocation of cognitive resources toward emotion regulation (reviews: Mather and Carstensen, 2005; Kryla-Lighthall and Mather, 2009; Mather, 2012).

Overall, life-span developmental theories have provided valuable insights into how older individuals can maintain or enhance their affective well-being despite age-related losses in many life domains. Independent of their specific explanatory processes, however, affective well-being has been considered in these theories from a broad and dimensional perspective. That is, research based on these theories typically examined whether processes of developmental regulation, socio-emotional selectivity, or biases in affective information processing are associated with a broader aggregate of emotional experiences such as positive affect or negative affect. Past theoretical work is thus well suited to explain age differences in broad affective dimensions, but it may fall short in explaining age-differences in the salience and functions of different discrete negative or positive emotions subsumed under positive or positive affect. As a consequence, a discrete emotions perspective may be needed to complement past theoretical work. Such an approach may help better understand multidirectional age differences in short-term affective reactions and longer-term affective well-being. In addition, it may raise awareness that emotions are not only consequences of cognitive or motivational processes, but also can cause effective cognitions and behaviors.

A DISCRETE EMOTIONS PERSPECTIVE ON EMOTIONAL AGING

Functional emotion theories emphasize the adaptive value of discrete emotions and emotional dispositions (e.g., Frijda, 1986; Campos et al., 1989; Lazarus, 1991; Izard, 1993; Levenson, 1994; Ekman, 1999; Keltner and Gross, 1999). According to these theories, emotions provide important information to the self and others and help motivate our own and others' behavior. For example, some emotions push individuals away from certain thoughts, memories, or actions, whereas other emotions make certain thoughts, memories, or actions more likely. Functional approaches traditionally have focused on the adaptive value of negative emotions. From this perspective, the overall purpose of negative emotions is to eliminate a threat or an imbalance between the individual and his or her environment. More specifically, negative emotions are thought to prompt time-tested adaptive actions enabled and supported by specific action tendencies (Frijda, 1986), patterns of physiological activity (Levenson, 1994), configurations of facial expressions (Ekman, 1999), and subjective feelings (e.g., Izard, 1993). Functional approaches to emotion have emphasized that each discrete negative emotion serves a specific and distinct function (e.g., fear creates the urge to escape, disgust the urge to expel; e.g., Frijda, 1986; Levenson, 1992).

AGE DIFFERENCES IN NEGATIVE AFFECT: THE SAMPLE CASE OF ANGER AND SADNESS

To explore the usefulness of a discrete emotion approach, we focus on the functions of two emotions, anger and sadness for two reasons. First, empirical studies examining age differences in discrete emotions have largely focused on these two emotions. Second, and more important, different from other discrete emotions, anger and sadness are closely and differentially associated with the two higher-order classes of developmental regulation, goal engagement and goal disengagement. As a consequence, a theoretical framework that addresses age differences in the salience and adaptivity of anger and sadness appears to be a reasonable starting point for developing a more comprehensive discrete emotions approach.

A central tenet of theories of life-span development has been that each stage in the life cycle is characterized by a specific configuration of environmental challenges as well as personal needs, beliefs, and future expectations (e.g., Heckhausen and Schulz, 1995). We build on this assumption and argue that age-specific configurations may increase or decrease the experience and adaptive value of specific emotions (see also Haase et al., 2012). This proposition provides a theoretically important extension of functional emotion theories as it suggests that not only the emotion itself but also characteristics of the individual and his or her immediate and broader social context, most of which substantially change across the adult life-span, determine the adaptive value of specific emotions.

To begin, young adulthood has been described as a phase of growth during which individuals have greater opportunities to develop their potentials than their older counterparts. Thus, processes of growth and optimization rather than maintenance or compensation should have priority in young adulthood (Baltes and Baltes, 1990; Freund and Baltes, 1998, 2002; Ebner et al., 2006). Consistent with this view, SST assumes that young, as compared with older adults' goals tend to be more future-oriented and focused on acquiring new resources such as knowledge or information (e.g., Carstensen et al., 1999). Moreover, life-span theories of developmental regulation (e.g., Brandtstädter and Greve, 1994; Heckhausen et al., 2010) have proposed that, in young adulthood, perceptions of high personal control and a tenacious pursuit of goals are not only highly prevalent, but also closely tied to well-being (Wrosch and Heckhausen, 1999; Rothermund and Brandtstädter, 2003; Lachman, 2006). Finally, there is evidence suggesting that individuals are most willing to engage in and reflect on social conflicts when they are young (Labouvie-Vief et al., 1989; Birditt and Fingerman, 2005; Blanchard-Fields et al., 2007).

Given that young adults typically pursue many future-related goals and have a strong need to accomplish them, the elicitor of anger, which is the appraisal that one's own goals are intentionally ignored or blocked by others, should be particularly frequent and salient in young adulthood. In addition, the situational control appraisals, action tendencies, and social motivations typical of anger are likely to be more readily accessible in young adulthood than in old age. In fact, according to discrete emotion theories, anger prototypically involves the belief in high situational control (Lazarus, 1991), triggers a reactant "moving against" state of action readiness (Frijda et al., 1989), and promotes goal persistence (Lench and Levine, 2008). In addition, anger facilitates efforts to bring others' behaviors back in line with one's own goals (Fischer and Roseman, 2007). Thus, relative to older adults, young adults should experience anger more intensively and more frequently. Moreover, because anger may at times help young adults to overcome obstacles in accomplishing age-normative tasks, it could be adaptive, at least in certain contexts, and benefit young adults' longer-term affective well-being (Haase et al., 2012).

In marked contrast to young adulthood, old age has been characterized as a phase of loss and decline (Lindenberger and Baltes, 1997; Smith and Baltes, 1997; Baltes and Mayer, 1999) during which social, cognitive, and physical resources become increasingly limited and processes of maintenance and compensation gain importance (Baltes and Baltes, 1990; Labouvie-Vief, 2003). Life-span theories have proposed that, given the limited resources in old age, perceptions of low personal control and goal adjustment processes become increasingly frequent and adaptive (e.g., Wrosch and Heckhausen, 1999; Rothermund and Brandtstädter, 2003; Lachman, 2006). In addition, according to SST, because perceived future life-time shrinks with increasing age, older adults' tend to be particularly present-oriented in their goal pursuits, focused on creating emotionally meaningful experiences, and likely to avoid social conflicts for the sake of maintaining social harmony in the current moment (Birditt and Fingerman, 2005; Carstensen, 2006; Blanchard-Fields, 2007).

Given that, relative to young adults, older adults increasingly face losses of fundamental resources and tend to adjust their goals accordingly, the elicitor of sadness, that is, the appraisal of a situation as an irreversible loss, should be particularly frequent and salient in old age. In addition, the situational control appraisals, action tendencies, and social motivations that are linked to sadness are likely to be more readily accessible in old age than in earlier life periods. In support of this assumption, discrete emotion theories suggest that sadness prototypically goes hand in hand with a perception of low situational control (Lazarus, 1991). In addition, it triggers processes of adaptive goal disengagement (Frijda et al., 1989; Nesse, 2000; Wrosch and Miller, 2009) and signals to others the need for closeness, sympathy, and support (Andrews and Thomson, 2009). As a consequence, relative to young adults, older adults should experience sadness more intensively and frequently. Moreover, because sadness is likely to help older adults deal with losses by facilitating disengagement from unattainable goals and enhancing social support, it could be adaptive, at least in certain contexts, and facilitate older adults' longer-term affective well-being (see also Kunzmann and Grühn, 2005; Haase et al., 2012).

EMPIRICAL EVIDENCE

A small but growing body of evidence is consistent with the notion that sadness and anger follow contrasting trajectories across the adult life-span. For example, research has shown that older adults report less anger and anger-related regulatory strategies during interpersonal conflicts than their younger counterparts (Blanchard-Fields and Coats, 2008). An age-related reduction in the intensity of anger reactivity was also found when young and older adults were confronted with film clips of an old woman talking about problems in a nursing home (Charles et al., 2001) or audio-taped conversations, in which two individuals were ostensibly making disparaging remarks about a third person (Charles and Carstensen, 2008). Age differences in sadness-reactions, by contrast, have been shown to be reversed (i.e., higher among older adults) or non-significant (Charles et al., 2001; Charles and Carstensen, 2008). Other studies have investigated age differences in emotional reactions to stimuli specifically designed to elicit either anger or sadness. In this line of work, older, as compared with younger, adults reported less anger in response to anger-eliciting stimuli, but equal or higher sadness in response to sadness-eliciting stimuli (Tsai et al., 2000; Labouvie-Vief et al., 2003; Kunzmann and Grühn, 2005; Kunzmann and Richter, 2009; Seider et al., 2011; Streubel and Kunzmann, 2011).

Age-related differences in the experience of anger and sadness have also been examined on the level of affect frequency in a longitudinal field study with a national sample of German adults covering most of the adult lifespan (Kunzmann et al., 2013). More specifically, cross-sectional and longitudinal findings from this study consistently suggest that the frequency of anger increases from late adolescence into young adulthood, but shows a steady decrease from midlife to old age. By contrast, the frequency of sadness remained stable over most of adulthood and increased in old age (Kunzmann et al., 2013). Extending this work, a recent study explored age differences in anger and sadness by focusing on the intensity and frequency of emotional experiences on a typical day and their implicit associations with participants' self (Kunzmann and Thomas, 2014). Consistent with a discrete emotions perspective, older adults experienced anger less frequently and less intensively than young adults, but there were no age differences in the experience of sadness. Furthermore, this study provided initial evidence for the idea that anger, but not sadness, becomes less self-descriptive with age (Kunzmann and Thomas, 2014).

Finally, there is preliminary evidence indicating that the effects of anger and sadness on affective well-being are age-differential as well (Haase et al., 2012). In this laboratory study, anger experiences in response to neutral film clips with ambiguous contents were associated with high affective well-being in middle-aged adults but not in young or older adults. Sadness reactions, by contrast, were associated with high affective well-being in older adults, but not in younger or middle-aged adults (Haase et al., 2012). These findings lend support to our previous predictions, although according to our framework, anger should be adaptive in young adulthood as well.

CONCLUSIONS AND OUTLOOK

Life-span theories' current focus on the explanation of age-related changes in the overall quality of affective experience does not account well for multidirectional and multifunctional age differences in specific emotions. A discrete emotions perspective on aging therefore complements life-span theories as it allows more differentiated predictions. According to this view, all emotions—positive and negative—are adaptive in particular contexts. Thus, although most individuals value high emotional well-being (Tsai et al., 2006), and report pro-hedonic emotion regulatory goals more frequently than contra-hedonic goals (Riediger et al., 2009), from a functionalist view, a life without negative emotions would be impoverished, unhealthy, and short. Instead, it assumes that negative emotions are useful experiences. They serve specific functions and may be adaptive if they enable individuals to manage critical life circumstances.

Our approach and review is consistent with this view by documenting the usefulness and importance of a discrete emotions approach. It demonstrates multidirectional age differences in the experience of anger and sadness by indicating that the salience of anger decreases across the life-span, particularly during middle adulthood and old age, whereas the intensity and frequency of sadness remains stable or increases in old age. In addition, it provides preliminary evidence suggesting such age differences in emotional reactions may contribute to individuals' general affective well-being.

To further clarify the roles of specific negative emotions, future research should determine the conditions that give rise to adaptive consequences of anger reactions (in young adulthood) and sadness reactions (in old age). Certainly, chronic or unwarranted anger and sadness are unlikely to contribute to high affective well-being at any age. Instead, it may be the match between situational circumstances and emotional reactions that could determine the adaptive value of age-related experiences of anger and sadness. To examine such situation by emotion interactions, future research should also incorporate time windows of different lengths because specific negative emotions may not be strongly associated with high levels of concurrent affective well-being. Rather, the experience of certain negative emotions could restore and optimize individuals' affective well-being over longer periods of time if they trigger and facilitate behavioral processes that over time help individuals to adjust successfully to age-related opportunities and constraints.

A second task for future work is to shed further light on the mechanisms that can explain age differences in anger and sadness. Our theoretical framework is motivational in nature in that we argue that each place in the life-cycle is characterized by a specific configuration of developmental conditions that make certain emotions more salient and adaptive. However, theoretical accounts of age differences in cognitive and physiological resources may provide additional insights (Labouvie-Vief, 2003; Cacioppo et al., 2011). For example, anger may involve greater physiological arousal and may require more cognitive resources than sadness, and this may imply that older adults have fewer resources to experience anger than sadness.

Finally, it will be interesting to extend our framework by considering additional distinct negative and positive emotions. For example, there is preliminary research suggesting age-related increases in fear and age-related declines in disgust (Kunzmann et al., 2005; Teachman and Gordon, 2009). Future research should clarify the mechanisms that underlie such age differences in a variety of distinct emotions. Research along these lines may also broaden the age range of inquiry by additionally examining children and adolescents and consider the influence of individual differences in available resources and types of goals. We think that future research from a discrete emotion perspective is warranted and has the potential to contribute to our understanding of successful development across the lifespan.

AUTHOR NOTE

The completion of this manuscript was supported by grants from the German Research Foundation to Ute Kunzmann and by grants from Social Sciences and Humanities Research Council of Canada and Canadian Institutes of Health Research to Carsten Wrosch.

REFERENCES

Andrews, P. W., and Thomson, J. A. Jr. (2009). The bright side of being blue: depression as an adaptation for analyzing complex problems. *Psychol. Rev.* 116, 620–654. doi: 10.1037/a0016242

Baltes, P. B., and Baltes, M. M. (1990). *Successful Aging: Perspectives From the Behavioral Sciences.* New York, NY: Cambridge University Press.

Baltes, P. B., and Mayer, K. U. (1999). *The Berlin Aging Study: Aging from 70 to 100.* New York, NY: Cambridge University Press.

Birditt, K. S., and Fingerman, K. L. (2005). Do we get better at picking our battles? Age group differences in descriptions of behavioral reactions to interpersonal tensions. *J. Gerontol. B Psychol. Sci. Soc. Sci.* 60B, P121–P128. doi: 10.1093/geronb/60.3.P121

Blanchard-Fields, F. (2007). Everyday problem solving and emotion: an adult developmental perspective. *Curr. Dir. Psychol. Sci.* 16, 26–31. doi: 10.1111/j.1467-8721.2007.00469.x

Blanchard-Fields, F., and Coats, A. H. (2008). The experience of anger and sadness in everyday problems impacts age differences in emotion regulation. *Dev. Psychol.* 44, 1547–1556. doi: 10.1037/a0013915

Blanchard-Fields, F., Mienaltowski, A., and Seay, R. B. (2007). Age differences in everyday problem-solving effectiveness: older adults select more effective strategies for interpersonal problems. *J. Gerontol. B Psychol. Sci. Soc. Sci.* 62B, P61–P64. doi: 10.1093/geronb/62.1.P61

Brandtstädter, J., and Greve, W. (1994). The aging self: stabilizing and protective processes. *Dev. Rev.* 14, 52–80.

Brandtstädter, J., and Renner, G. (1990). Tenacious goal pursuit and flexible goal adjustment: explication and age-related analysis of assimilative and accommodative strategies of coping. *Psychol. Aging* 5, 58–67. doi: 10.1037/0882-7974.5.1.58

Cacioppo, J. T., Berntson, G. G., Bechara, A., Tranel, D., and Hawkley, L. C. (2011). "Could an aging brain contribute to subjective well-being? The value added by a social neuroscience perspective," in *Social Neuroscience: Toward Understanding the Underpinnings of the Social Mind,* eds A. Todorov, S. T. Fiske and D. A. Prentice (New York, NY: Oxford University Press), 249–262.

Campos, J. J., Campos, R. G., and Barrett, K. C. (1989). Emergent themes in the study of emotional development and emotion regulation. *Dev. Psychol.* 25, 394–402. doi: 10.1037/0012-1649.25.3.394

Carstensen, L. L. (2006). The influence of a sense of time on human development. *Science* 312, 1913–1915. doi: 10.1126/science.1127488

Carstensen, L. L., Isaacowitz, D. M., and Charles, S. T. (1999). Taking time seriously: a theory of socioemotional selectivity. *Am. Psychol.* 54, 165–181. doi: 10.1037/0003-066x.54.3.165

Carstensen, L. L., and Mikels, J. A. (2005). At the intersection of emotion and cognition: aging and the positivity effect. *Curr. Dir. Psychol. Sci.* 14, 117–121. doi: 10.1111/j.0963-7214.2005.00348.x

Charles, S. T., and Carstensen, L. L. (2007). "Emotion regulation and aging," in *Handbook of Emotion Regulation,* ed J. J. Gross (New York, NY: Guilford Press), 307–327.

Charles, S. T., and Carstensen, L. L. (2008). Unpleasant situations elicit different emotional responses in younger and older adults. *Psychol. Aging* 23, 495–504. doi: 10.1037/a0013284

Charles, S. T., Carstensen, L. L., and Mcfall, R. M. (2001). Problem-solving in the nursing home environment: age and experience differences in emotional reactions and responses. *J. Clin. Geropsychol.* 7, 319–330. doi: 10.1023/a:1011352326374

Ebner, N. C., Freund, A. M., and Baltes, P. B. (2006). Developmental changes in personal goal orientation from young to late adulthood: from striving for gains to maintenance and prevention of losses. *Psychol. Aging* 21, 664–678. doi: 10.1037/0882-7974.21.4.664

Ekman, P. (1999). "Basic emotions," in *Handbook of Cognition and Emotion*, eds T. Dalgleish and M. J. Power (New York, NY: John Wiley & Sons Ltd), 45–60.

Fingerman, K. L., and Charles, S. T. (2010). It takes two to tango: why older people have the best relationships. *Curr. Dir. Psychol. Sci.* 19, 172–176. doi: 10.1177/0963721410370297

Fischer, A. H., and Roseman, I. J. (2007). Beat them or ban them: the characteristics and social functions of anger and contempt. *J. Pers. Soc. Psychol.* 93, 103–115. doi: 10.1037/0022-3514.93.1.103

Freund, A. M., and Baltes, P. B. (1998). Selection, optimization, and compensation as strategies of life management: correlations with subjective indicators of successful aging. *Psychol. Aging* 13, 531–543. doi: 10.1037/0882-7974.13.4.531

Freund, A. M., and Baltes, P. B. (2002). Life-management strategies of selection, optimization and compensation: measurement by self-report and construct validity. *J. Pers. Soc. Psychol.* 82, 642–662. doi: 10.1037/0022-3514.82.4.642

Frijda, N. H. (1986). *The Emotions.* New York; Paris: Cambridge University Press Editions de la Maison des Sciences de l'Homme.

Frijda, N. H., Kuipers, P., and Ter Schure, E. (1989). Relations among emotion, appraisal, and emotional action readiness. *J. Pers. Soc. Psychol.* 57, 212–228. doi: 10.1037/0022-3514.57.2.212

Haase, C. M., Heckhausen, J., and Wrosch, C. (2013). Developmental regulation across the life span: toward a new synthesis. *Dev. Psychol.* 49, 964–972. doi: 10.1037/a002923110.1037/a0029231

Haase, C. M., Seider, B. H., Shiota, M. N., and Levenson, R. W. (2012). Anger and sadness in response to an emotionally neutral film: evidence for age-specific associations with well-being. *Psychol. Aging* 27, 305–317. doi: 10.1037/a0024959

Heckhausen, J. (1997). Developmental regulation across adulthood: primary and secondary control of age-related challenges. *Dev. Psychol.* 33, 176–187. doi: 10.1037/0012-1649.33.1.176

Heckhausen, J., and Schulz, R. (1995). A life-span theory of control. *Psychol. Rev.* 102, 284–304. doi: 10.1037/0033-295x.102.2.284

Heckhausen, J., Wrosch, C., and Schulz, R. (2010). A motivational theory of life-span development. *Psychol. Rev.* 117, 32–60. doi: 10.1037/a0017668

Isaacowitz, D. M., and Blanchard-Fields, F. (2012). Linking process and outcome in the study of emotion and aging. *Perspect. Psychol. Sci.* 7, 3–17. doi: 10.1177/1745691611424750

Izard, C. E. (1993). Four systems for emotion activation: cognitive and noncognitive processes. *Psychol. Rev.* 100, 68–90. doi: 10.1037/0033-295x.100.1.68

Keltner, D., and Gross, J. J. (1999). Functional accounts of emotions. *Cogn. Emot.* 13, 467–480.

Kryla-Lighthall, N., and Mather, M. (2009). "The role of cognitive control in older adults' emotional well-being," in *Handbook of Theories of Aging, 2nd Edh.* eds V. L. Bengston, D. Gans, N. M. Pulney, and M. Silverstein (New York, NY: Springer Publishing Co), 323–344.

Kunzmann, U., and Grühn, D. (2005). Age differences in emotional reactivity: the sample case of sadness. *Psychol. Aging* 20, 47–59. doi: 10.1037/0882-7974.20.1.47

Kunzmann, U., Kupperbusch, C. S., and Levenson, R. W. (2005). Behavioral inhibition and amplification during emotional arousal: a comparison of two age groups. *Psychol. Aging* 20, 144–158. doi: 10.1037/0882-7974.20.1.144

Kunzmann, U., and Richter, D. (2009). Emotional reactivity across the adult life span: the cognitive pragmatics make a difference. *Psychol. Aging* 24, 879–889. doi: 10.1037/a0017347

Kunzmann, U., Richter, D., and Schmukle, S. C. (2013). Stability and change in affective experience across the adult life span: analyses with a national sample from Germany. *Emotion* 13, 1086–1095. doi: 10.1037/a0033572

Kunzmann, U., and Thomas, S. (2014). Multidirectional age differences in anger and sadness. *Psychol. Aging* 29, 16–27. doi: 10.1037/a0035751

Labouvie-Vief, G. (2003). Dynamic integration: affect, cognition, and the self in adulthood. *Curr. Dir. Psychol. Sci.* 12, 201–206. doi: 10.1046/j.0963-7214.2003.01262.x

Labouvie-Vief, G., Devoe, M., and Bulka, D. (1989). Speaking about feelings: conceptions of emotion across the life span. *Psychol. Aging* 4, 425–437. doi: 10.1037/0882-7974.4.4.425

Labouvie-Vief, G., Lumley, M. A., Jain, E., and Heinze, H. (2003). Age and gender differences in cardiac reactivity and subjective emotion responses to emotional autobiographical memories. *Emotion* 3, 115–126. doi: 10.1037/1528-3542.3.2.115

Lachman, M. E. (2006). Perceived control over aging-related declines: adaptive beliefs and behaviors. *Curr. Dir. Psychol. Sci.* 15, 282–286. doi: 10.1111/j.1467-8721.2006.00453.x

Lazarus, R. S. (1991). Cognition and motivation in emotion. *Am. Psychol.* 46, 352–367. doi: 10.1037/0003-066x.46.4.352

Lench, H. C., and Levine, L. J. (2008). Goals and responses to failure: knowing when to hold them and when to fold them. *Motiv. Emot.* 32, 127–140. doi: 10.1007/s11031-008-9085-1

Levenson, R. W. (1992). Autonomic nervous system differences among emotions. *Psychol. Sci.* 3, 23–27. doi: 10.1111/j.1467-9280.1992.tb00251.x

Levenson, R. W. (1994). "Human emotion: a functional view," in *The Nature of Emotion. Fundamental Questions*, eds P. Ekman and R. Davidson (New York, NY: Oxford University Press), 123–126.

Lindenberger, U., and Baltes, P. B. (1997). Intellectual functioning in old and very old age: cross-sectional results from the Berlin Aging Study. *Psychol. Aging* 12, 410–432. doi: 10.1037/0882-7974.12.3.410

Mather, M. (2012). The emotion paradox in the aging brain. *Ann. N.Y. Acad. Sci.* 1251, 33–49. doi: 10.1111/j.1749-6632.2012.06471.x

Mather, M., and Carstensen, L. L. (2005). Aging and motivated cognition: the positivity effect in attention and memory. *Trends Cogn. Sci.* 9, 496–502. doi: 10.1016/j.tics.2005.08.005

Nesse, R. M. (2000). Is depression an adaptation? *Arch. Gen. Psychiatry* 57, 14–20. doi: 10.1001/archpsyc.57.1.14

Reed, A. E., and Carstensen, L. L. (2012). The theory behind the age-related positivity effect. *Front. Psychol.* 3:339. doi: 10.3389/fpsyg.2012.00339

Riediger, M., Schmiedek, F., Wagner, G. G., and Lindenberger, U. (2009). Seeking pleasure and seeking pain: differences in prohedonic and contra-hedonic motivation from adolescence to old age. *Psychol. Sci.* 20, 1529–1535. doi: 10.1111/j.1467-9280.2009.02473.x

Rothermund, K., and Brandtstädter, J. (2003). Depression in later life: cross-sequential patterns and possible determinants. *Psychol. Aging* 18, 80–90. doi: 10.1037/0882-7974.18.1.80

Scheibe, S., and Carstensen, L. L. (2010). Emotional aging: recent findings and future trends. *J. Gerontol. B Psychol. Sci. Soc. Sci.* 65B, 135–144. doi: 10.1093/geronb/gbp132

Seider, B. H., Shiota, M. N., Whalen, P., and Levenson, R. W. (2011). Greater sadness reactivity in late life. *Soc. Cogn. Affect. Neurosci.* 6, 186–194. doi: 10.1093/scan/nsq069

Smith, J., and Baltes, P. B. (1997). Profiles of psychological functioning in the old and oldest old. *Psychol. Aging* 12, 458–472. doi: 10.1037/0882-7974.12.3.458

Streubel, B., and Kunzmann, U. (2011). Age differences in emotional reactions: arousal and age-relevance count. *Psychol. Aging* 26, 966–978. doi: 10.1037/a0023424

Teachman, B. A., and Gordon, T. (2009). Age differences in anxious responding: older and calmer, unless the trigger is physical. *Psychol. Aging* 24, 703–714. doi: 10.1037/a0016813

Tsai, J. L., Knutson, B., and Fung, H. H. (2006). Cultural variation in affect valuation. *J. Pers. Soc. Psychol.* 90, 288–307. doi: 10.1037/0022-3514.90.2.288

Tsai, J. L., Levenson, R. W., and Carstensen, L. L. (2000). Autonomic, subjective, and expressive responses to emotional films in older and younger Chinese Americans and European Americans. *Psychol. Aging* 15, 684–693. doi: 10.1037/0882-7974.15.4.684

Wrosch, C., Dunne, E., Scheier, M. F., and Schulz, R. (2006). Self-regulation of common age-related challenges: benefits for older adults' psychological and physical health. *J. Behav. Med.* 29, 299–306. doi: 10.1007/s10865-006-9051-x

Wrosch, C., and Heckhausen, J. (1999). Control processes before and after passing a developmental deadline: activation and deactivation of intimate relationship goals. *J. Pers. Soc. Psychol.* 77, 415–427. doi: 10.1037/0022-3514.77.2.415

Wrosch, C., and Miller, G. E. (2009). Depressive symptoms can be useful: self-regulatory and emotional benefits of dysphoric mood in adolescence. *J. Pers. Soc. Psychol.* 96, 1181–1190. doi: 10.1037/a0015172

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 14 January 2014; accepted: 10 April 2014; published online: 06 May 2014.
Citation: Kunzmann U, Kappes C and Wrosch C (2014) Emotional aging: a discrete emotions perspective. Front. Psychol. ***5****:380. doi: 10.3389/fpsyg.2014.00380*
This article was submitted to Emotion Science, a section of the journal Frontiers in Psychology.

frontiers in
PSYCHOLOGY

MINI REVIEW ARTICLE
published: 04 February 2014
doi: 10.3389/fpsyg.2014.00030

Facial age affects emotional expression decoding

Mara Fölster[1]*, Ursula Hess[2] and Katja Werheid[1]

[1] *Clinical Gerontopsychology, Department of Psychology, Humboldt-Universität zu Berlin, Berlin, Germany*
[2] *Social and Organizational Psychology, Department of Psychology, Humboldt-Universität zu Berlin, Berlin, Germany*

Edited by:
Natalie Ebner, University of Florida, USA

Reviewed by:
Natalie Ebner, University of Florida, USA
Derek Isaacowitz, Northeastern University, USA
Jessica Komes, Friedrich Schiller University, Germany

****Correspondence:***
Mara Fölster, Clinical Gerontopsychology, Department of Psychology, Humboldt-Universität zu Berlin, Rudower Chaussee 18, 12489 Berlin, Germany
e-mail: mara.foelster@hu-berlin.de

Facial expressions convey important information on emotional states of our interaction partners. However, in interactions between younger and older adults, there is evidence for a reduced ability to accurately decode emotional facial expressions. Previous studies have often followed up this phenomenon by examining the effect of the observers' age. However, decoding emotional faces is also likely to be influenced by stimulus features, and age-related changes in the face such as wrinkles and folds may render facial expressions of older adults harder to decode. In this paper, we review theoretical frameworks and empirical findings on age effects on decoding emotional expressions, with an emphasis on age-of-face effects. We conclude that the age of the face plays an important role for facial expression decoding. Lower expressivity, age-related changes in the face, less elaborated emotion schemas for older faces, negative attitudes toward older adults, and different visual scan patterns and neural processing of older than younger faces may lower decoding accuracy for older faces. Furthermore, age-related stereotypes and age-related changes in the face may bias the attribution of specific emotions such as sadness to older faces.

Keywords: emotional facial expressions, facial expression decoding, older face, aging, own-age advantage, response bias, expressivity

INTRODUCTION

Facial expressions convey important information on emotional states of our interaction partners (Ekman et al., 1982). Thus, the correct interpretation of facial expressions may facilitate emotional understanding and enhance the quality of interpersonal communication.

Recent evidence suggests that the correct interpretation of emotional expressions may be negatively affected in older age due to processes related to both the sender and the observer. The majority of the extant research has focused on the influence of the observers' age and concludes that older observers have deficits in the decoding of specific emotions (see Ruffman et al., 2008; Isaacowitz and Stanley, 2011, for reviews).

The age of those showing the facial expressions was initially less often considered. As a possible reason, the influential model of face processing by Bruce and Young (1986) postulated that the decoding of facial expressions is robust to the idiosyncratic features of a given face, which might be influenced by age, sex or other factors. However, this proposition has been subject to controversial debate (e.g., Schweinberger and Soukup, 1998; Schyns and Oliva, 1999; Kaufmann and Schweinberger, 2004; Calder and Young, 2005; Aviezer et al., 2011; Barret et al., 2011). Instead, it is likely that wrinkles, folds and the sag of facial musculature in the older face affect the interpretation of facial expressions. This assumption has been confirmed by recent results of decoding accuracy varying with the age of the face (Malatesta et al., 1987b; Borod et al., 2004; Ebner and Johnson, 2009, 2010; Murphy et al., 2010; Richter et al., 2011; Riediger et al., 2011; Hess et al., 2012; Ebner et al., 2012, 2013; Hühnel et al., 2014). Previous reviews have mainly focused on the age of the observer (Ruffman et al., 2008; Isaacowitz and Stanley, 2011) or on age-of-face effects on face identity recognition (e.g., Rhodes and Anastasi, 2012). Adding to this work, the present review is the first to focus on the influence of facial age on expression decoding and its possible underlying mechanisms, taking into account most recent work on this subject published after these previous reviews. Our aim was to compile and evaluate findings, thereby focusing on the question to which extent methodological differences between studies may account for inconsistent results. Further, we wish to identify unresolved research questions and suggest topics for future research. We will first give a very brief overview of the influence of the observers' age on decoding accuracy and the mechanisms underlying these effects. However, as this research has already been reviewed elsewhere (Ruffman et al., 2008; Isaacowitz and Stanley, 2011), we will mainly focus on the influence of the faces' age.

INFLUENCE OF THE OBSERVERS' AGE

An age-related decline in decoding facial expressions has been repeatedly reported (e.g., Calder et al., 2003; Ruffman et al., 2008; Isaacowitz and Stanley, 2011). However, recent evidence suggests that this decline is confined to specific emotions. An overview of mechanisms underlying emotion-specific effects of the observers' age on facial expression decoding is given in **Figure 1** (right part). Some studies found an age-related deficit in decoding negative, but not positive emotional expressions (Phillips et al., 2002; Williams et al., 2006; Keightley et al., 2007; Ebner and Johnson, 2009). In addition, older observers had a greater bias toward thinking that individuals were feeling happy when they were displaying either enjoyment or non-enjoyment smiles (Slessor et al., 2010; but see Riediger et al., under review). These results have been accounted for by an information processing bias by older observers, leading to increased attention

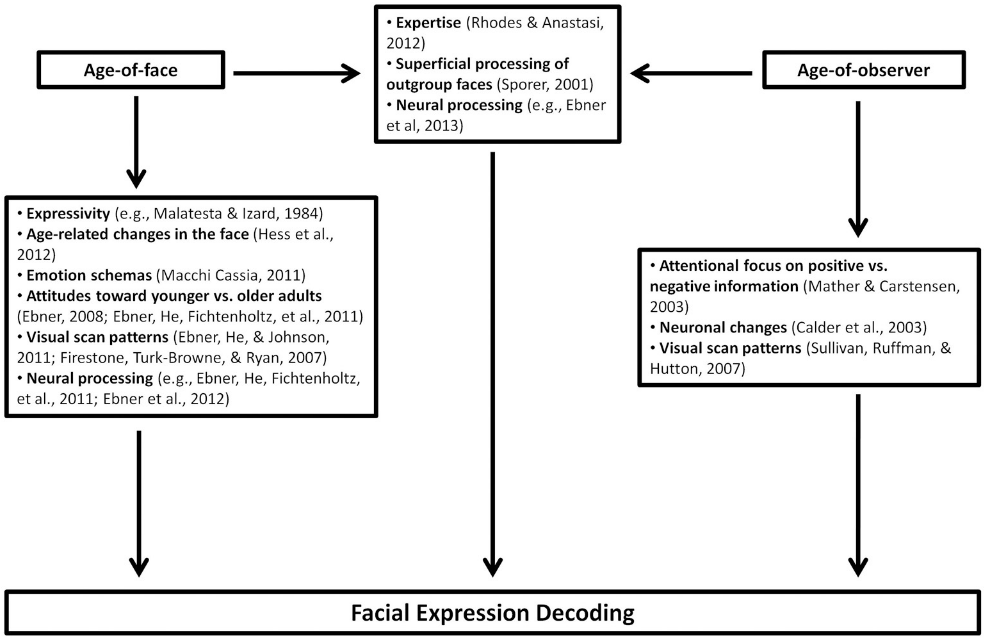

FIGURE 1 | Overview of mechanisms underlying effects of the age of the face (left part) and the age of the observer (right part) as well as own-age effects (central part) on facial expression decoding.

toward positive compared to negative information (Mather and Carstensen, 2003). This explanation is based on the socioemotional selectivity theory (SST, Carstensen and Charles, 1998), stating that older persons are, due to their limited future time perspective, inclined to engage in tasks related to emotional balance and well-being. Younger persons, in contrast, favor information seeking over emotionally rewarding goals and, thus, may be more inclined to attend to other persons' negative emotional states (Carstensen and Mikels, 2005). However, Isaacowitz and Stanley (2011) argued that the preserved ability to decode happiness may as well be due to the relative ease of the task, when happiness is the only positive response option. Supporting this assumption, age effects for positive emotions emerged when the task was more difficult (Isaacowitz et al., 2007). Further evidence against the SST-based account is that the majority of research on emotional prosody and body language suggests that older observers have difficulties to decode positive as well as negative emotions (emotional prosody: Taler et al., 2006; Ruffman et al., 2009a,b; Lambrecht et al., 2012, body language: Ruffman et al., 2009a,b, but see Montepare et al., 1999, for an exception).

Further conflicting the SST-based account, some studies found an age-related improvement in decoding disgust, together with no age differences for happiness and an age-related deficit in decoding sadness (Suzuki et al., 2007), or anger, fear and sadness (Calder et al., 2003). There are two alternative explanations for these findings.

The first explanation is based on observed age differences in visual scan patterns: older observers focus primarily on the lower part of the face and neglect the upper part (Wong et al., 2005; Sullivan et al., 2007). As the upper part plays a more important role for expressions of anger, fear and sadness, but not for disgust and happiness (Calder et al., 2000), this may explain why older observers are especially impaired in decoding these emotions. In line with this explanation, older observers' poor performance for decoding anger, fear and sadness correlated with fewer fixations to the top half of faces (Wong et al., 2005). However, Ebner et al. (2011c) found that visual scan patterns were independent of the observers' age, but rather varied with the expression. Thus, evidence for age differences in visual scan patterns is mixed. Furthermore, as already mentioned above, older observers' difficulties are not restricted to decoding facial expressions, but also emerge when decoding emotional prosody and bodily expression, at least rendering visual scan patterns as sole underlying mechanism unlikely.

The second explanation states that the brain regions that are responsible for decoding emotions, differ between the various emotions and that these regions are also differently affected by age-related changes (Ruffman et al., 2008; Ebner and Johnson, 2009; Ebner et al., 2012). As the frontal region, which is especially important for anger and sadness (Murphy et al., 2003), and the amygdala, which is important for fear (Murphy et al., 2003; Adolphs et al., 2005), are particularly affected by age-related changes (Jack et al., 1997; Bartzokis et al., 2003), a stronger age-related decline in decoding these emotions is predicted. In contrast, the basal ganglia, playing an important role for disgust (Phan et al., 2002), are less strongly affected by age-related changes (Raz, 2000; Williams et al., 2006), possibly resulting in a relatively preserved ability to decode disgust. Wong et al. (2005) further suggested that age-related declines in the frontal eye field, an area in the frontal lobe, may lead to deficits in visual attention, possibly leading to dysfunctional visual scan patterns. In addition, recent fMRI studies investigating brain activity in younger and older observers while viewing emotional faces suggest functional brain changes with age (Williams et al., 2006; Keightley et al., 2007). Although the pattern of results is somewhat mixed, older observers showed less amygdala activation (Gunning-Dixon et al., 2003; Fischer et al., 2005, 2010), but more prefrontal cortex activation (Gunning-Dixon et al., 2003; Fischer et al., 2010) compared to younger observers when viewing emotional faces. Fischer et al. (2005) suggested that this may represent an attempt to compensate for diminished functions in other brain regions than the frontal brain. Williams et al. (2006) further argued that this may reflect a shift from automatic processing to a more controlled processing of emotional information, possibly enabling older observers to better selectively control reactions to negative stimuli and finally leading to better emotional well-being. However, it may also be important to consider the valence of the facial expressions, and to differentiate between dorsomedial (dmPFC) and ventromedial prefrontal cortex (vmPFC). A recent study (Ebner et al., 2012) suggests that the vmPFC is more involved in affective and evaluative processing, whereas the dmPFC is involved in cognitively more complex processing. This functional dissociation seems to be largely comparable between younger and older observers. However, older observers showed increased dmPFC activity to negative faces, but decreased dmPFC to positive faces, possibly representing more controlled processing of negative compared to positive faces in older observers (Ebner et al., 2012).

INFLUENCE OF THE FACES' AGE

Concerning the age of the face, the majority of previous research found that posed emotional facial expressions were decoded less accurately in older compared to younger faces, irrespective of the target emotion (Borod et al., 2004; Riediger et al., 2011; Ebner et al., 2012, 2013) or with the exception of happiness (Ebner and Johnson, 2009; Ebner et al., 2011c), which may be due to ceiling effects. Hess et al. (2012) confirmed this finding with artificially created face stimuli displaying identical expressions for younger and older faces. As an exception, Ebner et al. (2010) found no age difference for posed fear expressions, but for happiness, anger, sadness, disgust, and neutrality expressions. Taken together, these results suggest that decoding emotional expressions is more difficult in older compared with younger faces. However, results obtained with spontaneous, dynamic expressions yielded a more heterogeneous pattern of results. Whereas Richter et al. (2011) confirmed the generally lower decoding accuracy for older faces, and Murphy et al. (2010) found a more accurate differentiation between posed and spontaneous dynamic smiles in younger than older faces, Riediger et al. (under review) found no main effect of facial age on the differentiation between spontaneous and posed dynamic smiles, Malatesta et al. (1987b) found no significant age difference on decoding emotional facial expressions and Hühnel et al. (2014) found even higher decoding accuracy for older faces displaying sadness. In the following, we will discuss possible mechanisms underlying these results. An overview of these studies is given in **Table 1** and an overview of the underlying mechanisms is given in **Figure 1** (left part).

EXPRESSIVITY

One possible explanation for reduced decoding accuracy for older faces may be that there actually is a difference in the way older and younger adults express emotions in their faces. Supporting this assumption, older adults performed worse than younger adults when following muscle-by-muscle instructions for constructing facial prototypes of emotional expressions (Levenson et al., 1991). Thus, due to age-related changes in flexibility and controllability of muscle tissue, the intentional display of facial emotions may become less successful with age and displays of unintended blended emotions may become more likely (Ebner et al., 2011c). In line with this assumption, observers more accurately judged whether videotaped speakers were telling the truth or lying when the speakers were older than when they were younger (Ruffman et al., 2012). Borod et al. (2004) further argued that an age-related decline in the frontal lobe may change emotional facial expressions, as frontal structures are especially important for the production of facial expressions and are highly vulnerable to aging.

Notably, these explanations may only account for age effects in posed expressions. For spontaneous expressions, results rather point to the assumption that younger and older adults do not differ in expressivity. In several studies, younger and older adults were filmed while reliving an emotional event or watching emotional film clips. Afterwards, their facial reactions were analyzed with objective coding systems such as FACS (Ekman et al., 1978), or MAX (Izard, 1979). An overview of these studies is given in **Table 2**. Although an early study suggested that older adults display more masked, that is, dissimulated, mixed and fragmented facial expressions than younger adults (Malatesta and Izard, 1984), later studies did not confirm these age differences in expressivity (Levenson et al., 1991; Tsai et al., 2000; Kunz et al., 2008), or even found higher expressivity for older faces (Malatesta-Magai et al., 1992). Thus, intentional displays of emotions may become less successful with age, but spontaneous emotional facial reactions seem to remain equally expressive throughout the life span. Besides, lower decoding accuracy for older faces cannot be fully explained by age differences in expressivity, because this effect has also been found when artificially created face stimuli controlled for expressivity were used (Hess et al., 2012).

Nevertheless, analyses of spontaneous facial expressions suggest that there may be age-related "dialects," that is, slight differences in the way older and younger adults express certain emotions. For example, older adults expressed sadness mainly through a lowered head, whereas younger adults also showed lowered brows (Malatesta and Izard, 1984). While reliving anger and sadness eliciting episodes, younger adults showed longer durations of shame, contempt and joy expressions, which may be interpreted as a cynical, self-conscious, perhaps mocking facial presentation that is common in younger adults (Magai et al., 2006). Older adults, on the other hand, showed more knitted brows, possibly indexing a generalized distress configuration in a regulated form, serving to indicate that negative emotion is present, but protecting social partners from emotional contagion (Magai et al., 2006). Notably, these age differences were not related to a corresponding age difference in experienced emotions

Table 1 | Summary of research on age-of-face effects on decoding accuracy.

Authors	Age-of-face	Stimuli description/database	Target emotions	Observers	Dependent variables	Main age-of-face results
Borod et al., 2004	30 YA, 30 MA, 30 OA, only females	Still posed expressions, developed for this study	Happiness, pleasant surprise, sadness, disgust, neutrality	12 YA, 12 MA, 12 OA, only females	Multiple choice emotion identification Confidence of rating	OA faces were rated less accurately and with less confidence than YA faces No own-age effect
Ebner et al., 2011c	8 YA and 8 OA per emotion	Still posed expressions [FACES developed by Ebner et al., 2010]	Happiness, anger, fear, sadness, disgust, neutrality	30 YA, 30 OA	Multiple choice emotion identification Visual scan patterns	Higher accuracy for YA than OA faces for anger, fear, disgust, sadness and neutrality No age-of-face effect for happiness No own-age effect Both YA and OA looked longer at own-age than other-age faces Longer looking at own-age faces predicted better own-age expression identification
Ebner and Johnson, 2009	8 YA and 8 OA per emotion	Still posed expressions [FACES developed by Ebner et al., 2010]	Happiness, anger, neutrality	32 YA, 24 OA	Multiple choice emotion identification Self-reported contact to YA and OA	Higher decoding accuracy for YA than OA faces for anger and neutrality No age-of-face effect for happiness No own-age effect The more contact observers reported with the own age group, the less they were able to identify expressions of the other age group No relationship between own-age contact and own-age decoding accuracy

(Continued)

Table 1 | Continued

Authors	Age-of-face	Stimuli description/database	Target emotions	Observers	Dependent variables	Main age-of-face results
Ebner et al., 2012[1]	16 YA and 16 OA per emotion	Still posed expressions [FACES developed by Ebner et al., 2010]	Happiness, anger, neutrality	30 YA, 32 OA	Multiple choice emotion identification fMRI data	Higher accuracy for YA than OA faces No age-of-face by emotion interaction No own-age effect Functional dissociation between vmPFC (affective processing) and dmPFC (cognitive control) Greater dmPFC activity for OA compared to YA faces
Ebner et al., 2010	58 YA, 56 MA, 57 OA	Still posed expressions (development and validation of FACES in this study)	Happiness, anger, fear, sadness, disgust, neutrality	52 YA, 51 MA, 51 OA	Multiple choice emotion identification Age estimation	Higher accuracy for YA than OA faces for happiness, anger, sadness, disgust, and neutrality No age-of-face effect for fear No own-age effect Happy faces were perceived as younger and fearful faces as older than faces with other expressions
Hess et al., 2012	6 YA, 6 OA	Morphed identical facial expressions to neutral faces from Minear and Park (2004)	Happiness, anger, sadness	65 YA	Continuous emotion rating	OA faces were rated as more intense on inaccurate emotions, but as less intense on accurate emotions than YA faces
Hühnel et al., 2014	4 YA, 4 OA	Videos of adults talking about biographic episodes (without sound)	Happiness, anger, sadness, disgust	39 YA, 39 OA, only females	Continuous emotion rating Mimicry measured via facial EMG	Higher accuracy for YA than OA faces for happiness and disgust Higher accuracy for OA than YA faces for sadness No age-of-face effect for anger No own-age effect No age-of-face effects on mimicry
Malatesta et al., 1987a	14 OA	Photos of posed expressions	Happiness, anger, sadness, fear, neutrality	30 YA	Multiple choice emotion identification Personality test results of posers	Emotions rated in the neutral face were congruent with the posers' dominant trait emotions

(Continued)

Table 1 | Continued

Authors	Age-of-face	Stimuli description/database	Target emotions	Observers	Dependent variables	Main age-of-face results
Malatesta and Izard, 1984	10 YA, 10 MA, 10 OA, only females	Videos of women talking about biographic episodes (without sound)	Happiness, anger, sadness, fear, affection	30 adults (no specification of age)	MAX-Coding of facial expressions Multiple choice emotion identification	MAX-Coding: see **Table 2** OA faces received less anger, but more sadness attributions than YA faces
Malatesta et al., 1987b	10 YA, 10 MA, 10 OA, only females	Videos of women talking about biographic episodes (without sound)	Sadness, fear, anger	10 YA, 10 MA, 10 OA, only females	Multiple choice emotion identification Rating of intensity of dominant emotion	No significant age-of-face effect on decoding accuracy Own-age bias in decoding accuracy Trend for more frequent attribution of sadness to OA than YA faces
Matheson, 1997	10 YA 10 OA, chronic pain patients	Videos of patients undergoing motion tests	Posed, masked and true pain, neutrality	39 YA, 24 OA	Rating of intensity of experienced pain	More pain attribution to OA, for all experimental conditions
Murphy et al., 2010	13 YA, 11 OA, only females	Videos of women talking about an imagined pleasant scenario (posed smile), pleasant biographical experience/response to winning a prize (spontaneous smile)	Posed smile, spontaneous smile	23 YA, 26 OA	Multiple choice rating of posed vs. spontaneous smile	Higher accuracy for YA than OA faces No own-age effect
Richter et al., 2011	4 YA, 4 OA, only females	Videos of women talking about biographic episodes (played with vs. without sound)	Happiness, anger, sadness	48 YA, 35 OA, only females	Continuous emotion rating, correlation of observers' and actors' ratings of felt emotions	Higher accuracy for YA than OA faces, no interaction with emotion Younger observers showed an own-age advantage when videos were played with, but not without sound
Riediger et al., 2011	58 YA, 56 MA, 57 OA	Still posed expressions [FACES developed by Ebner et al., 2010]	Happiness, anger, sadness, fear, disgust, neutrality	52 YA, 51 MA, 51 OA	Continuous emotion rating	OA faces were rated as more intense on inaccurate emotions, but as less intense on accurate emotions Own-age effect for happiness and anger Attribution of more inaccurate neutrality, anger, and sadness to OA than YA faces

(Continued)

Table 1 | Continued

Authors	Age-of-face	Stimuli description/database	Target emotions	Observers	Dependent variables	Main age-of-face results
Riediger et al., under review, Study 2	16 YA and 16 OA per smile type	Videos of adults watching amusing film clips (spontaneous smile), or posing smiles	Posed smile, spontaneous smile	48 YA, 49 OA	Multiple choice rating of posed vs. spontaneous positive-affect smile	More frequent attribution of positive-affect smile to OA than YA faces, effect was more pronounced for YA than OA observers Own-age advantage in decoding posed smiles for both YA and OA, and in decoding spontaneous smiles for OA No main effect of facial age on decoding accuracy

YA, younger adults; MA, middle-aged adults; OA, older adults; [1]As Ebner et al. (2013) report identical emotion decoding data to Ebner et al. (2012), the former study is not mentioned in the table.

(Malatesta and Izard, 1984; Magai et al., 2006). However, it is unclear whether these differences are actually due to the participants' age, or whether these are cohort-specific differences. Thus, long-term studies examining several cohorts in different ages would be necessary to follow up this question.

AGE-RELATED CHANGES IN THE FACE

Decoding accuracy for older faces may also be reduced due to age-related changes in the face such as wrinkles and folds (see Albert et al., 2007; Porcheron et al., 2013; for overviews of age-related changes in the face). The wrinkles and folds in the older face may resemble emotional facial expressions and lead to the impression of a permanent affective state (Hess et al., 2008). These background affects may make older adults' facial expressions more ambiguous and reduce the signal clarity (Ebner and Johnson, 2009; Hess et al., 2012). Thus, when emotional expressions were rated on multiple intensity scales for target as well as non-target emotions instead of forced-choice scales, raters attributed less of the target emotions, but more non-target emotions to older faces (Riediger et al., 2011; Hess et al., 2012). Further supporting this account, no age-of-target effects emerged for decoding emotional prosody (Dupuis and Pichora-Fuller, 2011), suggesting that lowered decoding accuracy for older targets may be specific to faces.

These age-related changes in the face may also systematically bias emotional attributions. Hess et al. (2008) suggested that facial expressions and morphological features can have similar effects on emotional attributions ("functional equivalence hypothesis"). Thus, age-related changes in the face may both reduce the signal clarity and bias emotional attributions. Physiognomic features that are frequently found in older faces, such as for example down-turned corners of the mouth may be misinterpreted as emotional expressions. Supporting this assumption, older faces received more sadness attributions than younger faces (Malatesta and Izard, 1984).

However, so far it is unclear whether these effects are due to general aging effects *per se* (e.g., loss of muscle tone) or due to trace emotions (Malatesta et al., 1987a). Interestingly, emotions participants attributed to older senders' neutral expressions were congruent with senders' dominant trait emotions (Malatesta et al., 1987a). Thus, frequently experienced emotions may leave a trace on the face ("habitual emotional expressions"), so that in older age, the neutral expression resembles these emotions. However, to our knowledge, this result has not yet been replicated. Clearly, more research on the relationship between emotionality and age-related changes in the face is needed. Here, long-term studies may constitute a valuable extension of previous research.

EMOTION SCHEMAS

As an alternative explanation for reduced decoding accuracy for older faces, Ebner et al. (2011a) suggested that facial expression prototypes are more likely young faces. The authors argue that emotion schemas may be developed in childhood from the young faces of parents and TV and movie depictions of facial expressions, where older individuals are underrepresented (Signorielli, 2004). Thus, emotion schemas may be better calibrated to decode

Table 2 | Summary of research on age differences in facial expressivity.

Authors	Age-of-face	Emotion induction	Target emotions	Coding system	Other dependent variables	Main results
Kunz et al., 2008	46 YA, 61 OA	Pressure stimulation, electrical stimulation	Pain	FACS (Ekman et al., 1978)	Self-reported pain	No age differences in facial expressions or self-reported pain
Levenson et al., 1991	20 OA, 62 YA	Muscle-by-muscle instruction for posing expressions Reliving biographical episodes	Happiness, anger, sadness, fear, disgust, surprise	FACS (Ekman et al., 1978)	Self-reported experienced emotions ANS activity	OA performed worse than YA when posing facial expressions and experienced the emotions to a lower degree than YA Spontaneous expressions and experiences of target emotions were comparable between YA and OA
Magai et al., 2006	32 YA, 32 MA, 32 OA	Reliving biographical episodes	Anger, sadness	MAX (Izard, 1979)	Self-reported experienced emotions	YA showed more shame, contempt and joy than OA OA showed more knitted brows than YA OA experienced more interest than YA and MA, no age differences for the remaining emotions Greater heterogeneity in experienced emotions in OA than YA, but this was due to age differences in chosen topics
Malatesta and Izard, 1984	10 YA, 10 MA, 10 OA, only females	Reliving biographical episodes	Happiness, anger, sadness, fear, affection	MAX (Izard, 1979)	Self-reported experienced emotions	OA showed more masked, mixed and fragmented partial expressions than YA OA showed more anger and contempt, less sadness than YA No age differences in experienced emotions
Malatesta-Magai et al., 1992	80 YA, 80 OA	Reliving biographical episodes	Anger, sadness, fear, interest, affection	MAX (Izard, 1979)	Self-reported experienced emotions	OA showed more anger, sadness, fear and interest than YA OA experienced more interest, no age differences for the remaining emotions
Tsai et al., 2000	48 YA, 48 OA	Watching emotional film clips	Sadness, amusement	Coding system by Gross and Levenson (1993)	Self-reported experienced emotions Cardiovascular response	No age difference in facial expressions No age difference in experienced emotions Smaller cardiovascular reactions in OA than YA

YA, younger adults; MA, middle-aged adults; OA, older adults.

emotions in younger than older faces. A strong effect of the frequency of contact with faces of specific age groups has been confirmed for face identity recognition (Harrison and Hole, 2009). Furthermore, studies investigating the ability to discriminate among individual faces suggest that early in childhood, perceptual processes become tuned to adult faces as the faces children have been most frequently exposed to since birth (see Macchi Cassia, 2011, for a review). Thus, 3-year old children who had frequent contact with elderly people showed no processing advantage for younger over older adult faces, whereas non-experienced children did (Proietti et al., 2013). However, these processes may still be modulated by experience with faces of different age groups during adulthood (Macchi Cassia, 2011). As not only younger, but also older adults substantially differ in the amount of contact with older people (Wiese et al., 2012), emotion schemas for older faces may still vary in older observers.

Pertaining to decoding accuracy, this explanation still needs empirical investigation. Future studies could examine a sample with frequent contact with older adults during childhood, for example children that grew up in multi-generational homes. If this sample showed less difference in decoding accuracy between younger and older faces than a control group, this would support the hypothesis of less elaborated emotion schemas as an underlying mechanism. Furthermore, the influence of experience with older faces during early and late adulthood may be investigated by examining individuals of varying age and with varying amount of contact with older adults.

ATTITUDES TOWARD OLDER ADULTS

An alternative explanation may be that younger adults are preferred over older adults (Ebner and Johnson, 2009). Although there are both positive and negative elements in age stereotypes (e.g., Hummert et al., 2004; Kornadt and Rothermund, 2011), both younger and older adults showed more positive implicit attitudes (Ebner et al., 2011b) and explicit evaluations (Ebner, 2008) of younger than older faces. In addition, young adults implicitly associated themselves more closely with the concept of being young than old (Wiese et al., 2013b).

Furthermore, as individuals resort on stereotype knowledge about social groups when decoding ambiguous facial expressions of strangers (Hess and Kirouac, 2000), stereotypes may also, just like age-related changes in the face, bias the attribution of emotions. For example, if individuals hold the stereotype of older persons being less satisfied, they may be more prone to attribute sadness and less prone to attribute happiness to an older compared to a younger face. Higher decoding accuracy for emotions corresponding to stereotypes and lower decoding accuracy for emotions contradicting stereotypes may result. This may not that much apply to the posed expressions typically used in emotion decoding studies, which are rather unambiguous, but more to spontaneous expressions that we encounter in everyday life, which can be mixtures of several emotions, or be masked behind socially more desirable emotions. In line with this assumption, for spontaneous expressions, Hühnel et al. (2014) did not replicate the pattern of generally lower decoding accuracy for older faces. Instead, happiness and disgust were more accurately decoded in younger faces, whereas sadness was more accurately decoded in older faces. Also, the previously mentioned result that older faces received more sadness attributions (Malatesta and Izard, 1984) may not only be due to age-related changes in the face, but also to age-related stereotypes. In this vein, observers attributed more pain (Matheson, 1997), but less anger (Malatesta and Izard, 1984) to older faces. In addition, individuals displaying a happy facial expression were perceived as younger than individuals displaying a fearful, angry, disgusted or sad expression (Voelkle et al., 2012). In the same vein, Bzdok et al. (2012) found a negative association between the perceived age and happiness of faces. Although this pattern of results is somewhat mixed, it seems that youth is more likely associated with happiness, whereas older age is more likely associated with sadness.

However, aging stereotypes in emotional domains were not found in explicit measures, possibly because they are socially undesirable. When participants were directly asked to describe "typical" younger and older individuals, relatively neutral stereotypes in social and emotional domains were found (Boduroglu et al., 2006). Also, not all studies using spontaneous expressions found emotion-specific effects of the faces' age on decoding accuracy (Malatesta et al., 1987b; Richter et al., 2011). Furthermore, contradicting the assumed association between youth and happiness, Riediger et al. (under review) found a more frequent attribution of positive emotions to smiles shown by older compared to younger individuals. Clearly, more research is needed, using more subtle or implicit measures for age-related stereotypes, such as IAT (implicit association test), and relating them to attributed emotions.

VISUAL SCAN PATTERNS

There is some evidence that visual scan patterns may differ, depending on the age of the face that is being observed. Specifically, both younger and older observers looked longer at the eye region of older than younger neutral faces, and longer at the mouth region of younger than older neutral faces (Firestone et al., 2007). Considering the above mentioned higher importance of the eye region for expressions of anger, fear, and sadness, and the mouth region for sadness and disgust, one could expect higher decoding accuracy for younger than older faces for disgust and happiness, but not for anger, fear and sadness. However, among the studies examining age-of-face effects on decoding accuracy, only one was in line with this pattern (Hühnel et al., 2014). The majority of previous research found lower decoding accuracy for older faces, independent of the type of expression. Furthermore, other studies found that visual scan patterns were independent of the faces' age (He et al., 2011) or depended on the type of expression (Ebner et al., 2011c). Thus, Ebner et al. (2011c) only confirmed the result of longer looking at the eye region of older than younger faces for expressions of anger. For disgust, the opposite pattern with longer looking at the lower half of older than younger faces was found. There were no age differences for happy, fearful, sad or neutral faces. Thus, the result of different visual scan patterns for younger than older faces may not be generalizable across all facial expressions. In addition, whereas young observers' expression identification of young faces was better the longer they looked at the upper half of faces, older observers' expression identification of young faces was better the longer they looked at the lower half of faces (Ebner et al., 2011c). Thus, the assumption of one visual scan pattern leading to higher accuracy for both younger and older observers and younger and older faces might not always be appropriate.

Considering these mixed results, more research on this topic, relating visual scan patterns for faces with varying age and facial expressions to decoding accuracy is needed to decide whether visual scan patterns may account for age-of-face effects on decoding accuracy. So far, evidence rather contradicts the assumption of visual scan patterns as an underlying mechanism.

NEURAL PROCESSING

To our knowledge, previous EEG studies only examined the neural processing of neutral, but not emotional younger and older faces (e.g., Wiese et al., 2008, 2012; Ebner et al., 2011b; Wolff et al., 2012). These studies revealed that the age of the face influenced both early and late ERP components (Ebner et al., 2011b), suggesting that age already influences early processing stages. For older faces, enlarged amplitudes of the N170, a negative deflection over occipito-temporal sites, have been found (Wiese et al., 2008, 2012), suggesting that structural encoding may be more difficult for older faces. Further, enlarged Late Positive Potentials (LPP, a positive deflection over parietal sites) for older faces suggest more controlled processing of older than younger faces (Ebner et al., 2011b). This latter assumption is further supported by recent fMRI results of greater dmPFC activation for older than younger emotional faces (Ebner et al., 2012). However, so far only very little research on neural processing of younger and older emotional faces has been conducted, allowing no definite conclusion on neural processing as an underlying mechanism. Thus, further research examining the relation of neural processing of emotional younger and older faces to decoding accuracy is needed.

OWN-AGE ADVANTAGE

Apart from the above mentioned main effects of the ages of the observer and the face, age congruence between the observer and the face might influence decoding accuracy as well. As emotions are less accurately decoded in out-group than in-group faces (Thibault et al., 2006) and age is an important social category, one could expect an own-age advantage in face processing.

In line with this assumption, participants tended to look longer at own-age faces and longer looking at own-age faces predicted better own-age expression identification (Ebner et al., 2011c); they were more distracted by own-age faces (Ebner and Johnson, 2010) and fMRI-Studies report different activities for own-age than other-age faces (Wright et al., 2008; Ebner et al., 2011a, 2013), possibly indexing a preference for and more interest in own-age faces. Some EEG-studies report partly comparable own-age and own-race effects on ERPs for neutral faces (Wiese et al., 2008; Ebner et al., 2011b; but see Wiese, 2012; Wiese et al., 2013a, for partly different ERP correlates). Furthermore, several studies found that participants remembered own-age faces better than other-age faces (see Rhodes and Anastasi, 2012, for a meta-analysis). There are two main explanations for this latter finding. Firstly, social cognitive theories suggest that faces of out-group members are cognitively disregarded and more superficially processed than faces of in-group members (Sporer, 2001). Secondly, more experience or contact with members of the own age group may lead to higher perceptual expertise with own-age faces (Rhodes and Anastasi, 2012) and to higher familiarity with the expressive style of the own age group (Malatesta et al., 1987b). So far, evidence is more in line with the latter explanation, as the amount of contact appears to be related to face identity recognition (Harrison and Hole, 2009; Wiese et al., 2012, 2013b; Wolff et al., 2012) and facial expression decoding accuracy (Ebner and Johnson, 2009) of other-age faces. Hugenberg and colleagues (Hugenberg et al., 2010, 2013) suggested an integration of both theories in the Categorization- Individuation Model, which may also be useful to explain the own-age advantage. According to this model, own-group biases may be due to the combined influence of social categorization, the motivation to individuate and perceptual experience (Hugenberg et al., 2010). An overview of possible mechanisms underlying own-age effects on decoding accuracy is given in **Figure 1** (central part).

It is likely to assume that these in-group effects in face processing also influence facial expression decoding. Usually, facial expressions of in-group members are more accurately decoded than expressions of out-group members, even if group membership is manipulated (Thibault et al., 2006; Young and Hugenberg, 2010). In addition, automatic affective responses to other persons' emotional expressions are congruent for ingroup members, but incongruent for outgroup members (Weisbuch and Ambady, 2008). In an early study, Malatesta et al. (1987b) confirmed an own-age advantage in facial expression decoding accuracy. In addition, Riediger et al. (under review) reported an own-age effect on the ability to differentiate between spontaneous and posed smiles. Surprisingly though, the majority of the extant research found no own-age advantage (Borod et al., 2004; Ebner

Box 1 | Questions for future research.

Are age-related dialects for facial expressions due to aging effects *per se* (such as changes in flexibility and controllability of muscle tissue), or due to cohort-specific differences (such as differences in display rules)?
Does the frequency of contact to older adults during childhood and adulthood modulate age-of-face effects on decoding accuracy?
Are age-related changes in facial physiognomic features that resemble certain emotions due to aging effects *per se* (such as loss of muscle tone) or due to frequently experienced emotions, leaving a trace on the face?
Are age-related response biases in emotion decoding tasks related to implicit and explicit stereotypes of aging?
Is the lower decoding accuracy for older faces related to more negative attitudes toward older than younger adults?
Do visual scan patterns differ for younger and older emotional faces? If yes, might this effect explain age-of-face effects on decoding accuracy?
Are age-of-face effects on expression decoding related to differences in neural processing of younger and older emotional faces?
What is the time course of neural processing of age and emotional expression of a face?
Does the age of the target affect emotion decoding in other emotion channels than facial expressions, such as emotional prosody or body language?
Does the lower decoding accuracy for older faces affect the quality of interpersonal interactions and relationships for older adults?

and Johnson, 2009; Murphy et al., 2010; Ebner et al., 2011c, 2012, 2013; Hühnel et al., 2014) or an own-age advantage that was confined to specific emotions (Riediger et al., 2011). Thus, age congruence between the observer and sender of facial expressions seems to play a minor role for facial expression decoding, and the features that are important for identity recognition of faces may not be identical to those that are important for decoding facial expressions (Ebner and Johnson, 2009).

CONCLUSIONS AND FUTURE DIRECTIONS

To sum up, the age of the face seems to play an important role for the interpretation of facial expressions. Posed expressions are less accurately decoded in older compared with younger faces. However, for spontaneous expressions, results are rather mixed. As a possible explanation, older adults are less expressive when posing emotional expressions, but equally expressive when spontaneously showing emotions. Yet at the same time, age stereotypes and age-related changes in physiognomic features of the face may bias the attribution of certain emotions. Contrariwise, age congruence between observer and sender of facial expressions may only play a minor role for expression decoding.

Concerning the underlying mechanisms, more research is needed to decide which of the suggested mechanisms are likely to underlie age-of-face effects on decoding accuracy. Age differences in expressivity are unlikely to be the sole underlying mechanism, as age-of-face effects have also been found when expressivity was controlled for (Hess et al., 2012). Further, previous research rather argues against visual scan patterns as an underlying mechanism. For the remaining mechanisms, i.e., age-related changes in the face, emotion schemas, attitudes toward older adults, and neural processing, more research is needed to judge the applicability of these accounts. It is unlikely to assume only one single mechanism driving age-of-face effects. Rather, multiple mechanisms seem to affect decoding accuracy.

One of the aims of the present review was to outline promising areas of future research. Although several mechanisms have been proposed to underlie age-of-face effects on decoding accuracy, only very little research directly tested the influence of these mechanisms. Thus, in our view, the most important objective for future research in this area will be to directly examine the influence of each of these variables on decoding accuracy for younger and older faces. An overview of some interesting questions for future research is given in **Box 1**. For example, further EEG and fMRI studies would be suited to relate neural processing of younger and older emotional faces to decoding accuracy. In addition, long-term studies on age-related changes in the face and their relation to frequently experienced emotions, and on changes in emotion schemas, which may be related to contact frequency with different age groups, may shed further light on gradual evolvement of these mechanisms. Further research is also needed on the relationship between age-related stereotypes and decoding biases. Furthermore, so far the question whether age-of-target effects are specific for facial expressions, or whether they also emerge in other emotion channels, is not yet fully resolved, as there is only one previous study analyzing age-of-target effects on decoding emotional prosody (Dupuis and Pichora-Fuller, 2011). Finally, future studies may examine whether the lower decoding accuracy for older faces affects the quality of interpersonal interactions and relationships. Thus, we think that exploring age-of-face effects on facial expression decoding and the underlying mechanisms is a promising and interesting area for future research.

ACKNOWLEDGMENTS

This research was supported by grant WE 4836/1-1 from the German Research Foundation.

REFERENCES

Adolphs, R., Gosselin, F., Buchanan, T. W., Tranel, D., Schyns, P., and Damasio, A. R. (2005). A mechanism for impaired fear recognition after amygdala damage. *Nature* 433, 68–72. doi: 10.1038/nature03086

Albert, A. M., Ricanek, K., and Patterson, E. (2007). A review of the literature on the aging adult skull and face: implications for forensic science research and applications. *Forensic Sci. Int.* 172, 1–9. doi: 10.1016/j.forsciint.2007.03.015

Aviezer, H., Bentin, S., Dudarev, V., and Hassin, R. R. (2011). The automacity of emotional face-context integration. *Emotion* 11, 1406–1414. doi: 10.1037/a0023578

Barret, L. F., Mesquita, B., and Gendron, M. (2011). Context in emotion perception. *Curr. Dir. Psychol. Sci.* 20, 286–290. doi: 10.1177/0963721411422522

Bartzokis, G., Cummings, J. L., Sultzer, D., Henderson, V. W., Nuechterlein, K. H., and Mintz, J. (2003). White matter structural integrity in healthy aging adults and patients with Alzheimer disease: a magnetic resonance imaging study. *Arch. Neurol.* 60, 393–398. doi: 10.1001/archneur.60.3.393

Boduroglu, A., Yoon, C., Luo, T., and Park, D. C. (2006). Age-related stereotypes: a comparison of American and Chinese cultures. *Gerontology* 52, 324–333. doi: 10.1159/000094614

Borod, J., Yecker, S., Brickman, A., Moreno, C., Sliwinski, M., Foldi, N., et al. (2004). Changes in posed facial expression of emotion across the adult life span. *Exp. Aging Res.* 30, 305–331. doi: 10.1080/03610730490484399

Bruce, V., and Young, A. (1986). Understanding face recognition. *Br. J. Psychol.* 77, 305–327. doi: 10.1111/j.2044-8295.1986.tb02199.x

Bzdok, D., Langner, R., Hoffstaedter, F., Turetsky, B. I., Zilles, K., and Eickhoff, S. B. (2012). The modular neuroarchitecture of social judgments on faces. *Cereb. Cortex* 22, 951–961. doi: 10.1093/cercor/bhr166

Calder, A. J., Keane, J., Manly, T., Sprengelmeyer, R., Scott, S., Nimmo-Smith, I., et al. (2003). Facial expression recognition across the adult life span. *Neuropsychologia* 41, 195–202. doi: 10.1016/S0028-3932(02)00149-5

Calder, A. J., and Young, A. W. (2005). Understanding the recognition of facial identity and facial expression. *Nat. Rev. Neurosci.*6, 641–651. doi: 10.1038/nrn1724

Calder, A. J., Young, A. W., Keane, J., and Dean, M. (2000). Configural information in facial expression perception. *J. Exp. Psychol. Hum. Percept. Perform.* 26, 527–551. doi: 10.1037/0096-1523.26.2.527

Carstensen, L. L., and Charles, S. T. (1998). Emotion in the second half of life. *Curr. Dir. Psychol. Sci.* 7, 144–149. doi: 10.1111/1467-8721.ep10836825

Carstensen, L. L., and Mikels, J. A. (2005). At the intersection of emotion and cognition—aging and the positivity effect. *Curr. Dir. Psychol. Sci.* 14, 117–121. doi: 10.1111/j.0963-7214.2005.00348.x

Dupuis, K., and Pichora-Fuller, M. K. (2011). Recognition of emotional speech for younger and older talkers: behavioural findings from the toronto emotional speech set. *Canadian Acoustics* 39, 182–183. Available online at: http://jcaa.caa-aca.ca/index.php/jcaa/article/view/2471

Ebner, N. C. (2008). Age of face matters: age-group differences in ratings of young and old faces. *Behav. Res. Methods* 40, 130–136. doi: 10.3758/BRM.40.1.130

Ebner, N. C., Gluth, S., Johnson, M. R., Raye, C. L., Mitchell, K. J., and Johnson, M. K. (2011a). Medial prefrontal cortex activity when thinking about others depends on their age. *Neurocase* 17, 260–269. doi: 10.1080/13554794.2010.536953

Ebner, N. C., He, Y., Fichtenholtz, H. M., McCarthy, G., and Johnson, M. K. (2011b). Electrophysiological correlates of processing faces of younger and older individuals. *Soc. Cogn. Affect. Neurosci.* 6, 526–535. doi: 10.1093/scan/nsq074

Ebner, N. C., He, Y., and Johnson, M. K. (2011c). Age and emotion affect how we look at a face: visual scan patterns differ for own-age versus other-age emotional faces. *Cogn. Emot.* 25, 983–997. doi: 10.1080/02699931.2010.540817

Ebner, N. C., and Johnson, M. K. (2009). Young and older emotional faces: are there age group differences in expression identification and memory? *Emotion* 9, 329–339. doi: 10.1037/a0015179

Ebner, N. C., and Johnson, M. K. (2010). Age-group differences in interference from young and older emotional faces. *Cogn. Emot.* 24, 1095–1116. doi: 10.1080/02699930903128395

Ebner, N. C., Johnson, M. K., and Fischer, H. (2012). Neural mechanisms of reading facial emotions in young and older adults. *Front. Psychol.* 3:223. doi: 10.3389/fpsyg.2012.00223

Ebner, N. C., Johnson, M. R., Rieckmann, A., Durbin, K. A., Johnson, M. K., and Fischer, H. (2013). Processing own-age vs. other-age faces: neuro-behavioral correlates and effects of emotion. *Neuroimage* 78, 363–371. doi: 10.1016/j.neuroimage.2013.04.029

Ebner, N. C., Riediger, M., and Lindenberger, U. (2010). FACES- a database of facial expressions in young, middle-aged, and older women and men: development and validation. *Behav. Res. Methods* 42, 351–362. doi: 10.3758/BRM.42.1.351

Ekman, P., Friesen, W. V., and Ellsworth, P. (1982). "Does the human face provide accurate information?" in *Emotion in the Human Face*, ed P. Ekman (New York, NY: Cambridge University Press), 56–97.

Ekman, P., Friesen, W. V., and Hager, J. C. (1978). *Facial Action Coding System (FACS)*. Palo Alto, California: Consulting.

Firestone, A., Turk-Browne, N. B., and Ryan, J. D. (2007). Age-related deficits in face recognition are related to underlying changes in scanning behavior. *Aging Neuropsychol. Cogn.* 14, 594–607. doi: 10.1080/13825580600899717

Fischer, H., Nyberg, L., and Bäckman, L. (2010). Age-related differences in brain regions supporting successful encoding of emotional faces. *Cortex* 46, 490–497. doi: 10.1016/j.cortex.2009.05.011

Fischer, H., Sandblom, J., Gavazzeni, J., Fransson, P., Wright, C. I., and Bäckman, L. (2005). Age-differential patterns of brain activation during perception of angry faces. *Neurosci. Lett.* 386, 99–104. doi: 10.1016/j.neulet.2005.06.002

Gross, J. J., and Levenson, R. W. (1993). Emotional suppression—physiology, self-report, and expressive behavior. *J. Pers. Soc. Psychol.* 64, 970–986. doi: 10.1037/0022-3514.64.6.970

Gunning-Dixon, F. M., Gur, R. C., Perkins, A. C., Schroeder, L., Turner, T., Turetsky, B. I., et al. (2003). Age-related differences in brain activation during emotional face processing. *Neurobiol. Aging* 24, 285–295. doi: 10.1016/S0197-4580(02)00099-4

Harrison, V., and Hole, G. J. (2009). Evidence for a contact-based explanation of the own-age bias in face recognition. *Psychon. Bull. Rev.* 16, 264–269. doi: 10.3758/PBR.16.2.264

He, Y., Ebner, N. C., and Johnson, M. K. (2011). What predicts the own-age bias in face recognition memory? *Soc. Cogn.* 29, 97–109. doi: 10.1521/soco.2011.29.1.97

Hess, U., Adams, R. B., and Kleck, R. E. (2008). "The devil is in the details: the meanings of faces and how they influence the meanings of facial expressions," in *Affective Computing: Focus on Emotion Expression, Synthesis, and Recognition*, ed J. Or (I-techonline/I-Tech), 45–56. Available online at: http://www.intechopen.com/books/affective_computing/the_devil_is_in_the_details_-_the_meanings_of_faces_and_how_they_influence_the_meanings_of_facial_. doi: 10.5772/6187

Hess, U., Adams, R. B. J., Simard, A., Stevenson, M. T., and Kleck, R. E. (2012). Smiling and sad wrinkles: age-related changes in the face and the perception of emotions and intentions. *J. Exp. Soc. Psychol.* 48, 1377–1380. doi: 10.1016/j.jesp.2012.05.018

Hess, U., and Kirouac, G. (2000). "Emotion expression in groups," in *Handbook of Emotions*, ed M. Lewis (New York, NY: Guilford Press), 368–381.

Hugenberg, K., Wilson, J. P., See, P. E., and Young, S. G. (2013). Towards a synthetic model of own group biases in face memory. *Vis. Cogn.* 21, 1392–1417. doi: 10.1080/13506285.2013.821429

Hugenberg, K., Young, S. G., Bernstein, M. J., and Sacco, D. F. (2010). The categorization-individuation model: an integrative account of the other-race recognition deficit. *Psychol. Rev.* 117, 1168–1187. doi: 10.1037/a0020463

Hühnel, I., Fölster, M., Werheid, K., and Hess, U. (2014). Empathic reactions of younger and older adults: no age related decline in affective responding. *J. Exp. Soc. Psychol.* 50, 136–143. doi: 10.1016/j.jesp.2013.09.011

Hummert, M. L., Garstka, T. A., Ryan, E. B., and Bonnesen, J. L. (2004). "The role of age stereotypes in interpersonal communication," in *Handbook of Communication and Aging Research, 2nd Edn,* eds J. F. Nussbaum and J. Coupland (Mahwah, NJ: Lawrence Erlbaum), 91–114.

Isaacowitz, D. M., Löckenhoff, C. E., Lane, R. D., Wright, R., Sechrest, L., Riedel, R., et al. (2007). Age differences in recognition of emotion in lexical stimuli and facial expressions. *Psychol. Aging* 22, 147–159. doi: 10.1037/0882-7974.22.1.147

Isaacowitz, D. M., and Stanley, J. T. (2011). Bringing an ecological perspective to the study of aging and recognition of emotional facial expressions: past, current, and future methods. *J. Nonverbal Behav.* 35, 261–278. doi: 10.1007/s10919-011-0113-6

Izard, C. E. (1979). *The Maximally Discriminitive Facial Movements Coding System, MAX*. Newark, DE: University of Delaware.

Jack, C. R., Petersen, R. C., Xu, Y. C., Waring, S. C., O'Brien, P. C., Tangalos, E. G., et al. (1997). Medial temporal atrophy on MRI in normal aging and very mild Alzheimer's disease. *Neurology* 49, 786–794. doi: 10.1212/WNL.49.3.786

Kaufmann, J. M., and Schweinberger, S. R. (2004). Expression influences the recognition of familiar faces. *Perception* 33, 399–408. doi: 10.1068/p5083

Keightley, M. L., Chiew, K. S., Winocur, G., and Grady, C. L. (2007). Age-related differences in brain activity underlying identification of emotional expressions in faces. *Soc. Cogn. Affect. Neurosci.* 2, 292–302. doi: 10.1093/scan/nsm024

Kornadt, A. E., and Rothermund, K. (2011). Contexts of aging: assessing evaluative age stereotypes in different life domains. *J. Gerontol. B Psychol. Sci. Soc. Sci.* 66, 547–556. doi: 10.1093/geronb/gbr036

Kunz, M., Mylius, V., Schepelmann, K., and Lautenbacher, S. (2008). Impact of age on the facial expression of pain. *J. Psychosom. Res.* 64, 311–318. doi: 10.1016/j.jpsychores.2007.09.010

Lambrecht, L., Kreifelts, B., and Wildgruber, D. (2012). Age-related decrease in recognition of emotional facial and prosodic expressions. *Emotion* 12, 529–539. doi: 10.1037/a0026827

Levenson, R. W., Carstensen, L. L., Friesen, W. V., and Ekman, P. (1991). Emotion, physiology, and expression in old age. *Psychol. Aging* 6, 28–35. doi: 10.1037/0882-7974.6.1.28

Macchi Cassia, V. (2011). Age biases in face processing: the effects of experience across development. *Br. J. Psychol.* 102, 816–829. doi: 10.1111/j.2044-8295.2011.02046.x

Magai, C., Consedine, N. S., Krivoshekova, Y. S., Kudadjie-Gyamfi, E., and McPherson, R. (2006). Emotion experience and expression across the adult life span: insights from a multimodal assessment study. *Psychol. Aging* 21, 303–317. doi: 10.1037/0882-7974.21.2.303

Malatesta, C. Z., Fiore, M. J., and Messina, J. J. (1987a). Affect, personality, and facial expressive characteristics of older people. *Psychol. Aging* 2, 64–69. doi: 10.1037/0882-7974.2.1.64

Malatesta, C. Z., Izard, C. E., Culver, C., and Nicolich, M. (1987b). Emotion communication skills in young, middle-aged, an older women. *Psychol. Aging* 2, 193–203. doi: 10.1037/0882-7974.2.2.193

Malatesta, C. Z., and Izard, C. E. (1984). "The facial expression of emotion: young, middle-aged, and older adult expressions," in *Emotion in Adult Development*, eds C. Z. Malatesta and C. E. Izard (London: Sage Publications), 253–273.

Malatesta-Magai, C., Jonas, R., Shepard, B., and Culver, L. C. (1992). Type A behavior pattern and emotion expression in younger and older adults. *Psychol. Aging* 7, 551–561. doi: 10.1037/0882-7974.7.4.551

Mather, M., and Carstensen, L. L. (2003). Aging and attentional biases for emotional faces. *Psychol. Sci.* 14, 409–415. doi: 10.1111/1467-9280.01455

Matheson, D. H. (1997). The painful truth: interpretation of facial expressions of pain in older adults. *J. Nonverbal Behav.* 21, 223–238. doi: 10.1023/A:1024973615079

Minear, M., and Park, D. C. (2004). A lifespan database of adult facial stimuli. *Behav. Res. Methods Instrum. Comput.* 36, 630–633. doi: 10.3758/BF03206543

Montepare, J., Koff, E., Zaitchik, D., and Albert, M. (1999). The use of body movements and gestures as cues to emotions in younger and older adults. *J. Nonverbal Behav.* 23, 133–152. doi: 10.1023/A:1021435526134

Murphy, F. C., Nimmo-Smith, I., and Lawrence, A. D. (2003). Functional neuroanatomy of emotions: a meta-analysis. *Cogn. Affect. Behav. Neurosci.* 3, 207–233. doi: 10.3758/CABN.3.3.207

Murphy, N. A., Lehrfeld, J. M., and Isaacowitz, D. M. (2010). Recognition of posed and spontaneous dynamic smiles in young and older adults. *Psychol. Aging* 25, 811–821. doi: 10.1037/a0019888

Phan, K. L., Wager, T., Taylor, S. F., and Liberzon, I. (2002). Functional neuroanatomy of emotion: a meta-analysis of emotion activation studies in PET and fMRI. *Neuroimage* 16, 331–348. doi: 10.1006/nimg.2002.1087

Phillips, L. H., MacLean, R. D. J., and Allen, R. (2002). Age and the understanding of emotions: neuropsychological and sociocognitive perspectives. *J. Gerontol. B. Psychol. Sci. Soc. Sci.* 57, P526–P530. doi: 10.1093/geronb/57.6.P526

Porcheron, A., Mauger, E., and Russell, R. (2013). Aspects of facial contrast decrease with age and are cues for age perception. *PLoS ONE* 8:e57985. doi: 10.1371/journal.pone.0057985

Proietti, V., Pisacane, A., and Macchi Cassia, V. (2013). Natural experience modulates the processing of older adult faces in young adults and 3-year-old children. *PLoS ONE* 8:e57499. doi: 10.1371/journal.pone.0057499

Raz, N. (2000). "Aging of the brain and its impact on cognitive performance: integration of structural and functional findings," in *The Handbook of Aging and Cognition, 2nd Edn*, eds F. I. M. Craik and T. A. Salthouse (Mahwah, NJ: Lawrence Erlbaum), 1–90.

Rhodes, M. G., and Anastasi, J. S. (2012). The own-age bias in face recognition: a meta-analytic and theoretical review. *Psychol. Bull.* 138, 146–174. doi: 10.1037/a0025750

Richter, D., Dietzel, C., and Kunzmann, U. (2011). Age differences in emotion recognition: the task matters. *J. Gerontol. B Psychol. Sci. Soc. Sci.* 66, 48–55. doi: 10.1093/geronb/gbq068

Riediger, M., Voelkle, M. C., Ebner, N. C., and Lindenberger, U. (2011). Beyond "happy, angry, or sad?" Age-of-poser and age-of-rater effects on multi-dimensional emotion perception. *Cogn. Emot.* 25, 968–982. doi: 10.1080/02699931.2010.540812

Ruffman, T., Halberstadt, J., and Murray, J. (2009a). Recognition of facial, auditory, and bodily emotions in older adults. *J. Gerontol. B Psychol. Sci. Soc. Sci.* 64, 696–703. doi: 10.1093/geronb/gbp072

Ruffman, T., Sullivan, S., and Dittrich, W. (2009b). Older adults' recognition of bodily and auditory expressions of emotion. *Psychol. Aging* 24, 614. doi: 10.1037/a0016356

Ruffman, T., Henry, J. D., Livingstone, V., and Phillips, L. H. (2008). A meta-analytic review of emotion recognition and aging: implications for neuropsychological models of aging. *Neurosci. Biobehav. Rev.* 32, 863–881. doi: 10.1016/j.neubiorev.2008.01.001

Ruffman, T., Murray, J., Halberstadt, J., and Vater, T. (2012). Age-related differeces in deception. *Psychol. Aging* 27, 543–549. doi: 10.1037/a0023380

Schweinberger, S. R., and Soukup, G. R. (1998). Asymmetric relationships among perceptions of facial identity, emotion, and facial speech. *J. Exp. Psychol. Hum. Percept. Perform.* 24, 1748–1765. doi: 10.1037/0096-1523.24.6.1748

Schyns, P. G., and Oliva, A. (1999). Dr. Angry and Mr. Smile: when categorizazion flexibly modifies the perception of faces in rapid visual presentations. *Cognition* 69, 243–265. doi: 10.1016/S0010-0277(98)00069-9

Signorielli, N. (2004). Aging on television: messages relating to gender, race, and occupation in prime time. *J. Broadcast. Electron. Media* 48, 279–301. doi: 10.1207/s15506878jobem4802_7

Slessor, G., Miles, L. K., Bull, R., and Phillips, L. H. (2010). Age-related changes in detecting happiness: discriminating between enjoyment and nonenjoyment smiles. *Psychol. Aging* 25, 246–250. doi: 10.1037/a0018248

Sporer, S. L. (2001). Recognizing faces of other ethnic groups: an integration of theories. *Psychol. Pub. Policy Law* 7:36. doi: 10.1037/1076-8971.7.1.36

Sullivan, S., Ruffman, T., and Hutton, S. B. (2007). Age differences in emotion recognition skills and the visual scanning of emotion faces. *J. Gerontol. B Psychol. Sci. Soc. Sci.* 62, P53–P60. doi: 10.1093/geronb/62.1.P53

Suzuki, A., Hoshino, T., Shigemasu, K., and Kawamura, M. (2007). Decline or improvement? Age-related differences in facial expression recognition. *Biol. Psychol.* 74, 75–84. doi: 10.1016/j.biopsycho.2006.07.003

Taler, V., Baum, S., and Saumier, D. (2006). "Perception of linguistic and affective prosody in younger and older adults," in *Paper presented at the Twenty-eighth Annual Conference of the Cognitive Science Society*, (Vancouver), 2216–2221.

Thibault, P., Bourgeois, P., and Hess, U. (2006). The effect of group-identification on emotion recognition: the case of cats and basketball players. *J. Exp. Soc. Psychol.* 42, 676–683. doi: 10.1016/j.jesp.2005.10.006

Tsai, J. L., Levenson, R. W., and Carstensen, L. L. (2000). Autonomic, subjective, and expressive responses to emotional films in older and younger Chinese Americans and European Americans. *Psychol. Aging* 15, 684–693. doi: 10.1037/0882-7974.15.4.684

Voelkle, M. C., Ebner, N. C., Lindenberger, U., and Riediger, M. (2012). Let me guess how old you are: effects of age, gender, and facial expression on perceptions of age. *Psychol. Aging* 27, 265–277. doi: 10.1037/a0025065

Weisbuch, M., and Ambady, N. (2008). Affective divergence: automatic responses to others' emotions depend on group membership. *J. Pers. Soc. Psychol.* 95, 1063–1079. doi: 10.1037/a0011993

Wiese, H. (2012). The role of age and ethnic group in face recognition memory: ERP evidence from a combined own-age and own-race bias study. *Biol. Psychol.* 89, 137–147. doi: 10.1016/j.biopsycho.2011.10.002

Wiese, H., Komes, J., and Schweinberger, S. R. (2012). Daily-life contact affects the own-age bias and neural correlates of face memory in elderly participants. *Neuropsychologia* 50, 3496–3508. doi: 10.1016/j.neuropsychologia.2012.09.022

Wiese, H., Komes, J., and Schweinberger, S. R. (2013a). Ageing faces in ageing minds: a review on the own-age bias in face recognition. *Vis. Cogn.* 21, 1337–1363. doi: 10.1080/13506285.2013.823139

Wiese, H., Wolff, N., Steffens, M. C., and Schweinberger, S. R. (2013b). How experience shapes memory for faces: an event-related potential study on the own-age bias. *Biol. Psychol.* 94, 369–379. doi: 10.1016/j.biopsycho.2013.07.001

Wiese, H., Schweinberger, S. R., and Hansen, K. (2008). The age of the beholder: ERP evidence of an own-age bias in face memory. *Neuropsychologia* 46, 2973–2985. doi: 10.1016/j.neuropsychologia.2008.06.007

Williams, L. M., Brown, K. J., Palmer, D., Liddell, B. J., Kemp, A. H., Olivieri, G., et al. (2006). The mellow years? Neural basis of improving emotional stability over age. *J. Neurosci.* 26, 6422–6430. doi: 10.1523/JNEUROSCI.0022-06.2006

Wolff, N., Wiese, H., and Schweinberger, S. R. (2012). Face recognition memory across the adult life span: event-related potential evidence from the own-age bias. *Psychol. Aging* 27, 1066–1081. doi: 10.1037/a0029112

Wong, B., Cronin-Golomb, A., and Neargarder, S. (2005). Patterns of visual scanning as predictors of emotion identification in normal aging. *Neuropsychology* 19, 739–749. doi: 10.1037/0894-4105.19.6.739

Wright, C. I., Negreira, A., Gold, A. L., Britton, J. C., Williams, D., and Barrett, L. F. (2008). Neural correlates of novelty and face-age effects in young and elderly adults. *Neuroimage* 42, 956–968. doi: 10.1016/j.neuroimage.2008.05.015

Young, S. G., and Hugenberg, K. (2010). Mere social categorization modulates identification of facial expressions of emotion. *J. Pers. Soc. Psychol.* 99, 964–977. doi: 10.1037/a0020400

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 29 October 2013; paper pending published: 10 January 2014; accepted: 10 January 2014; published online: 04 February 2014.

Citation: Fölster M, Hess U and Werheid K (2014) Facial age affects emotional expression decoding. Front. Psychol. ***5****:30. doi: 10.3389/fpsyg.2014.00030*

This article was submitted to Emotion Science, a section of the journal Frontiers in Psychology.