ADAPTIVE HOT COGNITION: HOW EMOTION DRIVES INFORMATION PROCESSING AND COGNITION STEERS AFFECTIVE PROCESSING

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ADAPTIVE HOT COGNITION: HOW EMOTION DRIVES INFORMATION PROCESSING AND COGNITION STEERS AFFECTIVE PROCESSING

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Influential theories have argued that affective processing is fundamentally different from cognitive processing. Others have suggested that theoretical boundaries between affective and cognitive processing are artificial and inherently problematic. Over recent years, different positions on these issues have fueled many empirical studies investigating the mechanisms underlying cognitive and affective processing. Where and on what basis should we draw the line between cognition and emotion? Are there fundamental distinctions to be made between the way emotion influences cognition and cognition influences emotion? How does the reciprocal interaction between emotion and cognition lead to adaptive behavior? This Research Topic explores the nature of the reciprocal interaction between emotion and cognition from a functional perspective.

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EDITORIAL
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Editorial: Adaptive Hot Cognition: How Emotion Drives Information Processing and Cognition Steers Affective Processing

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Editorial on the Research Topic

Adaptive Hot Cognition: How Emotion Drives Information Processing and Cognition Steers Affective Processing

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INTRODUCTION

Efficiently regulating our emotions can have important consequences for our survival. Whereas some situations ask for immediate action with no room left for doubts, such as when a fast-moving car is about to bump you from your bike at an intersection, other situations ask for careful consideration and reflection, such as when deciding whether to stop the life support of a beloved one. Both situations involve a life that is at risk, intense feelings and emotions and also demand a decision, albeit they cover very different timespans and differ on many other aspects as well. The current special issue includes 17 unique contributions and integrates different viewpoints on fundamental issues in the interaction between affect and cognition, gathering both empirical and theoretical contributions based on various approaches and methodologies from disciplines including cognitive psychology, social psychology, psychophysiology and neuroeconomics.

Many of the contributions we received included experimental studies where emotional manipulations were intertwined with social processes including the perception of emotions from another person or the effect of emotions on social decisions such as choosing to trust or cooperate with someone or instead pursue ones own goals and maximize personal gains. For social species like humans, effectively communicating emotions and intentions and recognizing emotion signals from others and subsequently responding with the appropriate behavior, is of pivotal importance for a healthy social life (Kret and Ploeger, 2015). Not surprisingly, most of our emotions can be associated with social events and/or decisions and this is thus clearly reflected in this special issue as well. For example, in their contribution, de Valk et al. demonstrated that being confronted with another person's facial or bodily expressions of emotion, and anger in particular, yielded faster actions in observers. This work builds on the early work by Nico Frijda, showing that all emotions are closely linked to action tendencies. He postulated that in order to attempt to better understand emotions, we should study actions rather than cognitions, feelings or emotions (i.e., Frijda et al., 1989). Although all emotions link to actions, the links for some emotions are stronger than for others. Because threatening signals are thoroughly processed (Williams et al., 2006) and rapidly detected (Hansen and Hansen, 1988; Öhman et al., 2001; Pinkham et al., 2010), they prepare for greater action preparedness (Schutter et al., 2008; Van Loon et al., 2010; Borgomaneri et al., 2014) and for quick actions (Coombes et al., 2005). As is shown in the article by de Valk et al. this is the case when processing another's facial and bodily expressions alike. Although action preparedness has traditionally been conceptualized in terms of the contrast between defensive compared to appetitive motivational tendencies, Bouman et al. demonstrate the generality of emotional influences on goal-directed action in an investigation of whole-body movement initiation in reaction to emotional pictures. They found that high arousal pictures have similar effects on forward gait initiation, independent of the valence of the picture content, which suggests that arousal is a crucial factor in explaining the link between emotion and action.

Expressions of emotion are readily picked up by observers and possibly, the mimicry of these emotional expressions might improve that even further, as Kret (2015) outlines in a review article included in this special issue. She states that, when people unconsciously mimic their interaction partner's expressions of emotion, they come to feel reflections of those companions' emotions, which in turn influence the observer's own emotional and empathic behavior. Whereas the majority of previous research focused on facial actions as expressions of emotion, this article includes research on emotion signals from sources beyond the face muscles that are more automatic and difficult to control. For example, the perception of implicit sources such as gaze and tears and autonomic responses such as pupil-dilation, eyeblinks and blushing are all very subtle reflections of a person's inner state of mind, yet they are visible to observers and because they can hardly be controlled or regulated by the sender, they have the potential to provide important "veridical" information. Interestingly, evidence is accumulating that these kinds of expressions, such as for example observing someone's pupils dilate during eye contact, without people being aware of them, do have profound effects on social decisions that people make including whether to trust someone or not (Kret et al., 2015). Interestingly, the automatic pick-up of facial and postural emotion has become a topic of increasing interest in the literature on persuasion through emotion in advertising. In their contribution, Lewinski et al. integrate the existing evidence and propose that people can resist persuasion by controlling their facial expression of emotion when exposed to an advertisement, which shows its viability as a novel and effective strategy to counteract attempts at persuasion.

Arousal, whether evoked by looking someone deeply in the eyes (Kret et al., 2015) or by hearing a frightening sound (Lee et al.) has a strong impact on emotional and cognitive processes and can have a profound positive impact on memory as well. As mentioned before, emotional information receives preferential processing, facilitating adaptive strategies for survival. But in addition, the presence of emotional stimuli and the associated arousal modify the processing of surrounding non-emotional information (Mather and Sutherland, 2011). As in the example with the biking incident described in the beginning, it is very possible that the next day at the intersection, you will be more cautious or without realizing why, even take a detour. Intriguingly, these types of decisions that are often considered "rational" can thus be driven or at least colored by unconscious affective processes. Drawing from findings from behavioral economics and neuroeconomics, Luo and Yu (2015) propose a new model of emotion and reason in decision making, which focusses on identifying factors explaining when emotions help or hurt decision making depending on the type of contexts in emotions occur. That our decisions are not always as rational as we think, even in situations that are relatively risky and where monetary gains and losses are at stake, became even more evident in an experiment by Markiewicz and Kubińska. In their study, authors provided important insights into information processing differences between affective and deliberate risk taking decisions during a card game. Specifically, they show that in a "hot" version of the Columbia Card Task, emotion interferes with correct information processing because it impairs the engagement of effortful, rule-based processes which require working memory resources. In addition, their article discusses benefits and pitfalls of different versions of the Columbia Card Task, which can benefit future studies in further disentangling affective and cognitive processing.

Markiewicz and Kubińska did not study individual differences, but if they had done so, as Steimke et al. did, they could perhaps have observed that some individuals are more prone to be put off track by emotional events than others. Especially self-control, or, the ability to exert control over ones impulses can help endure aversion, resist temptations and ignore distractions, as shown by the study by Steimke et al. Also, investigating individual differences, Zhang et al. showed that test-anxious students showed a significant deficit in executive attention when they were faced with emotional distracters, which is consistent with the idea that emotional distraction depends on an interaction between dispositional and situational factors. Over the past years, a large body of research has focused on the neural systems underlying our capacity to regulate our emotions by reappraising emotional events. Indeed, individuals may use different emotion regulation skills to modulate their spontaneous reactions. In their meta-analysis of 21 recent neuro-imaging studies Messina et al. (2015) found that modulation of neural activity not only of executive but also semantic networks may be critical for emotion regulation through reappraisal.

In this special issue, several contributions investigated emotion-cognition interactions by examining social decisions in games, such as the Ultimatum Game, Cyberball Game, Trust Game and even Tetris. For example, Ruissen and de Bruijn compared the effect of playing a cooperative vs. competitive Tetris game on a subsequent social Simon task, which measured the extent of self-other integration of action representations. Less self-other integration was observed in participants who had previously played a competitive game, compared to cooperative or solo versions of the game, which shows that the nature of the social relation between actors is sufficient to modulate social action representations. Cerit et al. (2015) used the Ultimatum Game to investigate the effect of prolonged tryptophan supplementation (a precursor of serotonin) on social cognition. Given that previous experimental manipulations indicated that serotonin increases pro-social perception, they expected to find that the supplement would lead to less rejection of unfair offers during the game. In contrast to this, however, they observed that increasing serotonin availability actually *increased* the rejection of very unfair offers, which suggests that the effects of acute vs. prolonged boosting of serotonin may have opposite effects on social cognition. Sellaro et al. (2015) also used a game setting to study the interaction between emotion and cognition. Participants in their study were exposed to social exclusion or ostracism, by observing someone else getting socially excluded. Previous research had already shown that both being ostracized and observing ostracism of another person activates the insula and the prefrontal cortex (PFC) (Dietrich et al., 2008; Kraus et al., 2013). In their experiment, Sellaro et al. investigated a putative relationship between insula-PFC activity and prosocial helping behavior toward an ostracized person during a Cyberball game. By using transcutaneous Vagus Nerve Stimulation (tVNS) they stimulated the vagus nerve and hence, indirectly boosted insula and PFC activation. In contrast to what they expected, applying tVNS did not modulate reactions to vicarious ostracism. It is always hard to interpret null-findings, yet publishing these results is of pivotal importance in order to avoid publication bias and to provide valuable insights that are helpful in designing future experiments and the authors did indeed make useful suggestions in that direction in their discussion of the results. Three of the authors involved in this study additionally wrote a second article in this issue where they discuss the effects of yet another manipulation on helping behavior (Steenbergen et al., 2015). In this study, their manipulation worked, and they showed that charitable donating could be promoted by administering the food supplement L-Tryptophan, the biochemical precursor of serotonin. Once again, it turns out that our decisions are often not rationally taken at all and this study shows that the food we eat can alter the way we think about charity and foster helping behavior. In a third study, two of the authors of the previous study performed an experiment investigating the effect of an environmental factor (an arousing "peppermint" vs. a calming "lavender" olfactory fragrance) on social interactions while performing the Trust Game (Sellaro et al., 2015). In this game, participants can transfer money to an alleged trustee in order to index interpersonal trust. Interestingly, the authors observed an increase in the money transferred due to the calming fragrance, which, consistent with the previously mentioned study, suggests that social decisions can be influenced by domain-general cognitive-control states.

In the above discussed literature, the social and emotional component were often intertwined. Whether seeing someone else's emotions, feeling another's pain whilst being excluded by others or considering another's potential monetary losses, these experiences all impact on our immediate and future behavior and decisions. That said, sometimes emotions can be triggered by very basic non-social events as well. In their study, Lu et al. investigated the affective cues present in naturalistic scenes. From an evolutionary perspective, natural scenes provide important information for observers that help them to keep safe. As is the case with social emotional cues, it is therefore also adaptive for individuals to efficiently extract such non-social information from the environment. By using a psychophysical approach and signal detection theory, authors investigated how contrast and color modulated fearfulness ratings of images of natural scenes and in order to stimulate future research, developed a fearful stimulus set including a wide range of fearfulness levels which can be controlled on a range of low-level properties. In another psychophysical study, Li and Yuen investigated a time-drag effect when participants are presented with dynamically changing sequences of facial expressions. They observed that dynamic stimulus presentations of facial expressions induced an overestimation of perceived duration, whereas overall, static presentations did not. Although this effect was observed for different expressions, it was most pronounced in angry expressions, which demonstrates that affective modulations are not only present in the spatial domain of visual perception, but extend to the temporal domain as well.

CONCLUSION

The wide-range of contributions included in this special issue underscore the general conclusion that emotion plays an important role in many diverse areas of cognition including social interactions, motivational behavior, decision-making, memory, attention and perception (Dolan, 2002). From a functional point of view, the pervasiveness of emotion-cognition interactions should not be surprising considering that the underlying biological systems have presumably been continuously shaped by evolution in such a way as to promote adaptive behavior in situations that are relevant for survival or reproduction (Kret, 2015). Another key conclusion concerning the relationship between cognition and emotion that has been emerging in the field and that has been corroborated in this special issue, is that it is probably counterproductive to try to separate them (Pessoa, 2008). Instead, current thinking emphasizes their interdependence in ways that challenge a simple division of labor into separate cognitive and emotional domains and instead views the two domains as two sides of the same coin (Bocanegra, in press). We hope that bringing together this wide range of contributions increased the understanding of how emotion drives information processing and cognition steers affective processing and that the empirical evidence and theoretical ideas brought up new questions in readers and will continue to uncover exciting new avenues for future research.

AUTHOR CONTRIBUTIONS

BB and MK conceived of the special issue and wrote the manuscript in close collaboration. We declare no conflict of interest.

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Embodied Resistance to Persuasion in Advertising

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From the literature on resistance to persuasion in advertising, much is known about how people can resist advertising by adopting resistance strategies, such as avoidance, counter-arguing, and selective attention (e.g., Fransen et al., 2015b). However, the role of emotion regulation and bodily expression in resisting persuasion is so far underexplored. This is a surprising observation if one considers that at least 40% of advertisements use positive emotions (i.e., happiness) to persuade people to like the ad, brand, and product (Weinberger et al., 1995). In this article we present a framework in which we apply previous knowledge and theories on emotion regulation and embodiment to the process of resistance to persuasion. In doing so, we specifically address the role of facial expression in the course of resistance. The literature and findings from our own research lead us to propose that people can resist persuasion by controlling their facial expression of emotion when exposed to an advertisement. Controlling the expression of emotions elicited by an ad (for example refusing to smile) might be a fruitful way to resist the ad's persuasive potential. Moreover, we argue that co-viewers can affect embodied resistance to persuasion. Showing the viability of embodied resistance to persuasion is relevant in view of the fact that ads trying to persuade us by addressing our positive emotions are ubiquitous. Embodied resistance might help people to cope with these induced positive emotions in order to resist advertisements and might therefore work as a novel and effective strategy to resist persuasion.

Keywords: resistance to persuasion, embodied emotion regulation, facial expression, consumer behavior, enjoyable advertisements

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INTRODUCTION AND OVERVIEW

When we think about persuasion in a consumer context, we often think about advertising. This is a justified association because advertising is a powerful and lucrative persuasion tool with revenues forecasted to grow to $536 billion worldwide in 2015 (Magna Global, 2014). Advertisements often serve to increase consumption without consideration given to the needs of prospective buyers. Therefore, many observers have raised significant concerns about the potentially undesirable effects of advertising and the persuasive tactics that marketers use to engage audiences (Boush et al., 1994; Calfee and Ringold, 1994; Darke and Ritchie, 2007). People sometimes believe that brands provide them with dishonest or distorted messages in their advertisements and feel inclined to stand up to these practices. They thus seem to desire control over whether or not they are persuaded by media and advertising. Although people may know that marketers create ads designed to influence their behavior (Friestad and Wright, 1994; Wright et al., 2005), some persuasion tactics nevertheless pose a distinct challenge. Therefore, some may want more tools in their repertoire to resist these types of advertisements.

The present paper is inspired by the apparent inequity between research on the effectiveness of advertisements on the one hand, and the limited amount of research on the tools to resist them on the other. From the perspective of emotion, many strategies that people use to resist persuasion are quite broad. Marketers, meanwhile, deftly play on specific emotions in their ads. Therefore, aiming resistance at emotions that are often used in advertising is important. In other words, a productive line of inquiry might lead to ways of helping people to cope with (positive) emotions used to elicit behaviors beneficial to marketers. We therefore endeavor to uncover concrete tactics for dealing with specific emotions like happiness in the service of resisting persuasive advertisements.

In the following sections, we begin with a summary of the usage and effects of enjoyable advertisements as a persuasive tool, followed by a discussion of resistance toward persuasion. Next, we present our propositions regarding embodied resistance to persuasion grounded in the specific context of advertising and we provide first empirical support for these from studies conducted in our own lab. Finally, we discuss the framework's implication for the theory and practice of persuasive communication and its relation to existing models.

ENJOYABLE ADVERTISEMENTS

The use of enjoyable advertisements is omnipresent; about 40% of all advertising is intended to be enjoyable and humorous (Weinberger et al., 1995). Amusing advertisements can be defined as "all forms of smile-inducing stimuli" that are persuasive and designed to induce attitude change (Duncan, 1979, p. 302). Amusement in advertisements has proven highly effective in shaping people's attitudes toward promoted products. Eisend's (2011) meta-analytic test of humor in advertising credits affect with a more primary role than cognition. Eisend specifically proposes that humor enhances "hot" cognitions in general (where positive cognition outweighs negative cognition) and reduces negative cognitions through distraction effects. Humor may also evoke generic positive responses (Gulas and Weinberger, 2006) and lead to transfer of affect through evaluative conditioning (De Houwer et al., 2001). By employing humor, amusing advertisements enhance many of the typically studied outcome variables in advertising research. Eisend (2009) concluded in his overview and meta-analysis of the effects of humor in advertising that the use of humor, in general, enhances attitudes toward the ad, positive affect, attention, cognitive positive responses, and recognition. Since positive emotions and humor are used extensively in advertising and often result in positive effects from the perspective of marketers, it is pertinent to focus on diminishing the effects of amusement and humor when motivated to resist persuasion.

RESISTANCE TO PERSUASION

We define resistance to persuasion as a usually motivated attempt to withstand persuasive attacks, conforming to the use of the concept by other researchers (e.g., Zuwerink and Cameron, 2003). Much is known from the literature regarding the strategies people employ to resist persuasion. Fransen et al. (2015b) recently proposed three types of resistance – avoidance, contesting, and empowering – to categorize the strategies adopted by people to resist the effects of advertising. Avoidance strategies consist of avoiding the ad altogether or only paying attention to those parts of a message that confirm existing beliefs. Contesting strategies entail a set of approaches that actively counter specific elements of the ad (e.g., counter arguing, source derogation, message derogation), while empowerment strategies focus on confirming existing attitudes (e.g., attitude bolstering and social validation). Fransen et al. (2015a) have then latter added one more type, biased processing, which refers to processing a message in such way that it fits existing attitudes and behavior or reduces it's relevance. Further, Kirmani and Campbell (2004) and Knowles and Linn (2004) proposed their own frameworks of resistance to persuasion, which we will not review here as we chose to present the most recent conceptualizations, i.e., Fransen et al. (2015a,b).

What is relevant for our reasoning here is that none of these frameworks and proposed strategies deals specifically with resisting the positive *emotional* or *affective* responses that are often elicited by advertisements and have been found to increase persuasion. Because the use of positive emotions in ads is ubiquitous and effective, the study of how consumers can resist persuasion by focusing on the emotions in the ad is clearly worthwhile.

Emotions and Embodiment in Regulation for Resistance

Although researchers know that marketers try to persuade people by using positive emotions, there is insufficient knowledge on how to resist these kinds of ads. Companies use amusing ads to influence us, and more to the point, to make us smile with enjoyment, which may subsequently results in persuasion. On this account, we propose that consumers might protect themselves against advertising's effects by "resisting" specific emotions that ads induce as part of their persuasive potential. They might accomplish this resistance by regulating their emotions when exposed to an ad (e.g., not smiling) away from the effects targeted by the ad. The literature supports the assumption that emotion regulation may find a viable starting point in the bodily expression of emotion, as we will argue below.

In a special issue on embodiment, Krishna and Schwarz (2014) presented recent findings demonstrating that people's attitudes and intentions are often embodied, at least partially. The implication is that the body plays a role in making up people's minds. Bodily states or changes in bodily states serve as sources of information when forming attitudes and intentions (Herbert and Pollatos, 2012). In the context of advertising, embodiment means that people smile at an amusing ad and interpret the related feelings of happiness as information to evaluate the ad and the promoted product. In other words, smiling at an ad causes us to like it more. When seeking to resist ads of this type, self-regulating this almost reflexive smiling response might ultimately reduce liking for the ad. We propose that people can resist advertising effects through modulating their "default" bodily response to the ad, including emotions targeted by the ad and the ensuing attitudes. We will refer to this process as embodied resistance to persuasion.

Moreover, the literature on persuasion and resistance reveals an emphasis on the individual consumer at the expense of other perspectives, such as group effects. Ads, like most forms of television programming, are often consumed in company, e.g., at home with family relatives, or friends. Ads that attempt to persuade using emotion or humor may derive added effect from emotion sharing in co-viewing persons. Consequently, a reasonable proposition might be that resistance to persuasion can likewise derive benefit from sharing emotion regulation across co-viewing individuals. We propose more specifically that mimicking emotional expressions of other viewers is key to shared emotion and shared regulation of emotion. Shared emotion regulation may be relatively easy because the individual viewer of an ad is "supported" by a co-viewer. Expanding the unit of analysis from the individual to the group, we speculate that under some conditions shared emotion regulation transforms into joint resistance to persuasion. In sum, we suggest embodied emotion regulation as a viable, new strategy for resistance to persuasion that can also be shared among co-viewing consumers.

EMBODIED RESISTANCE TO PERSUASION

How does resisting enjoyable advertisements by suppressing facial expression of happiness function in detail? We explain this in more detail in the theoretical framework below (summarized visually in **Figure 1**). We introduce each of the components and state the main tenets of embodied resistance in the subsequent sections.

Emotion

Embodied resistance to persuasion is a particular form of emotion regulation, namely regulation in the service of resistance. We first must define what we mean by emotion, facial expression, appetitive attitudes, and emotion regulation, mainly by singling out the definitions used from alternative theoretical approaches. Research on emotion has been dominated by Ekman's (1972) Basic Emotion Theory. New evidence (e.g., see Russell et al., 2003; Barrett et al., 2011; Lewinski, 2015c), however, has challenged this well-established theory, especially its claim that the commonly understood emotions are each discrete phenomena, category bounded, easy to produce, and readily recognizable (Russell, 2003; Barrett, 2006). We chose the componential conceptualization of emotion as an alternative that, like the basic emotion view, permits labeling emotions and expressions as categories, but unlike Basic Emotion Theory does not restrict the categorization of any emotion to a set of basic labels. On the contrary, emotions can be labeled according to outcomes of an ongoing process of *appraisal* of the emotional stimulus, giving rise to an essentially open set of labels. Obviously, any traditional basic emotion labels are not excluded from these outcomes.

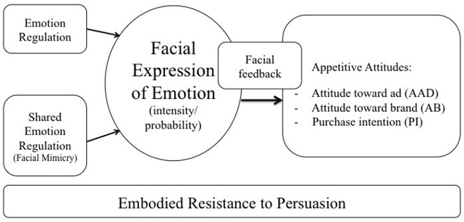

FIGURE 1 | Embodied resistance to persuasion.

Our framework has its starting point in Scherer's (2004, 2009) componential process model of emotions which conceives emotions as synchronized reactions of modules that operate in interdependency (Scherer, 2001). As with all emotion theories, affect is the foundation of emotion. Emotion is thus comparable to a luxury variant of affect: it contributes to affect a number of component emotion processes notably (1) an elaborate appraisal of the stimulus, including feeling and action tendencies as component processes, and (2) preparation for action. Scherer's model conforms to the appraisal-action schema observed in all major emotion theories. However, in our use of the componential model, the importance of the action component is especially pronounced. We subscribe to a premise not explicit in Scherer's model, namely that action readiness is a sine qua non for emotion (Frijda, 2007). We explore these concepts in more detail below.

Facial Expression

Facial expressions of emotion are semi-universal sequences of facial muscle contractions associated with the emotional state of a person. The traditional view of Basic Emotion Theory considers these expressions discrete, innate, and culturally universal (e.g., Ekman, 1972; Ekman and Cordano, 2011). However, evidence concerning the relationship between emotion and facial expression subverts the notion of basic emotion categories being related to fixed expressions (e.g., Jack et al., 2012; see Fernández-Dols, 2013 for a review). Recent social and psychological constructionist approaches (e.g., Russell, 2003; Barrett, 2009; Mesquita, 2010) propose that distinct emotions do not have singular, unique manifestation in facial expression, and are likewise not considered natural kinds associated with dedicated brain circuits.

We consider in particular that the set of traditional basic emotion expressions may be part of the much larger or indeed open array of emotion–expression combinations. For instance, one may safely assume that a smiling person is in a happy mood (e.g., Reisenzein et al., 2013). However, uncertainty arises when it comes to what aspects of emotion are "expressed" through a smiling face. Following the logic of functional accounts of emotion, facial expressions have been argued to reflect forms of action readiness (Frijda, 2007). The following practical example illustrates the use of attending to functional aspects of facial expression. Imagine someone observing you smiling intensely while watching an enjoyable commercial on television. This observer cannot be sure about your feelings at that particular moment but probably infers that when you are pulling your lip corner up (i.e., smiling), it means you are feeling happy. Frijda and Tcherkassof (1997) would argue that you are not only smiling and feeling happy, but that you are also expressing favorable action tendencies to approach the commercial. Marketers and advertisers have taken note of this relationship because they are interested not only in how consumers emotionally respond to an advertisement, but probably even more so in how consumers' feelings relate to behavioral tendencies toward the commercials, products, and brands. Following the action tendency view of emotion expression, we address the general question: can we tell from facial expression whether consumers faced with an advertisement have a particular action readiness toward the advertised product? More to the point is the question: do they want it? We subscribe to the hypothesis that facial expression of emotion reflects a state of action readiness (Frijda and Tcherkassof, 1997). In addition, we argue that action readiness (Frijda et al., 1989) in viewing ads takes the form of appetitive attitudes (as defined in Fishbein and Ajzen, 1975) toward ads, products, and brands.

Appetitive Attitudes

Fishbein and Ajzen's (1975), Ajzen and Fishbein (1980) definition is the starting point for our conceptualization of attitudes as action-oriented emotional responses. An attitude is the sum of the beliefs about the outcome of one's behavior with regard to the attitude's object. Ads, brands, and products can be objects of attitudes and emotions. Eagly and Chaiken (2007) recently defined attitudes as specific beliefs, namely evaluations of experience with the object. Attitudes represent a tendency to "evaluate a particular entity with some degree of favor or disfavor" (Eagly and Chaiken, 2007, pp. 598–599). Its property of a favorability evaluation is why attitude may be called appetitive.

Eagly and Chaiken (2007) distinguish three evaluative components in attitudes: cognition, affect, and behavior. These can be mapped onto the components of emotion. Cognition and affect evaluation correspond with appraisal of the object and global action motivation. For example, Breckler (1984) showed that affect measures correlated with physical distance taken to an object. The behavioral evaluation component of attitudes corresponds with what exactly one emotionally would like to do with the object. For instance, a readiness of approach to an ad evaluated as funny is specified as a tendency to engage in interested exploration, to pay attention, be with the ad, identify or care for the brand, possess the product and others (see Frijda, 2007). In recent years, attitudes, too, have been considered embodied inclinations, that is, attitudes involve a readiness of the body to act according to the evaluation (Niedenthal et al., 2005).

In the realm of advertising, the ad itself, the brand, and product purchase intentions are objects of appetitive attitudes. Because the model of emotion adopted here involves synchronized rather than strictly subsequent emotion component processes, we can only loosely sketch the temporal aspect of the emotional process. While viewing an amusing ad, typically a readiness to approach arises in the wake of or simultaneous with its appraisal as funny. In addition, while viewing or immediately following an ad, this approach motivation corresponds to distinct appetitive attitudes, each having their own behavioral implementations. From our embodied persuasion perspective, we propose, they include (1) immediate liking for the ad – involving a desire to attend it to the full and enjoy it; (2) brand liking – involving a tendency to identify with the brand – to associate the self with it; and (3) purchase intention – involving the tendency to put forth effort and invest resources to possess the product. Regulation of these emotions and their subsequent effects on appetitive attitudes might be crucial in persuasion and resistance processes.

Emotion Regulation

Emotion regulation is a conscious or unconscious sequence of steps taken to control or change emotions. The process of emotion regulation starts when internal or external stimuli trigger, through a semi-stable individual threshold, the affective appraisal. The cultural- and individual-specific patterns of self-regulatory actions lead to modification of the default response and hence final behavioral outcome (Gross and Thompson, 2007). Many types of emotion regulation have been reported (e.g., see Brans et al., 2013). Reflection, rumination, and distraction are examples of emotion regulation strategies, but we focus here on the two most general ones: antecedent- and response-focused strategies (Gross, 2002).

Cognitive reappraisal is an antecedent-focused strategy. Cognitive reappraisal, as a down-regulating strategy, changes the perception of emotional events to become more objective and analytical, decreasing felt emotion. For example, someone who has recently lost a parent can think, "Dying is natural to life and it happens sooner or later." Up-regulation leads to perceiving events in a subjective and involved manner, which increases felt emotion (Lazarus and Alfert, 1964). As a cognitive strategy, reappraisal modifies both appraisal and action readiness. Importantly, cognitive reappraisal is capable of increasing resistance to temptation. For example, Leroy et al. (2012a,b) found that reappraisal could make a task more appealing and temptation less attractive, thus aiding in resisting temptations.

Expressive regulation is the response-focused emotion regulation strategy that can either suppress or amplify outward signs of inner feelings (Gross and John, 2003). Suppression of bodily expressions has an inhibitory function and is generally associated with poorer well-being and psychological functioning (e.g., Svaldi et al., 2012). Amplification has an excitatory function, as it intensifies the organism's physiological responses. People experience stronger emotions when activation of the sympathetic nervous system is amplified (Demaree et al., 2004). As the name implies, expressive regulation taps more directly into the expression of emotion than cognitive reappraisal does.

Returning to our case of positive emotions provoked by enjoyable ads, we propose that amusing ads typically lead to an appraisal as "funny" and attractive, related to an approach motivation. This appraisal and the ensuing action readiness might be regulated, working toward controlling one's attitude with respect to the amusing stimuli, e.g., an ad. Assuming such self-regulation is feasible, emotion regulation is a tool that consumers could adapt for purposes of their own "defense" against persuasive advertising. From this perspective, we believe that our study of emotion regulation will contribute substantially to the literature of resistance to persuasion. Emotion may be regulated through adjusting one's thought patterns, feelings, or expressions. From those three ways, expression regulation is crucial to embodied emotion regulation, a concept discussed below.

Embodied Emotion Regulation through Facial Expression

We posit that bodily expression is a privileged point of application for emotion regulation. A general argument for this assertion is that emotions as a whole (including attitudes as emotional responses) are themselves embodied. All component systems of emotion appraisal, global motivation, and responses, that is, specific action tendencies and expressions have been shown to be affected by instructions or implicit cues leading to different body postures (Niedenthal et al., 2005). Therefore, it can be expected that the control of bodily expressions can affect all other emotion components.

Next, several arguments exist in favor of specifically facial expression as a privileged nexus of emotion regulation among the bodily concomitants of emotion. Facial muscles are hypothesized to have direct, two-way connections with the experienced and expressed emotion (Friesen and Ekman, 1983). Facial expression regulates emotion strength because facial expression feeds back on felt emotion intensity (Leventhal, 1984). Facial efference theory (Zajonc, 1985; Adelmann and Zajonc, 1989; Zajonc et al., 1989) takes as a starting point the well-known fact that facial musculature is controlled by afferent input originating in the brain's emotion centers and adds to this that, in turn, facial musculature activates efferent neural output to the emotion centers. Research in support of facial efference theory presents compelling biological evidence of facial muscle contractions influencing affective experiences by regulating blood flow (most prominently in the nasal area) to the brain.

The facial feedback hypothesis goes one-step further than postulating an efferent influence of expression on feeling. Indeed, this hypothesis is a "causal assertion that feedback from facial expression affects emotional experience and behavior" (Buck, 1980, p. 813). Strack et al. (1988) found (however, see the latest replication of Wagenmakers et al., in press), for example, that a forced smile resulted in higher humor appreciation. Zajonc (1985, p. 16) went on to demonstrate that "facial muscles act as ligatures on facial blood vessels and thereby regulate cerebral blood flow, which, in turn influences subjective feeling." For example, Zajonc et al. (1989) asked participants to read aloud stories containing ü (U-umlaut), a vowel that involves action of the corrugator muscle and nostril constriction. Those two movements are typically part of negative emotion expression. As predicted, reading aloud "Jürgen," "füchse," and "hühner" lead to higher forehead temperatures in contrast to stories containing "Peter," "hunde," and "katzen," because hypothetically the utterance of ü caused an airflow cooling the brain. This efferent influence presumably caused differences in experienced emotion. Participants reported liking the non ü-story more even when participant origin, content recall, or interest in German language were controlled for.

In sum, embodied resistance to persuasion could in principle deploy other means than facial expression or facial expression alone (e.g., breathing slowly or shaking the head in "no" gesture), but facial expression is an essential, arguably privileged and up to now most researched component of embodied emotion regulation. Therefore, we focus our theorizing mainly on facial expression.

Shared Emotion Regulation

Emotion regulation often occurs in the presence of others. We propose that a special form of embodied emotion regulation is mimicking others' facial expression and that facial mimicry is more spontaneous than emotion regulation. Response- and antecedent-focused emotion regulation is typically private. On the other hand, people often view ads together. One way, then, that emotion regulation might be extended from the isolated individual to a social situation involving a co-viewer is through subconscious mimicking of facial expression.

Facial mimicry is the action of specific muscles' regions in response to others' facial expressions (Bush et al., 1989). This phenomenon occurs automatically and spontaneously whenever another person is co-present and visible. The mere perception of facial expressions of others' emotions activates observers' facial muscles – as measured by facial electromyography – that correspond to the perceived emotion (Dimberg, 1982; Lundqvist, 1995). Facial mimicry occurs fast – within 300 ms (Dimberg et al., 2002) – and it may even be an innate aspect of perceiving others (Niedenthal et al., 2005). Importantly, we adopt Bush et al.'s (1989, p. 32) definition of facial mimicry because it involves the process of mimicking, which modulates the "(...) subject's own expressive displays rather than one-to-one mimicry outcomes".

We propose that mimicry combined with facial feedback results in shared emotion. An example is that when two smiling persons mimic each other, mutual feelings of liking are enhanced (for a review, see Lakin et al., 2003). As far as the mimicked other is regulating their emotion involving facial expression, the perceiver will follow the other in the regulation. Through this process, expression of emotion and its regulation in one individual will affect co-viewers and vice versa. Thus, facial mimicry may be the vehicle for interpersonal sharing of emotion but also of interpersonal sharing of regulation.

Competent consumers may deploy shared emotion regulation. For instance, imagine that a parent's disapproving facial expression in reaction to an ad of appealing but sugar-rich chocolate bar is mirrored by a change in the expression of a child watching the parent. Owing to properties of facial feedback, the child's initially positive facial expression is down regulated, leading to suppression of the child's positive feelings toward the amusing advertisement of an unhealthy but appealing chocolate bar. In line with this example, Rychlowska et al. (2014) showed that blocking mimicry made true and false smiles look the same. Thus, blocking facial mimicry (or showing opposite expression) may reduce children (or adults') ability to accurately interpret emotional signals delivered by the ad and hence decrease the ad's intended persuasive impact.

In Summary

We propose that the complete process involved in embodied resistance to persuasion is the following: in the default situation of viewing a properly enjoyable ad, consumers feel a substantial degree of happiness, as typically they do not regulate their emotion in any way. The contents of the amusing advertisement are appraised as amusing, and a corresponding appetitive action readiness is automatically incited. These antecedent components cause emotional responses indicative of happiness. One is the subjective feeling of happiness, another is its expression through facial movement, and a third is appetitive attitudes – specified forms of the readiness to pleasantly engage with the ad, brand, or product. Should a consumer be inclined to resist amusing ads, response-focused emotion regulation that suppresses appetitive attitudes will apply first to the facial expression response, because conscious control of facial expression is easy in comparison to other response systems. Likewise, we argue that in the event a consumer applies antecedent regulation, facial expression will again be primarily affected for the same reason, namely that facial expression is relatively easy to hold in check. Because of the interrelatedness of emotional response systems and, perhaps more particularly, the relatedness of facial expression with the appetitive attitude response system, suppression of facial movements propagates to lower feelings of happiness and appetitive attitudes. Through a feedback mechanism, suppressed facial expressions of happiness also influence (1) antecedent components of the emotions, i.e., appraisal of the ad as funny, and (2) the emotional approach tendency toward the ad. To the degree that this mechanism persists, the consumer exhibits embodied resistance to persuasion. When the ad is part of a co-viewing experience, facial mimicry contributes to shared emotion regulation. Mimicry involves changes in the consumer's facial movement that is targeted by the ad, propagating subsequently to appetitive attitudes through facial feedback. Mimicking facial expressions compatible with the amusing ad enhances the target consumer's happiness and attitudes toward the ad, brand, and product, while mimicking ad-incompatible facial expressions will suppress happiness and attitudes.

Empirical Evidence for Embodied Resistance to Persuasion

The empirical literature already consists of some research supporting the basic tenants of embodied resistance to persuasion. We review some of those studies below, which come from our own lab. We chose facial expression and emotion regulation as the focus of our studies because, as argued before, one prominent form of bodily expression is facial expression and another prominent form of self-regulation is emotion regulation. Therefore, we focus on resistance toward persuasion by facial expression manifested in emotion regulation and facial mimicry. The latter phenomenon expands the notion of embodied emotion regulation to social situations of individual consumers watching ads in the company of others. Our primary aim is thus to highlight the role of facial expression in suppressive emotion regulation for embodied resistance. The first, basic question is whether facial expression reliably predicts attitude change. The second question is whether emotion regulation of facial expression results in resistance toward persuasion. The third question is whether a shared form of emotion regulation – facial mimicry – influences facial expression and therefore attitudes of the consumers. In sum, the three testable hypotheses, we propose are:

During exposure to an enjoyable ad:

- H1: Facial expression of happiness predicts intensity of appetitive attitudes;
- H2: Suppressing facial expression of emotion helps consumers in downward regulation of appetitive attitude;
- H3: Mimicking other consumers' incompatible expressions (incompatible-mimicry) inhibits target consumers' facial expression of happiness and subsequently their appetitive attitudes.

In most of our studies presented below, participants were exposed to 30 s enjoyable video advertisements while their facial expression was estimated by automated facial coding software – FaceReader (for technical details and validity measures see Lewinski et al., 2014a). FaceReader's estimation of intensity of facial responses were afterward related to consumers' attitudes toward the ad and buying intentions. The majority of the experiments were carried out in cloud-based FaceReader Online through MTurk, which heightened the experiments' ecological validity in comparison to standard lab experiments as participants were recorded in their own homes using their own computers as in a standard ad watching situation.

In Lewinski et al. (2014b), we demonstrated that the intensity of facial expression predicts the intensity of consumers' appetitive attitudes in response to enjoyable advertisements. In that experiment participants viewed amusing advertisements. An emotional response to the ads was assumed to involve Frijda's (2007) action tendencies, such as *approach* and *be with* the ad and the brand, and to *possess* displayed articles. In this study, approach and be-with tendencies were operationalized as ad liking (Phillips, 2000) and brand liking (Chattopadhyay and Basu, 1990). Participants were recorded watching three popular high, medium, and low amusing video advertisements. Facial expression during exposure to the commercials was coded using FaceReader. Ad and brand liking were measured afterward. In the high and medium, but not in the low amusement conditions, positive correlations were found between happiness scores and appetitive attitudes (i.e., attitude toward the ad and the advertised brand). No such correlations were obtained for any other basic emotion (sadness, anger, surprise, fear, disgust) in any conditions. In a similar vein, Lewinski (2015a) showed that facial expressions of speakers, coded using FaceReader, predicted the number of video views on a YouTube channel, 8 months after, controlling for baseline views. Specifically, more of facial expression of happiness and sadness (both approach tendency emotions) and less of surprise expression (ambivalent emotion as to approach tendency) correlated with higher popularity of the video (as defined by video views), an outcome variable similar to ad liking. We propose that we have found initial support for the hypothesis that facial expression not only reflects communicative intent, feeling, mood, or appraisals, but may also equally reflect appetitive attitudes.

In Lewinski et al. (2015, February), we tested consumer resistance to persuasion through embodied emotion regulation in seven facial coding experiments. Across seven experiments, we showed that response- and antecedent-focused emotion regulation decreased (increased) positive (negative) responses to a variety of advertisements. In five experiments with amusing advertisements, we demonstrated a causal mediation path from emotion regulation to expression and further down to attitude change, although we did not fully replicate the same pattern for disgusting ads. Specifically, we found that expressive suppression and cognitive reappraisal had similar inhibitory effects on facial expression of happiness, which subsequently led to lower positive attitudes about the ad, brand and intention to buy. We assume that those lowered attitudes on the side of the consumer are indicative of a successful resisted persuasion attempt. Even though, in those experiments, other resistance to persuasion strategies (e.g., source derogation) were not compared directly with emotion regulation strategies, three experiments introduced effort in emotion regulation as an explanatory variable. Those subsequent experiments showed that the effort in not feeling happiness or not feeling anything (i.e., emotion regulation) was a significant predictor of intensity of facial expressions, and hence resisting persuasion depended on it, which in turn meant that the more consumers tried to regulate their emotional experience, the better off they were (i.e., more successfully resisted the advertisement).

So far, the viewing situation was limited to the individual consumer watching an ad in isolation. In Lewinski (2015, Unpublished, June) and in Lewinski et al. (2016), we added tests of shared ERP where we demonstrated effects of facial mimicry on consumers' attitudes and intentions in three experiments. In this study, we simulated a co-viewer using an avatar. Across three experiments, we demonstrated that during exposure to an amusing advertisement, shared emotion regulation modified consumers' happiness and subsequently their appetitive attitudes. Specifically, we found that consumers' incompatible mimicry – manipulated through a "disgusted" avatar – decreased consumers' felt and expressed happiness, which in turn caused lower attitudes and intentions. In one of the experiments, we included an eyetracking manipulation check to rule out the possible confounding effect of the presence of avatar. To precisely manipulate facial mimicry in the main studies, we developed an innovative method of a virtual avatar embedded into an advertisement, which was meant to reflect participants' anticipated facial movement pattern. We concluded that resistance to persuasion is enhanced by the presence of a skeptical co-viewer expressing their negative attitudes through facial expression.

Importantly, all support from empirical data described here came from experiments with random assignment and with a sample drawn from a representative American population (thus not a student sample). This means that any alternative predictor, such as the use of additional resistance strategies by subjects or sociodemographic status was spread equally across the conditions and hence cannot explain the findings. Further, the type of advertisement tested in the experiments, which contained different types of content, was judged as amusing and intended to evoke generic laughter responses. This is relevant in light of research on evaluative conditioning and the impact of resistance motivations as discussed by Sweldens et al. (2010) or Fransen et al. (2015a).

The studies reviewed above are a first empirical test of our framework concerning embodied resistance to persuasion. However, more empirical studies are needed in order to test the more general framework as well as the specific role of different expression systems, different types of ads and different types of attitudes (e.g., implicit attitudes).

IMPLICATIONS

Theory

We believe that our focus on emotion regulation as a resistance strategy contributes to filling the surprising lack of conceptualization on the role of emotion and embodiment in resistance to persuasion processes. As revealed in the introduction, only a handful of resistance strategies have been identified. So far, none of these strategies is emotion-specific (e.g., Knowles and Linn, 2004; Fransen et al., 2015a,b). Comprehensive theorizing modeling the dynamic, sequential, and componential nature of emotion and expression in persuasion is even more scant. In the current paper, we applied existing knowledge on embodiment and emotion regulation to the process of resistance toward persuasion. The widely known Approach–Avoidance Model of Persuasion (Knowles and Linn, 2004) includes only so-called Alpha and Omega strategies for attitude change (respectively making the message more attractive or focusing on reducing resistance to it), both of which lack an explicit emotion component. A recent paper by Fransen et al. (2015a) reporting three different types of resistance strategies (avoidance, contesting, and empowering) does not include emotion as a prominent component. To address this shortcoming in the literature on resistance to persuasion, we presented a new type of strategy that consumers may use to resist persuasion of (amusing) advertisements by regulating their own emotional and bodily responses. We explicitly revealed the mechanisms of embodied resistance to persuasion as well as its boundary conditions and specific elements.

The presented framework has further immediate implications for the theory of resistance to persuasion. For the first time, we consider the effects of a resistance strategy specifically tailored to the emotional content of an advertisement. We propose that positive attitude effects of amusing advertisements might be counteracted through different forms of cognitive reappraisal and expressive suppression, as well as incompatible facial mimicry. We furthermore argue that a model of regulation and resistance effects needs to take the expression of emotion into account.

A second contribution of the ERP framework is that it incorporates the body into consumers' self-awareness and self-regulation. The possible underuse of embodied emotion regulation is somewhat ironic given the immediate, permanent accessibility of the resource in question. Our bodies link our internal perceptions and actions to situations and stimuli in the world. In principle, individuals have exclusive control over their bodies' movements. The body is the primary and most-trusted source of information on external situations and internal states, and an ever-available instrument to act. In some situations, controlling the body may be easier than controlling the mind, as in the case of cognitive depletion (Wheeler et al., 2007). Competent consumers might recognize that they can to a large extent be master of their thoughts and emotions because these are embodied and situated.

Emotion Regulation

In our empirical studies we made a distinction between two slightly different ways of regulating emotions, one through direct instruction and another through facial mimicry as explained in the overview of experimental studies. We proposed that the two work in a similar manner but we do not exclude the possibility that there are important differences. It could be that response-focused emotion regulation (expressive modulation) influences the expression and hence attitudes both upward and downward. However, facial mimicry could have suppressive effects only. One possible explanation for this qualitative difference could be that when consumers' expressions are already compatible, they do not feel the need to mimic one another in order to up-regulate their experience. However, that reasoning would contradict findings by Raghunathan and Corfman (2006). Another explanation would be a simple ceiling-effect, which could be tested by including more neutral or ambiguous advertisements instead of only amusing ads. In any case, this issue is left as an open question that awaits further investigation.

The Role of Facial Expression

Our framework assumes that appetitive attitudes are immediate outcomes of consuming the advertising stimuli. Throughout, we forwarded the proposition that facial expression predicts attitudes rather than the other way around. Hence, smiling at an advertisement means you like it more. However, situations are conceivable in which appetitive attitudes may cause increased facial expressions of happiness. Short-term appetitive attitudes could potentially develop into long-term ones, becoming *a priori beliefs* about an ad or brand resulting from repeated exposure to the ad. Consequently, any time the ad is presented, beliefs are automatically activated, instigating the appropriate facial expressions. The attitudes considered in our studies have only immediate post-viewing appetitive attitudes within their scope. Predictive effects of longer-term *a priori* beliefs on facial expression are left unaccounted for.

However, the empirical studies reviewed did throw a consistent light on the direction of causality in the case of immediate viewing effects. We were faced initially with a causal direction issue: do I smile because I like an object or, conversely, do I like it because I smile? Lewinski et al. (2015, February) tested the latter possibility thoroughly and found it held up to scrutiny. Thus, we are confident to add to the literature on facial feedback a strong case for facial expression as a causal condition for affective, immediate, and post-viewing liking responses.

Advantages of Measuring Facial Expressions

An often-used method to assess how consumers react upon amusing advertising is to explicitly ask them what they think about an advertisement and how they think they *feel* about it. However, asking people directly how they feel is not only cognitively demanding and difficult for the subject, that interrogative pathway also brings undesired effects into the mix, such as increased self-awareness (Pryor et al., 1977) and social-desirability (Arnold and Feldman, 1981). Moreover, as self-report measures they are incapable of capturing a number of biologically anchored emotional expressions that are inaccessible to the subject's awareness. Physiological registrations can offer a solution to the shortcomings of explicit verbal measures of cognitive and emotional states. One such physiological measure is facial emotional expressions, which play a prominent role in our model and hence help in overcoming such disadvantages of self-reported emotions. Further automated coding of such expressions, with software such as FaceReader, eliminates the human factor in coding, which often can be less accurate, under certain conditions than coding algorithms (see Lewinski, 2015b), trained on objective material (such as in Olszanowski et al., 2015).

Practical Implications

Consumer Competence

Embodied resistance to persuasion aims to increase consumer competence by empowering them with additional resistance "tools" to counteract deliberate persuasive attempts that use amusement. The insights into embodied resistance to persuasion are relevant for consumers, consumers' interest groups and governmental and non-governmental consumer policy organizations. Consumer organizations, too, have emphasized the need for tools that help consumers to act autonomously when they are faced with consumer product supplies. The European consumer organization BEUC (Bureau Européen des Unions de Consommateurs), which represents more than four million consumers from a few dozen national consumer organizations across thirty-one European countries, has explicitly stated:

> "Empowering consumers is the holy grail of current EU strategy and research. It is also a policy target for national governments, often in tandem with policies for smarter regulation or deregulation. It means that consumers take decisions and

> choices into their own hands where they can – provided that they have the right tools to do so. (...). If the 500 million EU consumers have all [right tools], they can influence markets with their collective power. (...). The reality, however, as our members tell us, is rather different. Numerous elements converge to disempower consumers (...). Too often companies make deliberate use of consumer information fatigue and their *behavioral biases* in their *communication strategy*" (The European Consumer Organisation [BEUC], 2012, p. 7; "EU Consumers' 2020 Vision," emphasis added).

In a consumer context, embodied resistance to persuasion holds promise as a tool empowering consumers and thus adding to their competence. The behavioral control that it involves adds to available elements of consumer competence such as counter-arguing or attitude bolstering. In addition, for special groups of consumers who for one reason or another cannot efficiently resist appealing messages through counter-arguing or attitude bolstering, the body may be the only easily accessible resource for resisting persuasion. This is because one prominent advantage of embodied resistance to persuasion as a strategy is that it applies to behavioral expression in the first place.

Disadvantaged Groups

Specifically, consumers who are not proficient in generic resistance to persuasion and have difficulty dealing with cognitive instructions well can benefit from instruction to control their bodily expressions. For example, instructing such regular consumers to feign a specific facial expression, e.g., lowering their brows could help them to resist persuasion attempts. They might interpret their bodily act of brow lowering as the physical manifestation of their own thinking, possibly enhancing cognitive performance.

Consider that a young child who cannot yet counter-argue a persuasive message is already able to inhibit his or her smiling at an appealing object. Parents could show their child how to suppress facial expressions of happiness in response to a tempting ad, whereas they could not make the child comprehend and follow a verbal instruction to counter-argue the message. Parents can guide children in resisting persuasive messages by demonstrating how to counteract persuasion using their body. This assumption stems from and would be compatible with the findings from the well-known still-face paradigm in mother infant-interaction (Tronick et al., 1979). The still face of the mother (an extreme case of incompatible mimicry) provokes clearly negative reactions in the infants, including withdrawal.

Marketing Communication

Understanding embodied resistance to persuasion may not only inform pro-consumer institutions but also advertising agencies and corporate units of market or consumer behavior analysis. For example, ad copy testing could include measures of behavioral expressiveness to check whether consumers engage in embodied resistance to persuasion. Integrated marketing communication could deliver customized experiences based on consumers' embodied response profiles. That is, they should address consumers taking into account individual differences among them with regard to the non-verbal expression of emotions. In addition, the insights proposed based on our framework lead us to recommend salespersons acting in face-to-face situations to capitalize on naturally occurring mimicry responses of their audience. They should be able to influence purchase decisions of consumers by exhibiting facial expressions that when mimicked by the consumer, would increase their appetitive attitudes. Studies by van Baaren et al. (2003), Wang (2009) hint at such possibilities.

Our work is also relevant to marketers and advertisers who we know are using various "resistance-neutralizing tactics (...) tailored to the specific resistance strategy that is adopted by consumers" (Fransen et al., 2015b, p. 5). Marketers can benefit from understanding the mechanism behind the new consumer resistance strategy that we propose here.

LIMITATIONS AND DIRECTIONS FOR FUTURE RESEARCH

At least two exciting new avenues for the theoretical extensions of our framework open up thanks to the presentation of the basic premises of embodied resistance to persuasion in this paper. First, the consideration of the role of potential moderating factors in the causal paths of embodied resistance to persuasion is warranted. Below, in the limitations section, we identify as likely candidates motivation, persuasion knowledge, advertising skepticism, and emotion regulation as a trait. Second, to further develop the embodiment part of the framework, various modes of expression of emotion should be elaborated upon in more detail. That also means that the suppression of additional modes of expressing the emotion could have different, additive, multiplying, or no effects at all.

Spontaneous Embodied Resistance to Persuasion

One significant limitation of our framework is that we ignore the role of consumers' motivation to resist the ads. Some people may believe, for instance, that they are not affected by the ads, so they do not have to resist them. The existence of such a belief could be explained by the third-person effect (Davison, 1983), which argues that "a person exposed to a persuasive communication in the mass media sees this as having a greater effect on others than on himself or herself" (p. 1). Further, another issue related to the role of motivation to resist is people's persuasion knowledge (Friestad and Wright, 1994) and their skepticism toward advertising (Obermiller and Spangenberg, 1998). Embodied resistance to persuasion could predominantly be a tool used by consumers with above average knowledge of persuasive communication strategies, or who are skeptical of advertising in general. Also environments that cue different types of motivation (e.g., telic or paratelic; see e.g., Lewinski, 2015d) could have different effects on the resistance.

Yet another concept that dovetails with consumers' motivation to resist the ad in our model is emotion regulation as a stable trait. Emotion regulation is not only a temporal strategy moldable and sensitive to instruction, but also a chronic trait (Gross and John, 2003) measured through statements like, "When I want to feel more positive emotion (such as joy or amusement), I change what I'm thinking about" or "When I am feeling positive emotions, I am careful not to express them." The evidence that is presented so far is restricted to strategies induced by instruction. For future studies it might be interesting to consider if spontaneous, and not instructed, emotion regulation stemming from, for example, individual differences would be equally effective in resisting advertisements.

Finally, an important question is left open. Under which conditions is an embodied resistance to persuasion strategy more effective than a "standard" strategy? Going even further, can we hypothesize that under some conditions, engaging in both kinds of resistance at the same time would offer the greatest benefit to the consumer? However, interesting as a possibility, this hypothesis remains to be supported by further research and conceptualizations.

Other Forms of Expression of Emotion

In this paper, we did not consider the role of expression of emotion outside of facial expressions, though our framework allows for such possibilities. Alternative forms could encompass a head-down (sadness), clenched fist (anger), or straightened posture (pride). For example, sadness and anger are clearly negative emotions (Ekman et al., 1983) and should therefore decrease positive attitudes toward an entertaining advertisement. However, pride is an ambiguous emotion that is likely positive but also qualitatively different from, e.g., happiness and hence belonging to the same category as self-conscious emotions like embarrassment, shame, and guilt (Lewis, 2000). Thus, whether straightened posture would lead to lower or higher positive attitudes cannot be decided *a priori*. We did not consider those expressions because there is no automated way to code for them at any larger scale, a prerequisite for quantifying and interpreting significance and we could not have potentially generated enough empirical support to justify inclusion of those components explicitly in our model.

Further, e.g., Sweldens et al. (2010) showed that resistance instructions can counter explicit attitudes (and such were measured in the presented experimental data) but still influence implicit attitudes. This question is left open in our framework. It could be that emotion regulation, even though inhibiting facial expression would not further dampen implicit attitudes, i.e., attitudes captured by response time, IAT, galvanic skin response or other neuromarketing measures (such as fMRI or EEG), not filtered by any conscious verbalization process. However, because facial expression is itself a type of an implicit response in that sense, we predict that emotion regulation could be equally effective for resisting persuasion at an implicit attitude level. We think this is an exciting area to investigate in the future.

CONCLUDING REMARKS

Commercials aiming to persuade are ubiquitous and making consumers aware of how to use their body in resisting these unwanted temptations could contribute to consumers' empowerment. Embodied emotion regulation may be advocated as a novel and effective strategy to resist persuasion. To conclude, the working of embodied resistance to persuasion contributes to the growing scientific evidence that consumers' bodily feedback has powerful regulatory effects on their behavior. In particular, our work highlights the role of bodily feedback in consumer resistance to persuasive ads. The downplaying of one's emotional reactivity by either suppression or reappraisal empowers consumers, namely by helping them resist persuasive messages. We believe that embodied resistance to persuasion opens up a new avenue for persuasion research, showing that bodily emotion regulation mediated through facial behavior influences attitudes. In short, what we bodily express, influences not only how we feel and think but also whether or not we are persuaded.

AUTHOR CONTRIBUTIONS

PL, MF, and ET developed the outline, revised several drafts of the manuscript, prepared figures. PL performed the literature search, wrote all concept versions, presented preliminary results at research meetings and Etmaal 2015. MF and ET provided supervision.

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ORIGINAL RESEARCH
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Decomposing Self-Control: Individual Differences in Goal Pursuit Despite Interfering Aversion, Temptation, and Distraction

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Self-control can be defined as the ability to exert control over ones impulses. Currently, most research in the area relies on self-report. Focusing on attentional control processes involved in self-control, we modified a spatial selective attentional cueing task to test three domains of self-control experimentally in one task using aversive, tempting, and neutral picture-distractors. The aims of the study were (1) to investigate individual differences in the susceptibility to aversive, tempting, and neutral distraction within one paradigm and (2) to test the association of these three self-control domains to conventional measures of self-control including self-report. The final sample consisted of 116 participants. The task required participants to identify target letters "E" or "F" presented at a cued target location while the distractors were presented. Behavioral and eyetracking data were obtained during the performance of the task. High task performance was encouraged via monetary incentives. In addition to the attentional self-control task, self-reported self-control was assessed and participants performed a color Stroop task, an unsolvable anagram task and a delay of gratification task using chocolate sweets. We found that aversion, temptation, and neutral distraction were associated with significantly increased error rates, reaction times and gaze pattern deviations. Overall task performance on our task correlated with self-reported self-control ability. Measures of aversion, temptation, and distraction showed moderate split-half reliability, but did not correlate with each other across participants. Additionally, participants who made a self-controlled decision in the delay of gratification task were less distracted by temptations in our task than participants who made an impulsive choice. Our individual differences analyses suggest that (1) the ability to endure aversion, resist temptations and ignore neutral distractions are independent of each other and (2) these three domains are related to other measures of self-control.

Keywords: eyetracking, visual attention, disgusting pictures, erotic pictures, self-control task, willpower

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INTRODUCTION

Imagine you have to clean the toilet in your student housing with 20 inhabitants. Or imagine you are dieting, but you are offered a delicious piece of chocolate cake. Or imagine you are working on your annual tax declaration while your children try to grab your attention. What you need in all these different situations is self-control. You need to focus your attention and hold on despite aversive events, temptations, or distractions in order to reach a goal that you have set yourself. Until now, self-control has been measured using different paradigms, all of which entail conflicts between impulses and goal-directed behavior (Ach, 2006; Duckworth and Kern, 2011; Goschke, 2012). Only few studies assessed the specific selective spatial attentional processes underlying self-controlled behavior (Mann and Ward, 2007; Kelley et al., 2013). When focusing on individual differences, current tasks correlate at best moderately with each other, making it difficult to decide which of them is the most valid measure for trait self-control. One reason for such low correlations might be that all these tasks involve different impulse domains that are supposed to distract participants from goal attainment (Kuhl and Goschke, 1994; Kuhl and Fuhrmann, 1998; Tsukayama and Duckworth, 2010). For example, in some self-control tasks, participants have to endure aversive events such as pain (Kanfer and Goldfoot, 1966) boredom (Muraven et al., 1998) or solving an unsolvable task (Baumeister et al., 1998). Other self-control measures involve the ability to resist a positive temptation in order to reach a long-term goal – for example, resisting eating one marshmallow in order to receive two marshmallows later (Rosati et al., 2007; Mischel et al., 2011; Crockett et al., 2013, Privitera et al., 2015). A third group of self-control measures comprises cognitive tasks such as the Stroop or Flanker paradigm, in which emotionally neutral distractors need to be ignored (Gailliot et al., 2007). Automatic reactions to these impulse domains might differ between participants irrespective of their self-control ability (Tsukayama and Duckworth, 2010). Likewise, there is evidence that processes involved in the ability to control attention in a goal-directed manner might depend on the impulse category (Reeck and Egner, 2011; Jiang and Egner, 2014), thus providing further variability, which might underlie the weak correlations between self-control tasks addressing different impulse domains. Unfortunately, these correlations between different self-control tasks were rarely assessed within the same sample using the same task. Accordingly, other task-specific or sample-related differences might contribute to the finding of low correlations between self-control tasks. The current study introduces a modified attentional cueing paradigm that is intended to measure control of selective spatial attention mechanisms underlying self-control abilities in several impulse domains within one and the same paradigm (i.e., tolerating aversive stimulation despite an avoidance impulse, resisting erotic temptation, and ignoring neutral distraction). Furthermore, we investigate self-control in the face of the three impulse types from an individual difference perspective.

Self-Control: Definition and Background

The terms ‘self-control’ and ‘willpower’ are often used to describe the same phenomenon. Baumeister et al. (2007, 351) defined self-control as the “capacity for altering one’s own responses, especially to bring them into line with standards such as ideas, values, morals, and social expectations, and to support the pursuit of long-term goals.” Often a dual-system perspective is explicitly or implicitly used in order to describe self-control conflicts (Hofmann et al., 2009). The dual-system approach to self-control describes a “hot” impulsive system that reacts to stimuli in a direct or automatic manner and a “cool” reflective system with higher-level goal representations (Metcalfe and Mischel, 1999). When these two systems are in conflict, self-control needs to be exerted in order to reach high-level goals.

Self-control is an important prerequisite for successfully reaching long-term goals: people try to control themselves in situations involving conflicts between higher-level goals and immediate gratification several times per day (Hofmann et al., 2012).

Deficits in self-control may also be related to several psychiatric disorders (Tangney et al., 2004), such as addiction (Bechara, 2005; Buhringer et al., 2008), attention deficit hyperactivity disorder (Schweitzer and Sulzerazaroff, 1995), and obesity (Konttinen et al., 2009), highlighting the importance of self-control research.

Individual Differences in Self-Control - Domain-Generality vs. Domain Specificity

In line with the idea of the dual-system approach it has been proposed that self-control is domain-general in the sense that the same resources and mechanisms are involved independent of the specific type of self-control conflict (Baumeister et al., 2007; cf. Kana et al., 2013, for the issue of domain generality of cognitive control). This idea is supported by the finding that children who could resist eating one marshmallow in order to get two marshmallows later have been shown to be more successful later on in other life domains in which success requires self-control (e.g., school performance, ability to cope with stressful situations, ability to resist drugs, Mischel et al., 2011). As a consequence, the strategy for measuring self-control has typically been to select any task that involves a conflict between a momentary impulse and a higher-level goal without taking into account that there may be different impulse categories requiring different control processes.

In contrast, other authors argue for domain specificity in self-control. On the one hand, this includes studies, which found rather low correlations between and within different types of task categories used for self-control assessment. On the other hand, studies that used one task category (e.g., executive tasks) provide evidence for separable domains defined by the content of the impulsive reaction and their neural representation.

Concerning low correlations between task categories, Duckworth and Kern (2011) found in their meta analysis consistently low correlations between self-control tasks. They examined three different kinds of self-control measures: executive function tasks, delay of gratification tasks, and self- or informant-report questionnaires. While self-control questionnaires correlated with each other, delay of gratification tasks exhibited very low correlations with other delay of gratification tasks, albeit still higher than correlations with executive tasks. Convergent validity between questionnaires and self-control tasks was overall low or even non-existent. The authors concluded that "self-control is a coherent but multidimensional construct best assessed using multiple methods" (Duckworth and Kern, 2011, p. 1). Further support for this idea comes from Reynolds et al. (2006), who observed low correlations between questionnaires and executive tasks of impulsivity. Impulsivity shows a negative correlation with self-control (Ludwig et al., 2013) and can therefore be seen as a counterpart.

Although self-report measures of self-control have been shown to have high external validity as they correlate with life achievements (Tangney et al., 2004), the use of self-report measures for studying individual differences might have some disadvantages. One reason is that self-control is a socially desirable personality characteristic and thus self-report measures of self-control might be particularly prone to social desirability effects, lack of insight, and room for interpretation of item text (Johnson, 1981; Furnham, 1990; Back and Egloff, 2009). Accordingly, experimental tasks assessing different components of self-control are at least equally important for the evaluation of individual differences in self-control and the degree of domain-specificity.

With respect to findings regarding domain specificity within one task category, Tsukayama and Duckworth (2010) provided evidence in the self-report category for the idea that people's self-control success depends on the kind of impulses that need to be controlled, and that individuals react differently depending on their susceptibility to specific impulse domains (see also Tsukayama et al., 2012).

Here, we propose that at least three different kinds of impulses should be considered: appetitive, tempting impulses triggering an approach reaction, aversive impulses triggering an avoidance reaction, and neutral stimuli that introduce a cognitive conflict.

The distinction between appetitive and aversive motivational stimuli has already been made in the influential theory on motivational personality structure proposed by Gray (1970). The theory posits two basic motivational systems: the behavioral activation system, which is responsible for facilitating behavior and generating positive affect, and the behavioral inhibition system, which is responsible for inhibiting behavior and generating negative affect. According to this framework, individual differences in the sensitivity to reward or potential negative outcomes can be explained by differences in these two systems. Factor analysis of the Behavioral Inhibition System and Behavioral Activation System (BIS/BAS) scales developed by Carver and White (1994) revealed that the behavioral inhibition and the behavioral activation system indeed form two independent motivational forces (Jorm et al., 1998).

Further evidence for distinct mechanisms for control over temptations and control over aversions comes from several neuroscientific studies using experimental self-control paradigms. These suggest that control over temptations mainly involves a regulation of striatal reward regions by the prefrontal cortex (PFC), whereas control over emotions (with most studies focusing on negative emotions), involves a down-regulation of the amygdala by the PFC (Heatherton and Wagner, 2011). Mak et al. (2009) compared emotion regulation of positive and negative emotions. In addition to overlapping regions they observed that regulation of positive emotion was uniquely associated with activity in dorsolateral frontal regions and that regulation of negative emotions was uniquely associated with activity in regions in the left orbitofrontal gyrus, the left anterior cingulate gyrus, and the left superior frontal gyrus. Erk et al. (2007) conducted an fMRI study with positive and negative emotional distractors during working memory maintenance. They observed valence-specific activations in prefrontal control regions. Specifically, they found that individual differences in amygdala activity in reaction to negative pictures was negatively correlated with inferior PFC activity and individual differences in activity of the ventral striatum in reaction to positive pictures was negatively correlated with left superior PFC activity. Together, these studies indicate partially distinct processes involved in the regulation of positive and negative emotion, which may be seen as a facet of self-control.

Sometimes we get into conflicting situations, not because we are reacting emotionally, but because there is a neutral distraction or a cognitive conflict without emotional content (Schacht et al., 2010; Jiang and Egner, 2014). It should be noted that cognitive conflicts can trigger negative emotions even if the content of the conflict seems neutral (Fritz and Dreisbach, 2013). However, it has been suggested that the resolution of cognitive and affective conflict nonetheless relies on partially distinct neural circuitries (Etkin et al., 2006; Ochsner et al., 2009; Reeck and Egner, 2011; Reeck et al., 2012). This indicates that emotionally neutral distraction should also be considered when looking at individual differences in self-control and their underlying attentional mechanisms.

We thus propose that self-control can be exerted in the face of negative (aversion), positive (temptation), or neutral distractors, all of which are hindering the pursuit of higher order goals and that these form independent components of self-control (i.e., that individuals high vs. low in one of these abilities will not necessarily score higher on the other abilities). The fact that most current self-control tasks restrict themselves to one of the three domains may explain the low correlations between them.

The Present Self-Control Task

Our self-control task requires participants to attend to a cued target location while disgusting, erotic, and neutral pictures are presented as distractors. Participants could gaze away from the target location for the first 750 ms without any costs. After this initial period, when not fixated on the cued target location, participants might miss the target thereby risking a potential monetary reward, which they could get when performing well. Disgusting and erotic pictures are used because these naturalistic stimuli are evolutionarily relevant (Stark et al., 2005; Oaten et al., 2009) and therefore are highly likely to evoke aversion and attraction, respectively, in many participants. Aversive pictures are presented at the target location (participants have to control an avoidance reaction); erotic and neutral pictures are presented at a location different from the target location (participants have to control an approach reaction). Many authors have previously used distractors from different emotional valence (e.g., Elliott et al., 2002; Buchner et al., 2004). However, this has not been related to individual differences in self-control ability.

An attentional control paradigm was chosen because we assume that the ability to control attention in the face of distractors is a central component process supporting self-controlled behavior. Duckworth and Kern (2011) showed that performance in attentional tasks exhibited comparatively high correlations with informant questionnaires among various self-control measures. Additionally, attentional tasks have been used before in order to measure self-control (Carretie et al., 2004; Field et al., 2007; Back and Egloff, 2009). Furthermore, it has been shown that the acquisition of eyetracking data in attentional tasks can deliver additional information on individual differences in self-control (Kelley et al., 2013). For example, Friese et al. (2010) found that social drinking in combination with low working memory load affects initial orienting and attention maintenance on pictures of alcoholic beverages.

The aim of the present study was to assess the association of self-control and attentional control regarding three facets: ignoring aversive distractor, resisting tempting distractors and ignoring neutral distractors. We hypothesize that participants will not resist aversive, tempting, and neutral distractors at all times leading to costs in terms of error rates, reaction times (RTs) and increased gaze distance and variability from the target location. Furthermore, we expect that the three abilities form independent components of trait self-control. Moreover, we investigated the relationship of our task to conventional self-control measures. We therefore used an unsolvable anagram task in order to measure self-control during aversive events, a delay of gratification paradigm with food in order to measure self-control in the face of temptation, the Stroop task in order to measure self-control during neutral distractors, and questionnaires in order to assess general self-control ability.

MATERIALS AND METHODS

Participants and General Procedure

The final sample consisted of 116 participants, who provided manual response data and 109 (51 male, mean age 25.89, *SD* = 3.80) who also provided eyetracking data. We tested 126 healthy current and former university students. Ten participants were excluded from behavioral analyses and an additional seven from eyetracking analyses (see Appendix A, Exclusion of Participants). Participants came for 3 days of testing and received 75 Euro for their participation.

On the 1st day of testing, participants performed an unsolvable anagram task, a color Stroop task, and a short test of fluid intelligence (Leistungsprüfsystem Unterteil 3, Horn, 1983). On the 2nd day, participants performed our self-control task and afterwards rated all pictures that were used in the task on valence, arousal, and attraction. On the 3rd day, the delay of gratification paradigm was conducted. During the 3 days, participants also performed additional tasks and completed a range of personality questionnaires not reported here. The study was approved by the local ethics committee of the Charité - Universitaetsmedizin Berlin, Campus Mitte. All participants gave writen informed consent in accordance with the Declaration of Helsinki.

The Self-Control Eyetracking Task

Participants were instructed to indicate by button press whether they identified a white target letter as an "E" (right index finger) or an "F" (right middle finger). The target was briefly presented on a dark gray background. Participants were asked to respond as accurately and as quickly as possible. Four different types of distractors were possible: (1) a disgusting picture (e.g., of vomit, wounds, or spiders) at the location where the target letter would subsequently be presented, called the disgust condition; (2) a neutral picture presented at the target location, called the neutral ipsilateral condition; (3) a picture displaying a couple in an erotic situation displayed on the contralateral side of the screen relative to the target location, called the erotic condition; and (4) a neutral picture presented on the contralateral side of the screen, called the neutral contralateral condition (**Figure 1**). The letter size was 1.99° visual angle. The distractor pictures were 20.7° in width and 15.8° in height presented on a 36.5 cm by 27.5 cm screen with a resolution of 1024 pixels × 768 pixels.

Variable durations of distractors were introduced in order to prevent participants from anticipating the moment at which the target letter was presented. This required participants to fixate the target location continuously in order to ensure not missing the target letter. Prior to the first run, participants completed a training session that was excluded from the analysis. Participants were informed that after task completion, a lottery would take place, in which one trial would randomly be selected. If participants had responded correctly within 1000 ms on that trial, they received an additional 10 Euro (Paschke et al., 2015). Participants were informed that the money would be transferred to their bank account approximately 2 weeks after testing. The task was divided into four runs, each containing a calibration of the eyetracker followed by 75 trials. Trials were presented in a pseudorandom order. Picture presentation duration, letter, location of target presentation and transitions between conditions were balanced across the different distractor types. Directly after the picture presentation, the target letter was presented for 10 ms (if there was either no distractor or a distractor on the contralateral side of the screen), or for 40 ms if the picture was presented on the same side as the target. Pilot testing had indicated that this arrangement of presentation durations increases the probability that participants can report the letter only if they fixate the target position at the moment the target appears. Participants had 1000 ms for indicating the perceived letter by a key-press.

Stimuli consisted of pictures from the International Affective Picture System (Lang et al., 2008) and additional pictures from the internet. Prior to the study, all pictures were rated by 96 independent participants with respect to valence, arousal, and attraction/repulsiveness. The most appealing erotic pictures, the

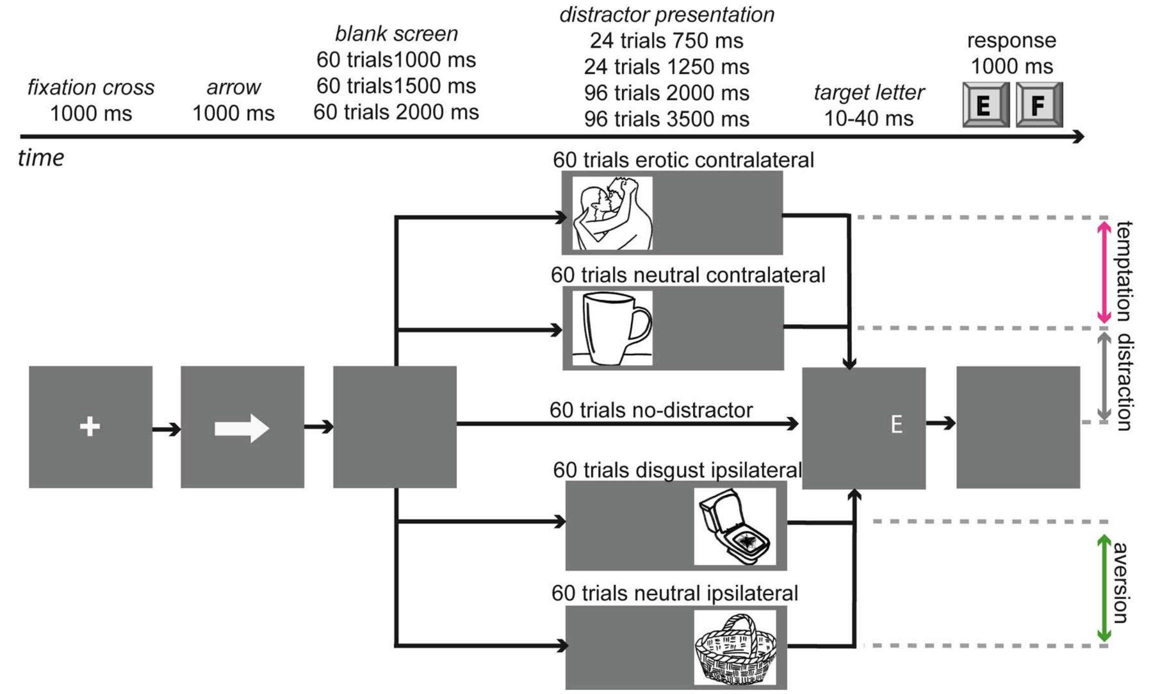

FIGURE 1 | Display of the trial Schema. Each trial starts with a fixation cross followed by an arrow indicating the location of the next target letter 5.9° of visual angle left or right from the center. After the arrow presentation the screen was empty for a variable delay. Drawings are placeholders for photographs from the International Affective Picture System (Lang et al., 2008) and the internet.

most repulsive disgusting pictures, and the most neutral pictures were selected and matched for brightness and picture complexity (see Appendix B for mean picture ratings, brightness, complexity, and red, blue, and green hue). There were 240 images (60 erotic, 60 disgusting, 120 neutral). Each picture was presented only once within the task.

Eyetracking data were acquired using a video-based eyetracker (sampling rate: 250 Hz, spatial resolution: 0.05°, Cambridge Research Systems, UK). Participants were seated 36 cm from the screen with their chin and forehead touching a chin rest. The refresh rate of the monitor was 60 Hz. Note that, due to the monitor refresh rate, true image durations differ slightly from the ones reported in **Figure 1**.

Questionnaires

Three self-control questionnaires were used: (1) the Brief Self Control Scale (Tangney et al., 2004), (2) the Self-Regulation Scale (Diehl et al., 2006), and (3) the reverse score of the Barratt Impulsiveness Scale-11 as a measure of the counterpart of self-control (Patton et al., 1995). Participants completed these online at home prior to the start of the experiment. Since these three questionnaires are highly correlated, we reduced these data to one general self-report score using factor analysis (see Results). As an estimate of reliability, Cronbach's alpha was calculated.

Unsolvable Anagram Task

A computer version of the unsolvable anagram task was used. Participants were provided with a letter sequence on the screen. The task was to find a word by sorting the letters (using all letters and each letter only once). There were four solvable anagrams of increasing complexity, followed by one unsolvable anagram (see Appendix D for the list of anagrams used). Participants wrote down the solved anagram on a piece of paper and then continued to the next anagram by a button press. Participants were told that they could continue to do the task as long as they liked and could call the experimenter whenever they wanted to stop. The task ended if participants (1) called the experimenter because they did not want to continue, (2) gave up on the unsolvable anagram by clicking the "next anagram" button, or (3) had tried to solve the unsolvable anagram for 15 min. The time until the participants gave up on the first anagram, for which they did not find a solution, was taken as the dependent measure of self-control (thus, the maximum time is 15 min). Because this experiment entails only one target trial, it is not possible to calculate internal consistency reliability.

Delay of Gratification

After 2 h during which participants did not eat, they were asked which of five different types of small chocolate sweets they preferred. After making the choice the participants were seated in a laboratory room and were presented with a plate with the unpacked chocolate. Participants were told that they could either eat the chocolate right away or could get double the amount in 45 min. Participants were then left in the room to make a decision. After 5 min the experimenter came back. At that point the chocolate had either been consumed or it was taken away for providing double the amount later. After the choice participants answered a questionnaire on their choice behavior, which was based on Rosati et al. (2007, Appendix C). This procedure was chosen in order to minimize confounding effects that limit the interpretation of delay task using unhealthy snacks in adults such as dietary restraints (Rosati et al., 2007) or interpretation of timing parameters (McGuire and Kable, 2013). Because this experiment entails only one target trial, it is not possible to calculate internal consistency reliability.

Stroop Task

In the Stroop task (e.g., De Houwer, 2003), color words were displayed in different ink colors. Participants indicated the color of the word by pressing a button with the index fingers of their left or right hand. Two colors were assigned to the right hand button and two colors where assigned to the left hand button. Trials were congruent (50%) if the color word was the same as the ink color it was displayed in. Trials were incongruent (50%) if the color word did not match the ink color it was displayed in. Trials started with a fixation cross presented for a variable duration (1100, 3100, or 5100 ms). Afterwards the color word was presented for 300 ms followed by a fixation cross presented for 600 ms, during which participants could react. The difference between incongruent and congruent items (i.e., the Stroop effect) was used as a measure for self-control during neutral distraction, with a big difference corresponding to low self-control. Note that the task additionally allows for the distinction between (a) merely semantically incongruent and (b) semantically plus response incongruent items. Because we were interested in the general Stroop effect, we did not differentiate between these types of incongruence. Split-half reliability was calculated by correlating the Stroop effect (incongruent minus congruent) of odd trials with even trials while controlling for the three conditions (congruent, semantically incongruent, semantically and response incongruent).

Data Analysis of the Self-Control Task

Analysis of the Task Effects

The analysis of the task effects was performed in Matlab (MATLAB version 2012b, Natick, Massachusetts: The MathWorks Inc.). For each condition the mean RT of all correct trials and the percentage of errors were calculated. In order to evaluate participants' gaze path during distraction, mean gaze distance from the center point of the target location was estimated across time bins of 100 ms starting at distractor onset for all on-screen measurements. For the duration of 750 and 1250 ms the final bin contained only 50 ms. Additionally, in order to compare the different conditions, the means and the standard deviation of the 100 ms time bins were averaged across the entire duration. The standard deviation of the gaze distance was included as a measure of exploration behavior (i.e., how much participants looked around during the presentation of distractors). For the no-distractor condition, eyetracking recordings started 100 ms prior to target presentation during the delay between arrow and target. Eye gaze location during these 100 ms was taken as control condition for the entire period of the neutral distractor picture presentation (up to 3500 ms). This was done because participants' gaze location in the final 100 ms prior to target onset should best reflect gaze location while expecting the target to occur. In order to evaluate the influence of aversive events, the disgust condition was compared to the neutral ipsilateral condition. The influence of temptation was estimated by comparing the erotic to the neutral contralateral condition. Neutral distraction was estimated by comparing the neutral distraction condition with the no-distractor condition.

Analysis of Correlations within the Task and with Other Self-Control Measures

All following data analysis steps were performed using SPSS (IBM SPSS Statistics 19). For the correlation analyses we used mean RTs (not the error data), because the distribution of the error rates was skewed with many participants making relatively few errors. Therefore, RTs can be assumed to be more sensitive in measuring individual differences in self-control. Three RT scores were calculated: aversion (disgust minus neutral ipsilateral), temptation (erotic minus neutral contralateral), and neutral distraction (neutral contralateral minus no-distractor condition). In order to relate task performance to questionnaire responses, a total self-control task score was also calculated by calculating the mean RT scores for aversion, temptation, and neutral distraction and then multiplying this by minus one. The multiplication by minus one was performed because the sum score of aversion, temptation, and neutral distraction refers to the degree of loss of control and not to self-control. In order to compare our task directly to other measures of self-control, we multiplied the "loss of control" score by minus one. Thus, the following formula was used for calculating the total score:

$$\begin{aligned}&\text{Total self-control task score} =\\&-1 * (\{[\mathrm{RT}_{\mathrm{disgust}} - \mathrm{RT}_{\mathrm{neutral\_ipsilateral}}]\\&+ [\mathrm{RT}_{\mathrm{erotic}} - \mathrm{RT}_{\mathrm{neutral\_contralateral}}]\\&+ [\mathrm{RT}_{\mathrm{neutral\_contralateral}} - \mathrm{RT}_{\mathrm{no-distractor\_condition}}]\}/3)\end{aligned}$$

For all correlation analyses Pearson correlations are reported. For within-task correlations, where we claim that there is *no* association between measures, we additionally report attenuation adjusted correlation coefficients. Attenuation adjusted correlations provide an estimate of the strength of a correlation under the premise that there would be no measurement error. The rationale behind attenuating is that null results may be the consequence of measurement errors instead of being the consequence of orthogonality. Attenuation adjusted correlations were calculated by dividing the correlation of the two variables (r_{xy}) by the square root of the multiplied reliabilities of the two correlated variables (r_{xx} and r_{yy}; see Spearman, 1904 on attenuation adjusted correlation coefficients).

$$\text{Attenuation adjusted correlations of variable x and y} = \frac{(\text{correlation of x and y})}{(\text{square root(reliability x} * \text{reliability y}))}$$

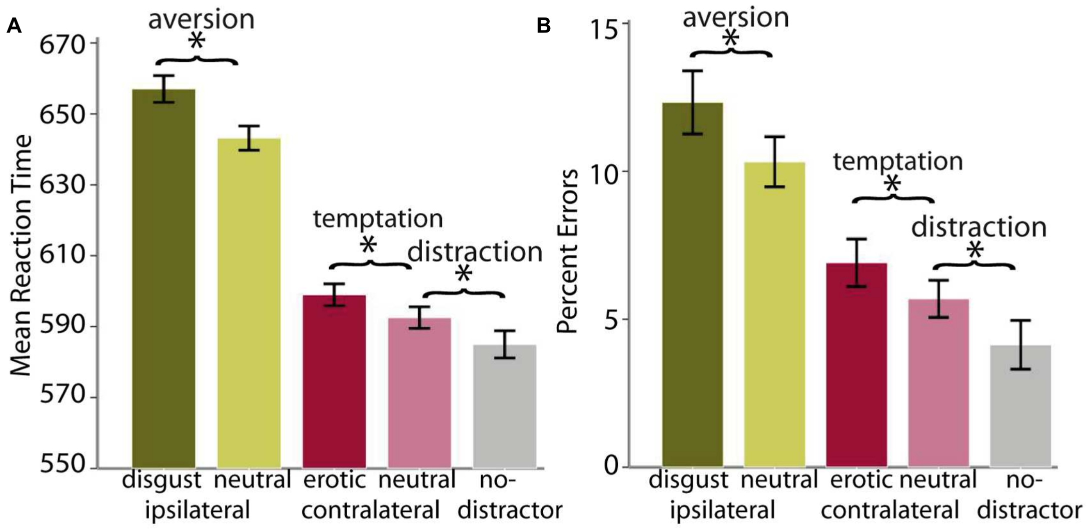

FIGURE 2 | Display of behavioral data. (A) Mean RTs and **(B)** percent errors. Asterisks (*) indicate a significant difference at $p < 0.05$, Bonferroni corrected for the six comparisons. Error bars represent the 95% confidence interval for within-subjects comparisons (Loftus and Masson, 1994).

Partial eta square (η_p^2) is reported as measure of effect size for significant group and condition comparisons.

Split-Half Reliability

For each measure of our self-control task, split-half reliability was calculated. For this, the pictures of each condition were divided into two halves. This was done by matching for distractor presentation duration and the response button but otherwise assigning pictures randomly into the two halves. From these, two difference-scores were calculated for each measure (aversion, temptation, and neutral distraction and a total self-control task score), as described above. Pearson's correlation coefficients between the two versions of each measure were then calculated as estimates of reliability.

RESULTS

General Results for the Conventional Self-Control Measures

Questionnaires

Because the three self-control questionnaires were highly correlated (all $r > 0.5$, all $p < 0.001$) and a factor analysis revealed that a single factor could explain 72 percent of the variance, they were reduced to this one factor using the regression method implemented in the SPSS factor analysis toolbox. Correlations between this factor and the Self-Regulation Scale, the Brief Self-Control Scale, and Barratt's Impulsivity Scale were 0.86, 0.87, and −0.82, respectively. All three scales showed a high reliability in our sample: Self-Regulation Scale ($\alpha = 0.85$), Brief Self-Control Scale ($\alpha = 0.83$), and Barratt's Impulsivity Scale ($\alpha = 0.82$).

Unsolvable Anagram Task

Only 44 participants were able to solve all anagrams besides the unsolvable one. All other participants failed at an earlier anagram [anagram number (*n number of participants*): 1 *(13)*, 2 *(31)*, 3*(26)*, 4*(2)*]. The time in minutes until participants gave up on the first anagram that they were not able to solve was taken as the dependent variable ($M = 5$ min and 55.32 s, $SD = 4$ min and 23.32 s).

Delay of Gratification

For the analysis of this task, 31 participants were excluded because one of the three following criteria applied as measured by the post-experimental questionnaire: the participant indicated that they (1) were not hungry or had no appetite (2) did not like chocolate (3) were on a diet or were trying to control chocolate intake. Of the remaining participants, 24 participants chose to eat one piece of chocolate immediately and 61 chose to wait for two pieces of chocolate.

Stroop Task

Comparison of the congruent condition ($M = 577.21$, $SD = 14.26$) with the incongruent condition ($M = 604.55$, $SD = 14.26$) revealed a significant effect on RTs, $t(115) = 2.712$, $p = 0.008$. Reliability estimates revealed a reliability, $r(114) = 0.41$, $p < 0.001$.

Main Task Effects: Comparison of the Different Conditions of the Self-Control Task

Reaction Times and Error Rates

Participants were generally slower and made more errors in the self-control conditions compared to their respective control conditions, indicating that additional processing was involved

TABLE 1 | Results of within-subject *t*-tests of percent errors and reaction times (RTs).

Measure	Comparison	*M*(*SD*) difference	*t*-value	*p*-value	η^2
Percent errors	Disgust vs. neutral ipsilateral	2.00 (5.82)	3.56	0.001	0.10
	Erotic vs. neutral contralateral	1.29 (4.81)	2.89	0.005	0.07
	Neutral contralateral vs. no-distractor	1.54 (4.45)	3.88	<0.001	0.12
Reaction times	Disgust vs. neutral ipsilateral	14.44 (24.53)	6.34	<0.001	0.26
	Erotic vs. neutral contralateral	6.83 (21.04)	3.49	0.001	0.10
	Neutral contralateral vs. no-distractor	7.55 (27.41)	2.88	0.005	0.07

For all comparisons df = 115.

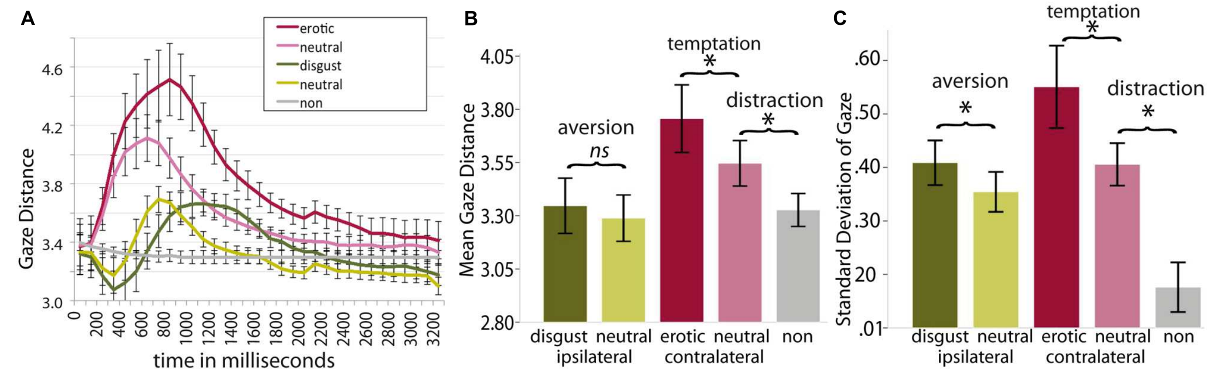

FIGURE 3 | Display of eyetracking data. (A) the path of gaze distance in visual angle from the target during distractor presentation starting at distractor onset, **(B)** mean of gaze distance, **(C)** and of the standard deviation of gaze distance during the entire distractor presentation. Asterisks (*) indicate a significant difference at $p < 0.05$, Bonferroni corrected for the six comparisons. Error bars represent the 95% confidence interval for within-subjects comparisons (Loftus and Masson, 1994).

TABLE 2 | Results of within-subject *t*-tests of the mean gaze distance and the standard deviation of the gaze distance in degree of visual angle.

Measure	Comparison	*M(SD)* difference	*t*-value	*p*-value	η^2
M gaze distance	Disgust vs. neutral ipsilateral	0.05 (0.44)	1.38	0.17	0.02
	Erotic vs. neutral contralateral	0.21 (0.58)	3.79	<0.001	0.11
	Neutral contralateral vs. no distractor	0.22 (0.80)	2.70	0.005	0.07
SD of gaze distance	Disgust vs. neutral ipsilateral	0.05 (0.20)	2.83	0.006	0.07
	Erotic vs. neutral contralateral	0.14 (0.39)	3.83	<0.001	0.12
	Neutral contralateral vs. no distractor	0.23 (0.38)	6.23	<0.001	0.26

For all comparisons df = 109.

when tempting, aversive or distracting stimuli were present (**Figure 2**). As displayed in **Table 1**, all three *t*-tests yielded significant results for RTs and error rates ($p < 0.05$, Bonferroni corrected for the six comparisons). The exact values for mean ratings of valence, arousal, and attraction as well as RTs and error rates can be found in Appendix E. Note that the distribution of error rates was significantly skewed, with most participants committing few errors. Despite this, for simplicity, results of parametric analyses are reported here. However, non-parametric analyses of the error data yielded similar results (Appendix F).

Eye Tracking Data

Gaze path, mean gaze distance, and standard deviation of the gaze distance are displayed in **Figure 3**. The gaze path analysis revealed an effect of distraction for the different conditions starting 200 ms after distractor onset and peaking at around 1000 ms after distractor onset (**Figure 3A**). The conditions were compared over the whole distractor presentation period by calculating the means for aversion, temptation, and neutral distraction (see **Table 2** for the results of *t*-testing). There was a significantly higher gaze distance during the erotic condition in comparison to the neutral contralateral condition and during the neutral contralateral condition in comparison to the no-distractor condition (**Figure 3B**), but not for the disgust condition compared with neutral ipsilateral distraction. Additionally, aversion, temptation, and neutral distraction all resulted in a higher standard deviation of the gaze distance as compared to their respective control condition (**Figure 3C**; $p < 0.05$, Bonferroni corrected for the six comparisons, see Appendix E for exact values of all conditions). In order to calculate the precision of the eye tracking calibration the mean deviation from target dots during calibration was averaged across sessions and participants. The calculation revealed a mean deviation of 0.22° and a standard deviation of 0.01° visual angle, indicating high accuracy of eyetracking data.

TABLE 3 | Split-half correlations of self-control sub-scores (aversion, temptation, and distraction RT scores) reveal significant reliability and are displayed along the first diagonal of the table.

	Aversion	Temptation	Distraction
Aversion	$r(114) = 0.24$, $p = 0.009^*$		
Temptation	$r(114) = 0.04$, $p = 0.67$, a(r) = 0.14	$r(114) = 0.30$, $p = 0.001^{**}$	
Distraction	$r(114) = -0.03$, $p = 0.72$ a(r) = −0.04	r (114) < 0.01, $p = 0.93$ a(r) = −0.03	$r(114) = 0.41$, $p < 0.001^{**}$
Unsolvable anagrams	$r(114) = 0.02$, $p = 0.81$	$r(114) < -0.01$, $p = 0.98$	$r(114) = -0.03$, $p = 0.72$
	i_r(107) = −0.04, $p = 0.67$	i_r(107) = −0.02, $p = 0.82$	i_r(107) = −0.02, $p = 0.85$
Delay of gratification	$t(83) = 1.51$, $p = 0.13$	$t(83) = 1.51$, $p = 0.13$	$t(83) = 0.53$, $p = 0.59$
	i_t(76) = −1.32, $p = 0.19$	i_t(76) = 2.01, $p = 0.048^*$	i_t(76) = 0.31, $p = 0.75$
Stroop effect	$r(114) = -0.12$, $p = 0.19$	$r(114) = 0.04$, $p = 0.66$	$r(114) = 0.09$, $p = 0.34$
	i_r(107) = −0.04, $p = 0.64$	i_r(107) = −0.19, $p = 0.048^*$	i_r(107) = −0.08, $p = 0.38$

Within-task correlation of the sub-score with each other reveals no significant correlation. Correlations attenuated for reliability are also reported [a(r)] but reveal correlations that are not much higher, suggesting independent components of self control. Correlations with the eyetracking scores (i_r) and t-testing with eyetracking scores (i_t) are additionally reported. Correlation across self-control measures using aversion (unsolvable anagrams), and distraction (Stroop) and t-testing of temptation (delay of gratification) reveal that eyetracking scores of temptation correlate positively with delay of gratification and negatively with the Stroop task RT effect while all other associations are insignificant. Asterisks (*) indicate significant correlations at 0.05. Double asterisks (**) indicate that correlations survive Bonferroni correction for multiple comparison (multiplication of p-value by total numbers of calculations reported in the table; in this case 15 number of comparisons) at 0.05.

Split–Half Reliability of all Reaction Time Task Measures

The reliability calculations revealed significant reliability for all task scores with a reliability of $r = 0.44$, $p < 0.001$, for the total task score. Furthermore, the three task sub-scores (aversion, temptation, and neutral distraction) showed a significant reliability (**Table 3**). Additionally to the reliabilities for the sub-scores, we calculated reliabilities for each condition (instead of using difference scores) as these are more comparable to questionnaire scores (which do not rely on difference scores either). This analysis revealed a reliability of $r = 0.90$, $p < 0.001$, for the erotic condition, of $r = 0.89$, $p < 0.001$, for the disgust condition of $r = 0.90$, $p < 0.001$, for the neutral contralateral condition, and of $r = 0.74$, $p < 0.001$, for the condition where no distractor is presented, indicating much higher reliability for single task scores than for difference-scores.

Correlations within the Task and with Conventional Self-Control Measures

Within-Task Correlations of Reaction Time Effects between Aversion, Temptation, and Neutral Distraction for the Self-Control-Task

To assess if participants who were good at one of the self-control conditions were also good at the other conditions, we calculated within-task correlations of RT effects between the three self-control task measures. For the results see **Table 3**. Aversion and temptation were not correlated, neither were disgust reaction and neutral distraction. Temptation and neutral distraction were negatively correlated, $r(114) = -0.31$, $p = 0.001$. This negative correlation probably arose because these two variables are not independent: the neutral condition serves as the experimental condition in the neutral distraction comparison and as the control condition in the temptation comparison. In order to

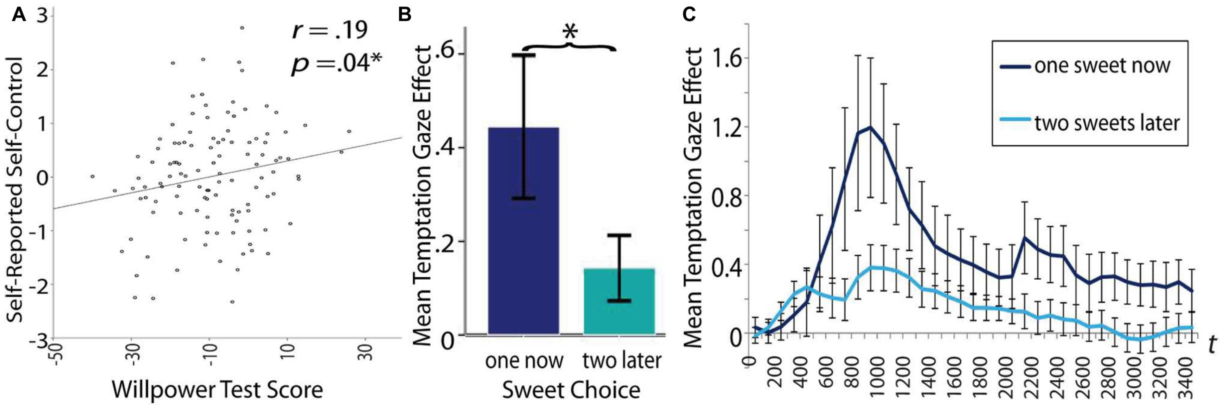

FIGURE 4 | Display of the association between different willpower measures. (A) positive correlation between the total willpower task score and self-reported willpower, **(B)** the mean gaze distance temptation effect (distance from target letter in trials with erotic distractors minus distance in neutral trials) was significantly higher for participants who chose the small immediate reward than for those who chose to wait for the larger, but delayed reward (error bars represent 95% confidence intervals). **(C)** This association between choice in the delay of gratification task and distractibility by tempting pictures is displayed over the whole distractor period starting at distractor onset (error bars represent the standard error of the mean). Asterisks (*) indicate a significant difference at $p < 0.05$.

test this, we split the data set for the neutral condition and calculated two neutral contralateral conditions with every second trial in each condition. All even trials served as the control condition for temptation, and all odd trials served as the experimental condition for the neutral distraction comparison, revealing no significant correlation (see **Table 3**). The within-task correlations indicate that the three measures (aversion, temptation, distraction) measure different components of self-control.

Correlation of Self-Control Measures with Self-Reported Self-Control

Only the total score of our task correlated significantly with self-report ($r = 0.19$; **Figure 4A**), in contrast to the conventional tasks which did not show any significant relation (**Table 4**). The correlation of our task with self-report remained significant even when controlling for gender, intelligence, mean hours of sleep on the day of testing, and age, $r(114) = 0.23$, $p = 0.013$. Correlation of the three task sub-scales (aversion, temptations, and neutral distraction) with the questionnaire score revealed a correlation of temptation with self-reported self-control and no correlation of neutral distraction and aversion with self-reported self-control. This might indicate that the positive correlation of the total score with self-report may be mainly driven by the temptation sub-score (see **Table 3**). The results of the correlation analysis of the anagram task and the Stroop task with self-report and t-testing of participants who delayed gratification ($M = -0.12$, $SD = 1.07$, $n = 24$), in contrast to those who did not ($M = 0.09$, $SD = 1.08$, $n = 62$) revealed no relation between conventional self-control task and self-reported self-control. These results indicate that our task might more closely assess what is measured by self-control questionnaires compared to conventional tasks.

Correlations between Domain-Specific Reaction Time Effects and Domain-Specific Conventional Self-Control Tests

There were no significant correlations between the domain-specific conventional self-control tests (anagrams, delay of gratification, and Stroop) and the respective domain-specific self-control RT scores (aversion, temptation, and neutral distraction; see **Table 4**). That is, there was no relation between the RT parameter of aversion and the time participants persisted with the unsolvable anagram task, no difference between participants choosing the small chocolate immediately ($M = -12.67$, $SD = 18.28$, $n = 24$) and participants waiting for two chocolates later ($M = 5.28$, $SD = 20.91$, $n = 62$), nor was there a relation between the parameter of neutral distraction and the Stroop incongruence effect.

TABLE 4 | Correlation of self-control tasks with self-reported self-control.

Task	Correlation with self-reported self-control
Self-control sum-score	$r(114) = 0.19$, $p = 0.042$*
Aversion task score	$r(114) = 0.02$, $p = 0.86$
Temptation task score	$r(114) = 0.19$, $p = 0.042$*
Distraction task score	$r(114) = -0.11$, $p = 0.25$
Unsolvable anagrams	$r(114) = -0.06$, $p = 0.52$
Stroop effect	$r(114) = 0.05$, $p = 0.61$
Delay of gratification	$t(83) = -0.85$, $p = 0.40$

Our task shows a correlation with self-report in contrast to the conventional tasks, which do not show any relation. Only the temptation sub-score of our task shows a correlation with self-report, whereas disgust and distraction do not correlate with self-report. Stars (*) indicate a significant correlation at 0.05. Note that none of the reported correlations would survive Bonferroni correction for multiple comparisons.

Correlations between Domain-Specific Task Eyetracking Effects and Conventional Self-control Tests

Comparisons of the domain-specific impulse eyetracking parameters (aversion, temptation, and neutral distraction separately) with the respective self-control tasks revealed that the gaze distance scores in the temptation condition were associated with the external measure of temptation, while all other comparisons revealed no significant associations (see **Table 3**). Specifically, participants who chose to eat the small chocolate immediately showed a higher gaze distance to the target location during presentation of erotic stimuli (as compared to neutral stimuli; $M = 0.44$, $SD = 0.74$, $n = 24$) in comparison to participants who patiently waited for two pieces of chocolate later ($M = 0.15$, $SD = 0.52$, $n = 54$; **Figures 4B,C**), $\eta^2 = 0.05$. Furthermore, correlating across domains revealed a significant negative correlation between the temptation gaze distance effect and the Stroop RT effect, but no relation for any other combination (**Table 3**). Note that the significant negative correlation between the temptation gaze effect and Stroop becomes insignificant when two possibly influential outliers are excluded from analysis (see Appendix G for the scatter plot and potential outliers).

DISCUSSION

In our study we put self-control to the test by using aversive, tempting, and neutral pictures in an eye gaze task. We show robust behavioral effects of aversion, temptation, and neutral distraction reflected in higher error rates and RTs as compared to control conditions. Gaze pattern analysis reveals higher gaze distance from the target location during presentation of erotic pictures as compared to neutral pictures (temptation), and for neutral pictures compared to the no-distractor condition (neutral distraction). Additionally, there was more looking around during aversion, temptation, and neutral distraction, reflected in a higher standard deviation of the gaze distance to the target. The eyetracking data thus indicate that the three distractor types indeed led to behavioral effects and not merely to arousal reactions. The total self-control task score obtained from the task (reflecting the ability to resist any of the three distractions) correlated with self-reported self-control. This indicates that our task measures a construct that is overlapping with self-report measures. Importantly, performance in the three self-control conditions did not correlate with each other, suggesting high individual differences in the effect of different emotions on information processing. This suggests that resisting pleasant temptations, enduring aversion, and ignoring neutral distractions are central and independent aspects of self-control.

The Eye Gaze Task as a Measure of Self-Control

Our data indicate that our task can indeed measure individual differences in self-control, and that it might be better suited for this than conventional measures. The score obtained from our task correlated significantly with self-reported self-control. In contrast, neither the anagram task, nor the delay of gratification task, nor the Stroop task correlated with self-report in this study. This is in line with a meta-analysis performed by Duckworth and Kern (2011). They showed that many commonly used cognitive self-control tasks do not correlate with self-reported self-control or correlate only weakly. The reason for this absence of correlations might be that conventional tasks only capture a fraction of self-control (Duckworth and Kern, 2011). In contrast, the advantage of our task is that we focus on attentional control assumed to be an important component of self-control and that provide a measure of various components of attentional control within one task: enduring aversive distractors, resisting tempting distractors, and ignoring neutral distractors.

Interestingly, correlation of the task components (aversion, temptation, and neutral distraction) with the questionnaire score revealed that temptation by itself is correlated with self-reported self-control ($r = 0.19$), whereas aversion and neutral distraction are not. This might indicate that the questionnaires used in this study mostly assess individual differences in resisting temptations, but do not measure individual differences in standing aversions or ignoring neutral distractions. This further highlights the need for investigating different impulse types more closely, also on a questionnaire level.

Another advantage of our paradigm is that the impulse categories can easily be extended or exchanged depending on the impulse category of interest. This can be particularly beneficial when the aim is to study patient groups whose self-control changes in reaction to particular impulse categories, for instance in addiction or eating disorders. For example, it has been shown that addiction might lead to an increased capture of attention and automatic approach reactions regarding the addictive substance (Field et al., 2007; Friese et al., 2010; Wiers et al., 2013). Thus, to study addiction, our task could be used with pictures of the addictive substance as tempting distractors.

Despite these promising findings, our task should be further validated as a measure of self-control. One reason is that the correlation with self-report does not substantially exceed the correlations reported by Duckworth and Kern (2011) and does not survive Bonferroni correction for multiple comparison. Furthermore, a prediction of real life self-control on the basis of task results could be seen as more convincing evidence for construct validity than a correlation with self-report. The reason is that questionnaires, although having many advantages such as high internal consistency and reliability (Carver and White, 1994; Tangney et al., 2004; Diehl et al., 2006), still rely on subjective judgment of one's own personality. This can be problematic, because correlations with external measures such as school performance may be spurious if the participants judge their own self-control based on their school success. The reason is that school success might not be solely related to self-control, but is profoundly influenced by other variables such as intelligence (e.g., Spinath et al., 2010), memory skills (Aronen et al., 2005), socioeconomic status (e.g., White, 1982) or self-efficacy believe (Zajacova et al., 2005). If participants judge themselves based on their school success, but school success is profoundly influenced by other factors, a positive correlation with self-report might not be meaningful for validation of the questionnaires.

Further validation in addition to questionnaires is therefore necessary. This could be accomplished by investigating participants that face a particular self-control challenge (e.g., dieters, Hare et al., 2009). The task design allows exchanging current stimulus material with pictures that may challenge self-control for that particular group (e.g., in the case of dieters, snack pictures). Another possibility for validation may be the use of experience sampling. Hofmann et al. (2012) used a beeper that samples the presence of self-control problems, the kind of problem and the executed behavior (controlled vs. not controlled) several times per day. On average, participants reported a self-control conflict every second time they were beeped. A correlation with these kinds of real-world self-control measures would be very convincing.

One could argue that a limitation of our task is that it refers to a relatively short time scale, as the reward for successful self-control is obtained already 2 weeks after testing. Moreover, the actual duration of active goal pursuit (i.e., the task itself) was only about 25 min. This relatively short time frame may also result in stronger effects of state factors that may influence self-control (e.g., blood glucose, Baumeister et al., 2007). In contrast, some (but certainly not all) real-life situations require the exertion of self-control over months or years (e.g., graduating, keeping a life-long healthy diet) and it was suggested that this long-term grit might be an even more essential key to life-success than relatively short-term self-control ability (Duckworth et al., 2007). Since some questionnaire items and temporal discounting items of conventional measures involve such potential long-term goals, this is one advantage of questionnaires and temporal discounting over our self-control task. However, there are also many real-life self-control situations in which the goal can be reached relatively soon, such as resisting eating the pralines that you bought as a gift or cleaning the toilet. Additionally, long-term goal pursuit can be decomposed into several smaller self-control situations. For example, graduating might be a long-term goal, but writing an essay might take just a few hours and can serve the relatively short-term sub-goal to pass one particular class. Therefore, we think that our task captures a wide range of everyday self-control problems.

A potential factor that might have resulted in a decrease of correlation coefficients in our study is the relatively homogenous group with all participants being university students or former students. The advantage of this homogeneous sample is a reduction of confounding factors. However, a more heterogeneous sample may result in higher variance of self-control scores and thereby a higher probability of detecting correlations.

The total task score of our task exhibited reliability similar to the reliability of the Stroop effect (our Task: $r = 0.46$, Stroop effect: $r = 0.41$) and similar to the reliability reported for Stroop in the literature ($r = 0.46$, Strauss et al., 2005). For emotional Stroop even lower reliabilities have been reported in previous studies (Strauss et al., 2005; Dresler et al., 2012) indicating that our task's internal coherence is comparable to commonly used tasks. Additionally, single condition reliabilities reveal a much higher reliability (r between 0.75 and 0.90), indicating that reliabilities are lower when using difference scores than when using single task scores. It has to be kept in mind that in single score reliability estimates, confounding factors may boost reliability-measures because general response tendencies such as fast reacting or extreme responding that do not relate to the trait of interest can be consistently high or low in particular participants leading to exaggerated correlations in split-half estimates without increasing reliability for measuring the trait of interest.

The generalizability to populations of a different moral background or a homosexual population should be further investigated, as the current study does not allow us to draw any conclusions in that direction. See Appendix H for gender comparison (no significant difference for error rates, RTs and gaze distance, only for standard deviation of the gaze distance). Furthermore it should be noted that, although we matched pictures on brightness and complexity and the compared categories do not differ significantly on these dimensions, stimuli could be matched even more precisely regarding these and other dimension such as color, line properties and number of people in the image in future studies, as low level image properties have been shown to guide attention and might explain why participants were more distracted by erotic and disgusting pictures than their respective control stimuli.

Resisting Temptations, Enduring Aversion, and Ignoring Neutral Distraction as Independent Aspects of Trait Self-control

The self-control sub-scores (aversion, temptation, and neutral distraction) seem to measure different aspects of self-control. This is reflected in the absence of correlations between these scores across participants. Thus, people who have a hard time suppressing approach reactions toward pleasant stimuli (e.g., resisting a cake during a diet) are not necessarily the ones who have a hard time suppressing avoidance reactions concerning unpleasant situations (e.g., going to the dentist). Distractibility by neutral distractors also did not correlate with distractibility by erotic pictures or by disgusting stimuli. This absence of correlations cannot be explained by an absence of reliability, as split-half correlations reveal moderate reliabilities for all three sub-scores. Thus, our findings indicate that resisting temptations, enduring aversion, and ignoring neutral distraction are independent aspects of self-control. Note, that temptation and distraction reliability even survive conservative Bonferroni correction for multiple comparisons, whereas aversion does not survive this correction and should therefore be interpreted with caution.

These results suggest that the impulsive system in the dual-system approach to self-control (Hofmann et al., 2009) should be subdivided (Heatherton and Wagner, 2011). Dual-system approaches typically assume that self-control challenges entail a conflict between an impulsive system and a reflective system (e.g., Epstein, 1990; Metcalfe and Mischel, 1999; Strack and Deutsch, 2004; Hofmann et al., 2012). Although we agree with the basic assumption of this model, our data imply that reality is more complex, and that at least the impulsive system consists of several sub-components. Our data indicate that one should differentiate impulses with respect to aversion, temptation, and distraction. We cannot, however, determine whether the three components are sufficient for completely explaining self-control behavior, or which other facets might be relevant. Future studies should investigate this.

Of note, our study attempted to decompose the impulsive part of the dual-system framework. We therefore cannot draw conclusions regarding the reflective system. This means that our data do not directly contradict Baumeister et al.'s (2007) hypothesis about the reflective system relying on a single, domain-general control resource. However, as there is also evidence for separable control processes depending on the content of attentional control, we consider it important to similarly investigate a possible decomposition of the reflective/control system based on the theoretical assumption that several higher cognitive processes are involved in self-control (Kuhl and Goschke, 1994; Buhringer et al., 2008; Goschke, 2012).

Correlations between the Task Sub-scores and Conventional Measures of Self-Control Ability

We also analyzed correlations between the sub-scores with previously used tasks that might be considered to measure these sub-components. We expected that distractibility by aversion would correlate with performance on the unsolvable anagram task, that distractibility by temptation would correlate with delay of gratification, and that distractibility by neutral distraction would correlate with Stroop task performance. We could only confirm the second of these hypotheses. That is, participants who chose to eat a tempting sweet directly instead of waiting in order to receive two sweets later also showed a higher distractibility by erotic pictures. More specifically, their gaze distance from the target location was higher. This effect was not present when looking at RT data, indicating that eyetracking data might in some cases be more sensitive in detecting individual differences concerning susceptibility to temptation. Note that the absence of a relation between our temptation RT score and delay decision may also be explained by problems in interpreting the delay task in adults. As has been noted previously, interpretation of the delay task as a measure of self-control can be problematic (Mischel et al., 2011; McGuire and Kable, 2013). However, we designed the task in a manner aimed at reducing confounding effects. Our task measures of aversion did not correlate with the external measure of aversion, the anagram task; and our task measures of distraction did not correlate with the external measure of neutral distraction, the Stroop task. As current questionnaires are not designed to distinguish between aversions, temptations, and neutral distraction, we have no means of determining the relation between task sub-scores and self-report of these facets of self-control. Development of a questionnaire that includes these facets may be conducive to the investigation of individual differences in self-control when having to rely on self-report.

Our results suggest that our measure of susceptibility for temptation (using erotic pictures) generalizes to other types of temptations and situations (i.e., decision-making about food). In contrast, our measure of aversion does not seem to measure the same ability as the unsolvable anagram task. The reason for this might be that unpleasantness induced by disgust is different from unpleasantness induced by a mentally exhausting task. One could also argue that our measure of enduring unpleasantness (aversion) is more pure than the anagram task, because performance on the anagram task also depends on factors other than the ability to endure unpleasantness. For example, we observed that participants who were particularly good with solvable anagrams also kept going longer on the unsolvable anagram, suggesting that continuing on an unsolvable task might depend critically on the experience with such tasks and the expectation of solving it, rather than merely on self-control. This is in line with the idea that self-efficacy beliefs strongly influence self-control ability (Lippke et al., 2009; Schwarzer, 2009). Furthermore, the anagram task might leave some room for strategies and meta-cognitive thoughts of the participants, which might obscure the real correlation between the tasks. Likewise, the validity of our self-control task might also be lowered by the possibility that some participants might have tried to strategically select some trials as "non-control" trials. For example, they might have decided to enjoy the erotic images on some trials, thereby risking not to win the lottery-based bonus payment at the end of the experiment. Assessing risk aversion and an according post-experimental questionnaire on strategic behavior might have provide additional information in this regard.

The absence of a correlation between Stroop task performance and distractibility by neutral pictures seems surprising, as both are attentional paradigms. In the Stroop task, the written word is supposed to distract participants from naming the display color of the text. However, in contrast to our distraction condition, this is an active interference induced by incongruence and not a mere distraction effect. In contrast, our task involves selective spatial attention. Furthermore, Nee et al. (2007) revealed that partially distinct neural mechanisms underlie different sorts of interference resolution tasks including Stroop and Flanker paradigms, suggesting that they might rely on different cognitive mechanisms. Additionally, the Stroop task contains a fairly artificial conflict situation, whereas using photographs as in our task might resemble real-life conflicts more accurately. Finally, the strength of the interference effect of words depends on practice effects (Cohen et al., 1990), which might vary across participants, compromising the extent to which inter-individual differences in the Stroop effect mirror self-control.

A possible future approach may include a more specific sub-categorization of distractor types (e.g., the use of disgusting, sad, and annoying pictures for aversion, and use of erotic, food and emotionally positive pictures for temptation) in order to investigate whether an even higher categorization increases the explanatory power of our task. Furthermore, a future approach may entail the use of real-life self-control conflicts categorized into the different impulse types for validating the task results.

Eye Gaze Patterns for Aversion, Temptation, and Distraction

Gaze pattern analysis reveals higher gaze distance for temptation and for distraction, but not for aversion as compared to the respective control conditions. Additionally, there was more looking around for all three self-control sub-components, reflected in a higher standard deviation of the gaze distance. This suggests that for temptation and distraction, the pictures attracted overt attention, suggesting that the attentional capture of objects can be an indicator for their attractiveness and that attention allocation forms an important mechanism in self-control behavior. This is in line with the findings that attentional deployment in toddlers is an important factor in predicting the ability to resist short-term temptations later in life (Sethi et al., 2000). Additionally, looking away from the tempting object has also proven to be a useful strategy in Mischel's delay of gratification experiment (Mischel et al., 1972), indicating that the degree of attention control can be used to predict self-control success.

One possible reason for why we, contrary to our prediction, did not find an effect of aversion on mean gaze distance is that aversion generally might not only trigger a reaction to look away, but also toward the picture, because of its high saliency. Furthermore, instead of looking away, participants might try to regulate their emotions in the face of disgusting pictures. This is in line with the finding that reappraisal forms a common strategy when regulating negative emotions and that this form of emotion regulation has also been found to be more effective in reducing negative affect than pure distraction (McRae et al., 2010). This might explain why aversion elicited different eye gaze correlates as compared to temptation or distraction. Note, that in the current task we cannot completely exclude the possibility that participants could recognize the target letter without fixating it. This could be insured by reducing letter size and presenting a mask after letter presentation in future studies.

CONCLUSION

In this work we advance beyond prior approaches to studying self-control by assessing attentional component processes of this trait. We present a self-control task in which participants have to control themselves in the face of aversive events, temptations, and neutral distractions using naturalistic stimuli. Our study indicates that self-control abilities concerning these three impulse categories form independent aspects of self-control.

AUTHOR CONTRIBUTIONS

All authors listed, have made substantial, direct and intellectual contribution to the work, and approved it for publication.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://journal.frontiersin.org/article/10.3389/fpsyg.2016.00382

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Competitive Game Play Attenuates Self-Other Integration during Joint Task Performance

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Joint task performance is facilitated by sharing and integrating each other's action representations. Research has shown that the amount of this so-called self-other integration depends on situational aspects related to the social context, including differences in the social relationship between co-acting individuals. There are indications that a cooperative relationship facilitates self-other integration while a competitive relationship results in more individualistic task performance. However, findings from previous studies in which the cooperative or competitive element was manipulated during task performance are inconsistent. Therefore, the present study aimed to manipulate the social relationship between two individuals prior to performing a social Simon task. This task is frequently used to measure self-other integration and distinction processes. A mixed-within-and-between-subjects design was used in which three groups of participants performed both a standard Simon task and a social Simon task after having played a Tetris game either individually, in cooperation with a co-actor, or in competition against another participant. Performance on the standard Simon task was not affected by the Tetris manipulation. However, a sustained effect of the induced cooperative versus competitive relationship was found on the social Simon Task. Less self-other integration was found in participants who had first played a competitive Tetris game compared to participants who had played a cooperative or solo version of the game. The current study thus demonstrates that an established cooperative or competitive relationship is sufficient to modulate the degree of self-other integration on subsequent joint task performance. Importantly, by using Tetris, attention to others' actions was beneficial both during cooperative and competitive game play and can thus not explain the competition-induced reduction of self-other integration.

Keywords: social Simon effect, self-other integration, social interaction, cooperation, competition

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INTRODUCTION

Interacting with other people is an important part of everyday life. In many daily activities, we perform a task together with another person such as a friend, spouse, colleague, or even a complete stranger. To successfully accomplish this, many processes are involved. We need to, for example, distinguish between our own actions and others', but also coordinate and integrate these actions accordingly. When performing a task jointly with another person, a cognitive representation of the actions and/or tasks of the other person is thought to facilitate successful joint performance (Sebanz et al., 2006; de Bruijn et al., 2011). The notion that people share each other's action representations during joint action is in line with concepts postulated in the theory of event coding (Hommel et al., 2001) and the ideomotor theory (Prinz, 1997). According to these theories, all actions are cognitively represented in terms of its action consequences. Observing someone perform an action activates the same cognitive representations as when we perform the action our self. Subsequently, when performing a task together with another person, a representation of the other's actions is automatically integrated into our own task representation, a process also known as self-other integration (see, e.g., Colzato et al., 2012).

Evidence that self-other integration is in general an automatic process comes from studies using a social version of the Simon paradigm in which the Simon task is shared between two individuals (Sebanz et al., 2003). In a standard Simon task (Simon and Rudell, 1967) participants have to respond to, e.g., the color of a stimulus presented left or right of a fixation cross by pressing one of two spatially located buttons. Due to automatic coding of the spatial location of stimuli and response buttons, task performance is facilitated when stimulus and response location are compatible but not when stimulus and response location are incompatible (Lu and Proctor, 1995). The difference in mean reaction time between compatible and incompatible trials is commonly referred to as the Simon effect. Interestingly, a similar compatibility effect is observed when the Simon task is distributed between two individuals. In this so-called social Simon task, two participants seated next to one another each respond to one of the two spatially presented stimuli, thus resulting in participants performing two complementary Go/NoGo tasks. As in the standard Simon task, people in this social version of the task also respond faster when stimulus and response location are compatible than when stimulus and response location are incompatible. In this case, the difference in reaction time on compatible and incompatible trials is referred to as the social Simon effect (SSE; Sebanz et al., 2003). The SSE is thought to follow from the integration of a cognitive representation of the co-actors task into one's own task representation (Sebanz et al., 2006; Dolk et al., 2014). According to the referential coding account by Dolk et al. (2014), the SSE emerges as a result of the perceived similarity between the action consequences of one's own task (e.g., a left button being pressed) and the action consequences of the co-actor's task (e.g., a right button being pressed). The spatial dimension distinguishes between the two action representations and is therefore needed as a reference to discriminate between the two action alternatives. As with the standard Simon effect, the SSE results from using this spatial dimension as a reference and is thus interpreted as reflecting the extent to which people integrate the action representations of another co-actor into their own cognitive representation during joint task performance. The SSE derived from the social Simon task is therefore often used as a measure for self-other integration and distinction processes (see, e.g., van der Weiden et al., 2016).

Recent research has shown that the amount of this self-other integration may be modulated by state variables including the relationship between actor and co-actor. For instance, individuals performing the social Simon task with a positive friendly acting co-actor showed a larger SSE than individuals performing the task with a negative unfriendly co-actor (Hommel et al., 2009). This implies that a positive relationship with the co-actor enhances self-other integration while a negative relationship with the co-actor results in less self-other integration. Also taking the perspective of the co-actor has been shown to enhance self-other integration (Müller et al., 2011b). Since a positive relationship or the ability to take the perspective of a co-actor are prerequisites for efficient cooperative behavior, we expect enhanced self-other integration when cooperating with another agent. Whether, on the other hand, self-other integration is beneficial in a competitive context may depend on contextual factors such as whether the task of a co-actor conflicts with one's own task or not. Previous studies have investigated how the cooperative or competitive nature of the relationship between two individuals affects self-other integration by giving a monetary reward to the best performing couples (cooperative condition) or the best performing participant of a couple (competitive condition) depending on their performance during the social Simon task (Ruys and Aarts, 2010; Iani et al., 2011). While these previous studies have shown that cooperation indeed seems to enhance self-other integration, findings from the competitive conditions are inconsistent. Iani et al. (2011) found a SSE when participants had to cooperate but not when participants had to compete against one another. Ruys and Aarts (2010), on the other hand, found shared representations both in a cooperative and competitive context. Importantly, these studies differed with respect to both the tasks (the use of visual versus auditory stimuli) and the setting (participants performed the task next to each other in the same room or in different adjacent rooms). When manipulating the social relationship between two individuals during performance of the social Simon task, such variances in task, setting, instructions, and individual differences in the interpretation of the instructions may have resulted in different outcomes. These contextual differences may for instance affect self-other integration by divergent effects on attentional processes. In certain situations it might be beneficial to always attend to the co-actors performance, for instance when one can learn from the decisions and mistakes of others (de Bruijn et al., 2009, 2012). However, in the social Simon task, where integrating the co-actors task results in interference with one's own task, performance is actually optimized by not attending to the co-actor's actions. Performance on the task may then thus importantly depend on contextual differences such as the co-actor being in the same room or in another adjacent room. Moreover, individual differences in motivation and attentional focus may affect self-other integration. While people are likely to maintain attention to the co-actor during cooperation, e.g., as a result of bonding, people may actually disengage from their opponent or the task because they are not motivated to compete or because they feel that they are losing the competition. de Bruijn et al. (2008) showed for instance that sharing of action representations only impaired performance of unsuccessful competitors while successful competitors were able to refrain from integrating the action representation of the co-actor. Depending on these variations, performing a task in a competitive setting may thus in certain contexts or individuals result in more attention for one's own task, while in other contexts people may also attend to the competitor's task. Because such contextual factors may, at least partly, explain previous findings, it remains unclear whether cooperative or competitive relationships differently affect the extent to which people share each other's task during performance of the social Simon task.

To prevent possible effects of contextual and motivational factors, the aim of the current study was to put people into a cooperative or competitive relationship *before* jointly performing a *neutral* social Simon task. By using the well-known computer game of Tetris as a way of manipulation before task performance, we made sure that the amount of attention toward own and other's actions during the cooperative and competitive context manipulation was matched. Different studies have shown that state induction prior to performance of the social Simon task (Kuhbandner et al., 2010; Colzato et al., 2013) may affect self-other integration. In these studies, a negative or self-oriented induction reduced the SSE whereas a positive or socially oriented induction enhanced the SSE. We expect similar sustained modulating effects of established cooperative and competitive relationships on performance of a neutral social Simon task. Moreover, since studies using different methods have suggested that competing with another person involves less integration of the self and other (Decety et al., 2004) whereas cooperating with another person is associated with increased self-other merging (De Cremer and Stouten, 2003), reduced SSEs are expected following competitive game play compared to cooperation.

MATERIALS AND METHODS

Participants

One hundred and sixteen undergraduate students from Leiden University participated in the study. Participants were randomly assigned to one of three conditions. Data from two participants were excluded because tasks were performed in an incorrect order. Data from the remaining 114 participants (105 females, Mean age = 19.45, Age range = 18–28) were analyzed. Participants received a financial compensation or course credits for their participation. Procedures were in accordance with the latest version of the declaration of Helsinki and approved by the local ethics committee (Institute of Psychology, Leiden University).

Tetris Manipulation

Tetris is a computer game originally designed by Alexey Pajitnov (1984), and exists in many versions. The Tetris game used in the present experiment (Tetris Classic, A. Pajitnov, 1992) can be played individually or together with another person, either in a cooperative or competitive mode. The game consists of a grid in which pieces of a different configuration of four adjacent squares fall down at a constant speed. Falling pieces can be moved left or right with the arrow keys and rotated in intervals of 90°. Pressing the down arrow key increases falling speed. The aim of the game is to fill rows at the bottom of the grid with squares. Each row completely filled with squares will disappear and results in a certain amount of points. The game ends when the stack of squares reaches the top of the grid. The speed by which pieces fall down increases for each level, and a new level starts after 10 rows have been completed. In both the cooperative and competitive condition participants played the game on the same computer within the same grid, with pieces falling down independently from two locations (left and right) at the top of the grid. The participant sitting on the left side of the keyboard controlled the pieces falling on the left side, while the other participant controlled the pieces falling on the right side. Pieces could be moved anywhere within the grid, and both participants could collect points by fitting their own pieces and completing rows at the bottom of the grid. In the cooperative condition participants had to earn as many points as possible together, in this way stimulating cooperative game play. In the competitive condition participants had to earn as many points as possible for themselves, which stimulated competitive game play. In the solo condition participants played Tetris individually sitting next to each other but each on their own computer and independent of the other participant. In the solo condition participants also received points for each row fully filled with squares. Earning points was solely used to stimulate cooperative, competitive, or individual game play, and had no further consequences Importantly, this setup ensured that it was not possible to ignore the actions of the co-actor and thus attention to these was matched during cooperative and competitive game play.

Task

A version of the Simon task was used in which red and green circles of 2 cm in diameter were presented 4.5 cm to the left or right of a fixation cross (see, e.g., Colzato et al., 2013; Ruissen and de Bruijn, 2015). Participants responded to the color of the stimulus by pressing the "z"-key on a computer keyboard in response to red stimuli, and the "m"-key in response to green stimuli. Trials consisted of a 500 ms fixation cross followed by the stimulus presented for 1500 ms or until a response had been made. Intervals between subsequent trials were varied randomly between 1000 and 1500 ms in steps of 100 ms. The task consisted of 256 trials (128 compatible and 128 incompatible) divided over four blocks. The color and location of stimuli were random and counterbalanced. In the standard Simon task participants performed the task alone (responding to both types of stimuli). In the social Simon task two participants performed the task together, the left participant responded to red stimuli and the right participant responded to green stimuli (See **Figure 1**).

Design and Procedure

A counterbalanced mixed between- and within-subject design was used. Participants were assigned to one of the three between-subject conditions (cooperative, competitive, solo). Depending on the assigned condition they first played 8 min of either the cooperative, competitive, or solo version of the Tetris game. This was followed by the standard Simon task or the social Simon task (within subjects). Next, participants played another 8 min

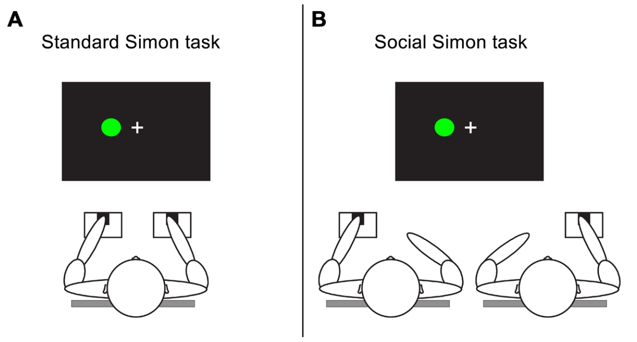

FIGURE 1 | A schematic representation of the tasks. In the standard Simon task **(A)** participants perform the task individually and respond to both red and green stimuli using left and right button presses. In the social Simon task **(B)** participants perform the task jointly responding each to one of the two colors with one response button.

of the same Tetris version, followed by the other Simon task. The sequence in which participants performed the standard and social Simon task was counterbalanced across participants.

Analyses

Reaction times (RTs) were collected for each participant. The first four trials of each block were not included in the analyses. Moreover, trials with erroneous responses and trials with reaction times below 150 ms and above 900 ms were also excluded (0.07%). The reaction-time cut off scores are based on earlier work from our lab where we used the same criteria in similar speeded choice-reaction time paradigms (see, e.g., de Bruijn et al., 2006, 2008, 2012). In line with previous studies (Sebanz et al., 2005; Hommel et al., 2009), reaction times for the standard and social Simon task were analyzed separately using a 2 × 3 repeated measures ANOVA with compatibility (compatible, incompatible) as within-subject factor and Tetris condition (cooperative, competitive, solo) as between-subjects factor. Significant main effects and interactions were further analyzed with one-tailed *t*-tests because of clear directional hypotheses. The significance criterion was set to $p < 0.05$.

RESULTS

Standard Simon Task

Analyses of the standard Simon task revealed a main effect of Compatibility [$F(1,111) = 230.24$, $p < 0.01$, $\eta_p^2 = 0.67$]. Participants responded faster on compatible ($M = 430$ ms) than on incompatible trials ($M = 458$ ms). There was no main effect of Tetris Condition [$F(2,111) = 0.29$, $p = 0.75$, $\eta_p^2 = 0.01$] nor a significant interaction between the two [$F(2,112) = 1.76$, $p = 0.18$, $\eta_p^2 = 0.03$]. See **Table 1** for means and standard deviations.

TABLE 1 | Mean reaction times (ms) as function of Tetris condition for the standard Simon task.

	Solo ($n = 38$)	Competitive ($n = 38$)	Cooperative ($n = 38$)
RT compatible	425 (54)	435 (51)	429 (44)
RT Incompatible	458 (56)	463 (48)	453 (39)
Standard Simon effect	33 (21)	28 (20)	24 (20)

Standard deviation in parentheses.

Social Simon Task

Figure 2 depicts mean reaction times in the social Simon task as function of Tetris condition and compatibility. Analyses of the social Simon task revealed a significant compatibility effect [$F(1,111) = 132.63$, $p < 0.01$, $\eta_p^2 = 0.54$] with faster RTs on compatible (363 ms) than on incompatible (377 ms) trials. The main effect of Tetris Condition was not significant [$F(2,111) = 1.54$, $p = 0.22$, $\eta_p^2 = 0.03$]. However, the interaction between Compatibility and Tetris Condition was significant [$F(2,111) = 3.81$, $p = 0.03$, $\eta_p^2 = 0.06$]. To further explore this interaction effect, we calculated the SSE by subtracting reaction times on compatible trials from reaction times of incompatible trials. We found significant SSEs in all three conditions [Solo: 18 ms, $t(37) = 7.66$, $p < 0.001$; Competitive: 10 ms, $t(37) = 5.84$, $p < 0.001$; Cooperative: 15 ms, $t(37) = 6.19$, $p < 0.001$]. Importantly, the SSE was smaller following a game of competitive Tetris compared to the cooperative Tetris condition [$t(74) = 1.74$, $p = 0.04$] and compared to the solo Tetris Condition [$t(74) = -2.92$, $p < 0.01$]. There was no difference in the SSE, however, between the cooperative and the solo condition [$t(74) = -0.98$, $p = 0.17$]. See **Table 2** for mean RTs and standard deviations. Please note that we checked for possible task order effects (standard versus social Simon task) with an Order × Condition × Compatibility ANOVA. There was no main effect of Order [$F(1,108) = 1.20$, $p = 0.28$]. Neither were any of the interactions with Order significant [all *F*'s < 1.93, all *p*'s > 0.150].

Errors

More errors were made on incompatible trials (Standard Simon task: 6.9%; Social Simon task: 1.4%) than on compatible trials (Standard: 3.5%; Social: 0.5%) in both Simon tasks [Standard: $F(1,112) = 89.49$, $p < 0.01$; Social: $F(1,112) = 26.90$, $p < 0.01$]. Error rates from both tasks did not differ significantly between the three conditions and the interaction with compatibility was not significant [All *F*'s < 1.8; all *p*'s > 0.17].

DISCUSSION

The present research showed that self-other integration during neutral joint task performance – as reflected in the SSE – depends on the pre-established cooperative or competitive relationship between two individuals. Although the SSE was present in all three contexts, it was significantly reduced following competitive game play. Playing a cooperative, competitive or solo Tetris game did not affect performance on the Standard Simon task. These findings show that people, in general, share each other's action representations when jointly performing a task. However, the present results demonstrate that when in a previously

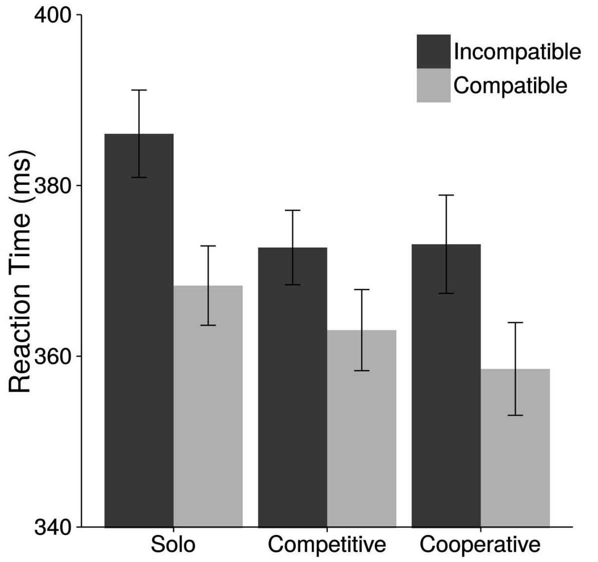

FIGURE 2 | Mean reaction times for the social Simon task. Reaction time as function of Tetris condition (solo, cooperative, and competitive) and spatial compatibility. Error bars show standard errors of the mean.

TABLE 2 | Mean reaction times (ms) as function of Tetris condition for the social Simon task.

	Solo ($n = 38$)	Competitive ($n = 38$)	Cooperative ($n = 38$)
RT compatible	368 (29)	363 (29)	358 (34)
RT incompatible	386 (32)	373 (27)	373 (35)
Social Simon effect	18 (14)	10 (10)	15 (15)

Standard deviation in parentheses.

established and task-unrelated competitive relationship, people do not integrate the task representations of the co-actor to the same degree as compared to a cooperative relationship.

The finding of general shared action representations is in line with Sebanz et al. (2006) who argued that humans – being social in nature – automatically integrate the task of the co-actor into one's own task during joint action. Interestingly, the present results show that cooperative or competitive game play prior to joint task performance lead to divergent effects on self-other integration. In contrast to previous studies (de Bruijn et al., 2008; Ruys and Aarts, 2010; Iani et al., 2011) we manipulated the relationship prior to a social Simon task, such that no additional cooperative or competitive instructions or changes to the paradigm were needed in the social Simon task. Therefore, the current results can importantly not have been modulated by possible performance differences following from such manipulations. The finding of reduced self-other integration following competitive game play suggests that the amount of self-other integration depends on the pre-established relationship between two individuals, which is in line with suggestions based on fMRI data (Decety et al., 2004) and from social dilemma games (De Cremer and Stouten, 2003).

The SSE emerges when both ones' own and others' actions are represented (Sebanz et al., 2003) and overlap exists between the two task representations (Dolk et al., 2014). A smaller SSE when people are in a competitive relationship could then either be explained by less integration of the co-actors action representation or by reduced perceived similarity between ones' own and the others' action representations. A reduced SSE in the competitive condition therefore suggests that people in a competitive relationship may not integrate the task of a co-actor to the same degree, or alternatively, may as a consequence of the competitive relationship see themselves and their actions as less similar to the actions of the other person. The latter of the two explanations is in line with studies showing that self-other integration depends on the perceived similarity between actor and co-actor, as people show more task integration when co-acting with a more human like agent (Müller et al., 2011a; Stenzel et al., 2014).

Comparable findings of an attenuated or even absent SSE following a competitive induction were recently published by Iani et al. (2014). In their study, the social Simon task was performed before and after a flanker task in which monetary rewards were used to induce cooperation and competition. They found a regular SSE before the manipulation and following cooperation but the SSE was absent following competition. Alternatively, these results may also be explained by attentional processes induced by the manipulation. When having to compete against another person, people may actually disengage from the co-actor and as a result be more focused on their own task. This may happen for example when people are not motivated to compete or give up during the competition or when it is actually beneficial for their performance not to integrate the task of the co-actor. The latter was shown in a study by de Bruijn et al. (2008) where they found that successful competitors on a competitive task were able to refrain from attending to the other task share. Such differences in attentional processes between the conditions might serve as an alternative explanation for the findings of Iani et al. (2014). In their competitive induction, in which the individual performance in a flanker task is rewarded, a shift toward increased focus on one's own task and ignoring the task of the co-actor is beneficial for successful performance. Enhanced and sustained focus on one's own task in the competitive induction task, may thus explain the absence of a SSE on a subsequent social Simon task. Importantly, however, in our Tetris game, attending to the other's task share and knowing the intentions of the co-actor, is equally important for successful performance in both the cooperative and competitive conditions. Our Tetris manipulation thus induced a cooperative or competitive state without simultaneously and directly influencing attentional processes. It should be noted, however, that even though our manipulation did not affect attention directly, attentional processes may still mediate the relationship between competition and self-other integration as being in a competitive state may generally narrow one's attention to one's own task performance.

At a neurochemical level, neuromodulators, including serotonin and oxytocin, plays a pivotal role in social interactions and social relationships (e.g., Lucki, 1998; Bartz and Hollander, 2006). Pharmacological studies have shown that the neurotransmitter serotonin is related to cooperative and competitive behavior. For instance, administration of a selective serotonin reuptake inhibitor (SSRI) facilitates cooperative behavior (Knutson et al., 1998; Tse and Bond, 2002), while depletion of tryptophan, the precursor of serotonin, reduces cooperative behavior (Wood et al., 2006). Similarly, research has shown that administration of the hormone oxytocin enhances cooperative behavior (Declerck et al., 2010) although the effects are context-dependent (Declerck et al., 2014). One explanation for the current findings is that during cooperative game play these neuromodulators are released and may thus have a sustained effect on self-other integration. In support of this, oxytocin-induced enhancement of self-other integration was recently demonstrated in our lab (Ruissen and de Bruijn, 2015). Individual differences in self-other integration, for example as evident in the ability to not integrate (see de Bruijn et al., 2008) may also be related to differences in availability or transportation of these neuromodulators. Therefore, further research is needed aimed at identifying the mechanisms underlying reduced self-other integration following competitive induction as well as elucidating the role of (social) neuromodulators in this process.

Our second hypothesis stated that a cooperative relationship would enhance the SSE in the same way as a competitive relationship attenuates the SSE. However, we did not find a larger SSE following cooperative game play compared to the solo condition, which might be explained by humans' automatic tendency to cooperate (Bowles and Gintis, 2013). It should be noted that our solo condition did not turn out to be an optimal neutral baseline condition. It was different from the cooperative and competitive conditions in that participants had not yet interacted with each other prior to the social Simon task. Being more or less familiar with the other person may as well affect the degree of self-other integration. One would expect familiarity to enhance self-other integration, for example, through increased perceived similarity. Alternatively, a person with whom you have not interacted before within your personal space may also result in more awareness of the other person. In terms of spatial coding (Dolk et al., 2013) a more salient co-actor can thus enhance the SSE independent of self-other integration. Future studies should aim at disentangling the relative influence of these different aspects further. However, the current study importantly shows that even in situations where attentional processes are matched as best as possible (i.e., cooperative versus competitive induction), self-other integration may be modulated depending on the nature of the previously established relationship.

Finally, the current findings show a sustained effect of competition on the social Simon task. No effect of cooperation or competition was found on the standard Simon task, which was performed in an individual setting. This outcome suggests that the cooperative/competitive manipulation currently used only affects self-other integration and not more general task related attentional processes that are reflected in the standard Simon effect. However, we remain cautious in concluding that the findings are exclusive for the social Simon task, as the two settings cannot be directly compared. The individual Simon paradigm is a two choice reaction-time task and the social Simon paradigm is a (one choice) go/no-go reaction-time task making it difficult to directly compare and interpret the resulting reaction-time patterns. To answer the question whether a competitive relationship only affects self-other integration, a design that better enables direct comparisons of individual and social task performance is needed.

To summarize, the present study showed a sustained effect of competitive game play on the SSE when the social Simon task was performed under neutral conditions. These findings suggest that people in a competitive relationship do not integrate the task representations of the co-actor to the same degree as people in a cooperative or neutral relationship. Importantly, these modulating effects cannot be fully explained by attentional processes, as in our manipulation attending to the other's task share was equally required in both cooperative and competitive game play. Our findings thus show that the established cooperative or competitive nature of the social relationship between two individuals is sufficient to modulate self-other integration, possibly through changes in perceived similarity.

AUTHOR CONTRIBUTIONS

All authors listed, have made substantial, direct and intellectual contribution to the work, and approved it for publication.

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The handling Editor declared a shared affiliation, though no other collaboration, with the authors and states that the process nevertheless met the standards of a fair and objective review.

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CORRECTION
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Corrigendum: Arousal and exposure duration affect forward step initiation

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Keywords: emotion, motor activity, gait, reaction time, kinematics

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A corrigendum on

Arousal and exposure duration affect forward step initiation
by Bouman, D., Stins, J. F., and Beek, P. J. (2015) Front. Psychol. 6:1667. doi: 10.3389/fpsyg.2015.01667

In the original article we had added an image of a barking dog as part of **Figure 1**. This image was taken from the International Affective Picture System (IAPS; Lang et al., 2008). However, this was done without permission of the Center for the Study of Emotion and Attention, for which we apologize. For this reason we have now replaced **Figure 1** with a modified version, whereby we removed said image.

AUTHOR CONTRIBUTIONS

All authors listed, have made substantial, direct and intellectual contribution to the work, and approved it for publication.

The original article was updated.

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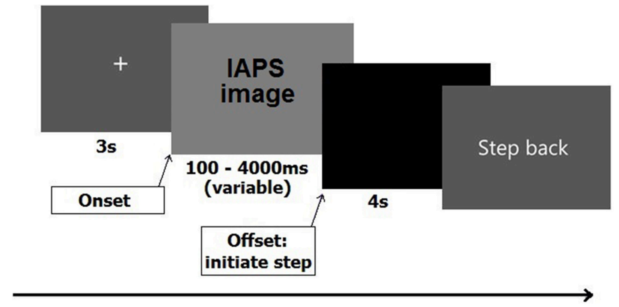

FIGURE 1 | **Sequence of stimulus events for one trial.**

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Information Use Differences in Hot and Cold Risk Processing: When Does Information About Probability Count in the Columbia Card Task?

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Objective: This paper aims to provide insight into information processing differences between hot and cold risk taking decision tasks within a single domain. Decision theory defines risky situations using at least three parameters: outcome one (often a gain) with its probability and outcome two (often a loss) with a complementary probability. Although a rational agent should consider all of the parameters, s/he could potentially narrow their focus to only some of them, particularly when explicit Type 2 processes do not have the resources to override implicit Type 1 processes. Here we investigate differences in risky situation parameters' influence on hot and cold decisions. Although previous studies show lower information use in hot than in cold processes, they do not provide decision weight changes and therefore do not explain whether this difference results from worse concentration on each parameter of a risky situation (probability, gain amount, and loss amount) or from ignoring some parameters.

Methods: Two studies were conducted, with participants performing the Columbia Card Task (CCT) in either its Cold or Hot version. In the first study, participants also performed the Cognitive Reflection Test (CRT) to monitor their ability to override Type 1 processing cues (implicit processes) with Type 2 explicit processes. Because hypothesis testing required comparison of the relative importance of risky situation decision weights (gain, loss, probability), we developed a novel way of measuring information use in the CCT by employing a conjoint analysis methodology.

Results: Across the two studies, results indicated that in the CCT Cold condition decision makers concentrate on each information type (gain, loss, probability), but in the CCT Hot condition they concentrate mostly on a single parameter: probability of gain/loss. We also show that an individual's CRT score correlates with information use propensity in cold but not hot tasks. Thus, the affective dimension of hot tasks inhibits correct information processing, probably because it is difficult to engage Type 2 processes in such circumstances. Individuals' Type 2 processing abilities (measured by the CRT) assist greater use of information in cold tasks but do not help in hot tasks.

Keywords: Columbia Card Task (CCT), Cognitive Reflection Test (CRT), dual process theory, dynamic risk taking, experience based probability format, information use

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INTRODUCTION

Decision theory describes risky situations as choices between lotteries characterized by outputs (gains and/or losses) and their probabilities. A rational agent making decisions in compliance with expected utility theory (von Neumann and Morgenstern, 1953) should concentrate on each parameter of a decision equally, thus taking into consideration all available information. The assumption that outcomes (or functions of them) are weighted by their probability underlies most economic and behavioral theories. On the other hand, studies constantly show that cognition is difficult and costly, partially because of peoples' limited processing capacity, including attention (Chabris and Simons, 2011). Among other things, this is why decision makers first try to simplify a decision problem in the so called "editing phase" (Kahneman and Tversky, 1979). Because of attention limitations they do not use all of the available risk information when making a decision. Therefore, many research paradigms (e.g., Active Information Search, Englander and Tyszka, 1980; Huber et al., 1997 and Mouselab) investigate the order of information acquisition (Schulte-Mecklenbeck et al., 2011).

However, relatively little has been said about differences in information use in affective (hot) and cognitive (cold) risk processing. Do people concentrate on different risk characteristics (losses of, and gains on, stakes, and their probabilities) in emotional risk taking (e.g., parachute jumping) compared to cognitive risk taking (e.g., pension scheme decisions)? Some studies (Pachur et al., 2014; Suter et al., 2015) have demonstrated that the impact of probabilities is strongly diminished for affect-rich outcomes. However, these studies used outcomes of different valences, assuming that medical outcomes are affect-rich and that monetary outcomes are affect-poor. Thus, they could have detected a domain difference (Sawicki and Markiewicz, 2015) rather than an affect magnitude difference. The assumption that probabilities have a diminished impact in affect-rich outcomes has solid foundations: Rottenstreich and Hsee (2001) and Sunstein (2002) both noted that affect-related decisions are insensitive to probabilities, however, here again, affect differences were mostly combined with different domains, this confound possibly leading to an error in the conclusions drawn. Thus, our present research question asked whether there are differences in the importance of risky situations' parameters (gain/loss/probability) in hot and cold decision processes within a single domain.

To explore differences in affective (hot) and cognitive (cold) risk processing within a single domain, Hot, and Cold versions of the Columbia Card Task (CCT) are used (Figner and Voelki, 2004; Figner et al., 2009). In each of the 63 rounds of both versions of the computerized CCT a participant (P) is informed about the number of loss cards (1, 2, or 3) hidden among 32 cards, the point value associated with each loss card (250, 500, or 750), and the point value associated with gain cards (10, 20, or 30)[1]. In the Cold version of the CCT, participants state in advance how many cards they want to turn over, in the Hot version participants turn over cards one-by-one until they decide to finish. In the Hot version, participants receive feedback immediately after turning over a card, while in the Cold version they receive feedback at the end of the final (63rd) round. P's task is to turn over cards and to achieve as great a total gain as possible at the end of the final round. Only 9 of the 63 rounds are generated randomly. The remaining 54 are programmed in such a way that loss cards appear at the end of the round (participants can choose cards safely for up to 32 cards minus the number of loss cards). The average number of turned over cards in the 54 rigged feedback rounds is taken as a measure of risk taking.

Apart from assessing risk taking, the CCT allows the calculation of "information use" Figner et al. (2009): the impact of three risk parameters (the gain amount, loss amount, and the probability of gains) on the risk taking behavior of an individual. To date, CCT studies have concentrated mostly on risk taking propensity (the number of turned over cards) in adults and adolescents, risk taking propensity's neural correlates (van Duijvenvoorde et al., 2015), risk taking propensity and emotion regulation strategies' correlates (Panno et al., 2012), the relationship of CCT risk taking propensity with personality traits (Penolazzi et al., 2012), and other risk measurement scores (Buelow and Blaine, 2015). In the CCT research paradigm papers usually report risk propensity scores, consideration of information processing is often omitted (Panno et al., 2012; Huang et al., 2013). However, CCT studies which have calculated information use demonstrate that it is generally greater in cold situations than in hot situations (Figner et al., 2009; Buelow, 2015). Here, though, we investigate which type of risk-related information matters most in cold and hot processes. Risky situations are traditionally defined by a set of characteristics involving payoffs and their probabilities, and loss levels, and their probabilities (von Neumann and Morgenstern, 1953). Thus, we were interested in whether higher information use in cold processes results from general or selective concentration on risky situation characteristics.

Pachur et al. (2014) claim that in affect-poor situations decision makers commonly rely on a compensatory process, trading off outcomes, and probabilities, whereas in affect-rich choices people more often rely on a non-compensatory heuristic process. Thus, in cold tasks decision makers should place significant weight on all three risk parameters (probability, gain amount, loss amount), while in hot tasks they should use a simplified approach and concentrate on one of the risk parameters. We therefore hypothesized that (H1) decision makers place different weights on risky situation parameters (gain amount, loss amount, and probability of gains), while making risky decisions in cold and hot tasks.

As defined by Figner et al. (2009), information use considers the number of significant parameters (using a dummy variable resulting from an ANOVA conducted for each participant for each parameter of a risky situation separately). This does not enable comparison of the decision weights for the decision parameters considered. Thus, to test H1 we developed a new way of measuring information use based on axiomatic Conjoint Measurement Theory (CMT; Luce and Tukey, 1964; Krantz et al.,

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[1] There is also a version of the CCT where every parameter can take one of two levels (10 and 30 for gain amount, 1 and 3 for number of loss cards, 250 and 750 for loss amount), e.g., Figner and Weber (2011), Panno et al. (2012), Penolazzi et al. (2012), and Buelow (2015).

1971) and discussed in detail in Section The Columbia Card Task (CCT). This new approach uses ordinary least squares (OLS) regression to explain the number of cards turned over in a given round in terms of the round's risk characteristics. Transformed regression betas serve as separate decision weights (summing to 1) for probability, loss, and gain amount—all expressed on an interval scale to provide an effective test of H1.

We also investigated factors that make people use risky situation-related information. In the view of dual-process theories, the mind operates using two types of processes: effortless and automatic processes (Type 1 processes, see Evans and Stanovich, 2013) and effortful, rule-based processes which use working memory resources (Type 2 processes). The most prominent model concerning the interplay between these systems is the "Default Interventionist" model, which suggests that Type 2 processes can intervene and override intuitive Type 1 responses when feelings as to the correctness of the intuitive answer are troublesome (Thompson et al., 2013)—see also alternative models such as those of Handley and Trippas (2015) and Pennycook et al. (2015). Further, the engagement of Type 2 explicit processes, which determine information use, depends on task characteristics (Rolison et al., 2011, 2012). We speculate that high emotional arousal associated with the CCT Hot version decreases the chance of Type 2 process usage compared to the CCT Cold version. If so, an individual's abilities to use Type 2 explicit processes (cognitive abilities such as numerical skill or working memory use) should predict information use only in the Cold, but not the Hot, condition. Likewise, it would be expected that WISC–III backward digit span test scores (which measure the storage and manipulation of meaningless numerical information: Wechsler, 1991) would be significantly positively correlated with information use in the Cold, but not the Hot, condition. However, previous research shows a positive correlation for both conditions (Figner et al., 2009), although the same study also demonstrated that tests of higher order executive functions (the Key Search Task, Zoo Map Test, Water Test (all from the Behavioral Assessment of Dysexecutive Syndrome task battery: BADS–C), which involve skills such as planning, novel problem solving, inflexibility, and perseveration, correlate with information use in the Cold, but not the Hot, condition. All these skills are assumed to be a function of involvement of the dorsolateral region of the prefrontal cortex (Cohen, 2005; Figner et al., 2009). Similarly, performance on the Wisconsin Card Sorting Task (WCST), which measures executive functions (such as abstract thinking, problem solving, perseveration, and cognitive set shifting), has been found to correlate with separate information use scores only in the Cold condition (Buelow, 2015). Because of these contradictory results we used another measure of cognitive ability: the Cognitive Reflection Test, CRT (Frederick, 2005), which uses three simple numeracy questions to assess an individual's ability to resist reporting the first response that comes to mind (generated by Type 1 processes) in favor of a reflective correct answer (generated by Type 2 processes). Thus, H2 was as follows: information use in the Cold condition is related to an individual's ability to resist Type 1 processing cues. However, no such relationship was expected in the Hot condition. In other words, the higher the ability to override Type 1 with Type 2 cues (as shown by CRT score), the higher is the ability to process all information (as indicated by the information use parameter in the CCT) in cold risky decision-making. We speculate that responding in the Hot task reflects a failure of Type 2 processing to become engaged (i.e., emotions block the possibility of overriding Type 1 with Type 2 cues): under such circumstances even reflective people should not use more information.

In the studies below we tested both hypotheses. Two studies are presented. Study 1 tests both H1 and H2, but Study 2 tests the robustness of H1 alone. H1 is tested by comparing decision weights for probability, loss amount, and gain amount across the hot and cold conditions, while H2 is tested by examining correlational patterns.

METHODS

Study 1

Study 1 was conducted to verify both H1 and H2.

Measures

The Columbia Card Task (CCT)

Hot and Cold versions of the CCT[2] (Figner and Voelki, 2004; Figner et al., 2009) were used to track the deliberative (cold) and affective (hot) processes involved in risk taking, and thereby to test the two hypotheses.

In each of 63 computer-generated rounds, a participant sees a deck of 32 cards (4 rows, 8 cards per row) face down. The participant is informed about the particular characteristics of a round: the number of loss cards (*n*) hidden among all the remaining gain cards (32-n), the monetary amount associated with each loss card, and the amount associated with the gain cards. In both versions, the participant (P) faces a similar decision problem, namely how many cards to turn over out of 32. In the Hot task, the participant is provided with both win/loss feedback after each card is turned over and feedback on the number of points after each single round. In each round of the Hot task, the participant points to a face-down card to turn it over and reveal its face. If the card is a gain card (a smiling face), the gain is added to the total game balance, and then the participant points to the next card. The participant can turn over cards until they decide that the risk of turning over the next card is too high *or* until they encounter the loss cards. Contrary to the Hot version, the Cold task only provides points feedback when the participant completes the entire task. The participant does not point to particular cards in the Cold task, but needs to decide how many of the 32 cards to turn over in the particular round that is described by the number of loss cards, loss amount, and gain amount. Furthermore, the participant knows that a draw will be made by the computer after they complete the entire task of 63 rounds. Only these rigged feedback rounds are used as an indicator of risk preference (measured as the average number of turned over cards in all 54 rigged rounds) and information use, which is quantified as the number of statistically significant differences between groups defined by three categorical variables:

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[2] Official webpage with demo version: http://www.columbiacardtask.org.

probability of loss, loss amount, and gain amount. With the initial value of information use set to 0, a value of 1 is added to the information use parameter if an ANOVA calculated separately for each respondent and each type of risk information reveals a significant main effect (at a significance level of $p < 0.05$).

The previously proposed information use parameter (Figner et al., 2009) does not enable comparison of the decision weights of risky decision parameters (gain, loss, and probability) at the individual level. Thus, we employ a conjoint analysis methodology (Orme, 2010), rooted in CMT (Luce and Tukey, 1964; Krantz et al., 1971), to propose a new way of measuring information use.

By analyzing individual choices with OLS regression [rather than ANOVA as proposed by Figner et al. (2009)] we obtain R^2coefficients specific to individual respondents, reflecting the extent of information's influence on risk taking. The OLS regression is calculated separately for each individual covering all 54 answers in rigged rounds, where the number of turned over cards serves as the dependent variable and the relevant round characteristics (gain level, loss level, and probability) are recoded into dummy variables—each defined by one characteristic within three possible levels of: gain (10, 20, 30), loss (250, 500, 750), and probability (1, 2, or 3 hidden loss cards)—which serve as independent variables. The independent variables are binary variables taking values of 0 or 1, thus, to avoid correlation of predictors (e.g., if the "2 hidden card" variable takes a value of 0, and the "3 hidden card" variable takes a value of 0, the "1 hidden card" variable must have a value of 1) each initial variable ("10 gain"; "250 loss," and "1 hidden card") is excluded from the regression equation following a common rule (Orme, 2010).

The regression R^2 explains how well the choice parameters (gain level, loss level, and probability) explain the number of turned over cards. Thus, it can serve as an alternative information use parameter–and potentially as an additional parameter for screening non-rational respondents and those who did not understand the task. Based on the regression coefficients (betas) we derived part-worth utilities. At the very beginning, the coefficients for the first levels of each attribute were derived from the intercept, as one third of this coefficient. One third of the intercept was also added to betas associated with the two remaining levels of attributes. Finally the "zero-centered diffs," standardization procedure (Sawtooth Software, 2012) was used to compare beta values between participants. The zero-centered diffs procedure is simply a rescaling transformation performed for each respondent. First, the mean of the betas for the three levels for every attribute is subtracted from each beta to obtain zero-centered data. Next, the coefficients are multiplied by a factor such that the sums of the three differences in the best and worst levels of each attribute is equal to the product of the number of attributes (k) and 100. This gives an average 100 point range in beta coefficients for every attribute. The final vector of beta coefficients is reported as part-worth utilities for every attribute level and these take values within the same interval scale.

Additionally, following a conjoint procedure, we calculated the relative importance score (RIS) for each attribute–this variable being measured on a ratio scale. The role of an attribute in making a decision is measured by the range of its levels of part-worth utilities. The RIS is the percentage that the range of part-worth utilities for a certain attribute constitutes in the sum of ranges of part-worth utilities for all attributes. RIS sum to 100% and determine the relative impact of each attribute in the final decision of each respondent, thus they are often called "decision weights." Finally, we also calculated the following variables: Loss amount INDEX; Gain amount INDEX; Probability INDEX. Thus, each index was multiplied by the product of its RIS and its coefficient of determination (R^2). This new way of measuring information makes it possible to ascertain which information type matters most in risky decision making—and allows comparisons between respondents based on this.

To illustrate this novel conjoint approach to CCT data analysis, let us consider responses given by an arbitrarily chosen participant in the rigged rounds shown in **Table 1**. Following Figner et al. (2009), three One-way ANOVAs should be run, where independent variables (each with three levels) are Loss cards, Gain amount, and Loss amount, and the dependent variable is the number of turned over cards. Information use in this approach is the number of ANOVAs that detect statistically significant differences among number of turned over cards for the three independent variables.

Data from **Table 1** is then recoded, as shown in **Table 2**, to run OLS regression. There are two dummy variables for Loss cards, namely Loss cards (2), Loss cards (3), level 1 being implicitly coded in these two dummy variables. If the Loss cards variable takes a value of 1, then both Loss cards (2) and Loss cards (3) are 0; if Loss cards is 2, then Loss cards (2) is 1, while Loss cards (3) is 0; and finally if Loss cards is 3, then Loss cards (2) is 0, while Loss cards (3) is 1. The variables Gain amount (20), Gain amount (30), Loss amount (500), and Loss amount (750) are created similarly.

Let us assume that $R^2 = 0.367$ and regression coefficients are as follows: $\beta_0 = 29.537$; $\beta_{\text{LossCard\_2}} = -1.278$; $\beta_{\text{LossCard\_3}} = -2.333$; $\beta_{\text{GainAmount\_20}} = 0.85$; $\beta_{\text{GainAmount\_30}} = 0.383$; $\beta_{\text{LossAmount\_500}} = -0.3$; $\beta_{\text{LossAmount\_750}} = 0.2$ (the first column of **Table 3**). The second column of **Table 3** shows the results of subtracting $\frac{\beta_0}{3}$ from the initial coefficients obtained by OLS regression. Following the "zero-centered diffs" procedure (Sawtooth Software, 2012), the means of new betas (from column 2) are then calculated for every attribute, with results as follows: Loss cards = 8.642; Gain amount = 10.257; Loss amount = 9.812. In column 3, the results of subtracting the means of each attribute

TABLE 1 | The example of an arbitrarily chosen participant's responses on the CCT.

Round No.	Turned over cards	Loss cards	Gain amount	Loss amount
1	15	3	10	750
2	32	2	10	750
3	15	2	30	250
4	24	1	10	250
5	7	2	20	500
6	15	2	20	750
...				
53	12	1	10	500
54	26	2	20	750

TABLE 2 | Transformed data from Table 1 for OLS regression.

No round	No turned over cards	Loss cards (2)	Loss cards (3)	Gain amount (20)	Gain amount (30)	Loss amount (500)	Loss amount (750)
1	15	0	1	0	0	0	1
2	32	1	0	0	0	0	1
3	15	1	0	0	1	0	0
4	24	0	0	0	0	0	0
5	7	1	0	1	0	1	0
6	15	1	0	1	0	0	1
. . .							
53	12	0	0	0	0	1	0
54	26	1	0	1	0	0	1

TABLE 3 | Calculation of part-worth utilities.

	Beta (1)	Subtracting $\frac{\beta_0}{3}$ (2)	Subtracting means (3)	Part-worth utilities (4)
Constant	29.537	–	–	–
Loss card (1)	–	9.846	1.204	98.039
Loss card (2)	−1.278	8.568	−0.074	−6.033
Loss card (3)	−2.333	7.512	−1.130	−92.006
Gain amount (10)	–	9.846	−0.411	−33.484
Gain amount (20)	0.850	10.696	0.439	35.747
Gain amount (30)	0.383	10.229	−0.028	−2.262
Loss amount (250)	–	9.846	0.033	2.715
Loss amount (500)	−0.300	9.546	−0.267	−21.719
Loss amount (750)	0.200	10.046	0.233	19.005

from the transformed betas in column 2 are presented. Part-worth utilities are in column 4. These are calculated based on the ranges of betas in column 3 for each attribute: the range for Loss cards is 2.333; for Gain amount 0.850; and for Loss 0.500. The sum of the ranges is 3.683, so every beta in column 3 is multiplied by 81.448 (300/3.683) to render the sum of the three differences in the best and worst levels of each attribute equal to 300. This gives an average 100 point range in beta coefficients for each attribute.

From the part-worth utilities we can find the utilities for any CCT round and can subsequently predict the participant's preferences between different CCT rounds. For example, the round characterized by 2 loss cards, gain amount equal to 20, and loss amount 750 has a utility of 48.715 ($-6.033 + 35.747 + 19.005$) and is less preferred than the round with 1 loss card, gain amount 10, and loss amount 250, which has a utility of 67.270 ($98.039 + (-33.484) + 2.715$).

Finally, the RIS for each attribute can be calculated. These are 63.35% for Loss cards, 23.07% for Gain amount, and 13.57% for Loss amount. RIS coefficients are obtained by rescaling ranges of part-worth utilities so that they sum to 100%. The ranges for part-worth utilities are as follows: 190.045 for Loss cards, 69.231 for Gain amount, and 40.724 for Loss amount, these summing to 300. Based on RIS values, we can conclude that for the participant whose decisions are presented in **Table 1** the most important attribute of the CCT rounds is probability while gain amount is less important.

The Cognitive Reflection Test (CRT)

The CRT uses three simple numeracy questions to assess individuals' ability to resist reporting the first response that comes to mind (generated by Type 1 processes/System 1) in favor of a reflective correct answer (generated by Type 2 processes/System 2). Each question is scored in a binary manner: correct = 1 and incorrect = 0, the total CRT score being the sum of these [a natural number between 0 and 3, representing a range from no correct answer (0) to three correct answers (3)]. Thus, higher scores imply a higher ability to resist implicit System 1 processes.

Participants

All participants gave their informed consent in accordance with the APA Ethical Principles of Psychologists and Code of Conduct, being fully debriefed at the end the study. Participants performed the study individually, in front of a computer separated from other PC stations by cubicles, providing privacy from other participants. Altogether $N = 497$ participants took part in Study 1 (73% females, aged $M = 24.26$; $SD = 5.13$), of which 380 were students of Cracow University of Economics and 117 were Kozminski University students. Students participated for course credits (with no monetary reimbursement) that depended on their CCT total score.

Procedure

The experiment used Inquisit (2012) by Millisecond Software (with a CCT script downloaded from the Inquisit Task Library). First, participants completed a prognostic strategy task (as described in Markiewicz et al., 2015)[3] not related to this paper, and then the CCT in either its Hot or Cold version. Initially a long version of the CCT was used, with 63 rounds ($27 \times 2 + 9$) in both the Hot and Cold conditions, and with three levels per parameter (1/2/3 loss cards, 10/20/30 gain amounts, 250/500/750 loss amounts). After the CCT, participants completed the CRT (Frederick, 2005) and a sociodemographic questionnaire.

Participants were randomly assigned to one of two conditions, taking either the Cold ($n = 233$, 74% females) or Hot ($n = 264$,

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[3] This task was performed for the purposes of another study not related to the current paper. The task did not involve a manipulation.

TABLE 4 | The general results of Study 1.

Study 1	CCT Cold, *n* = 233		CCT Hot, *n* = 264		*t*-test	*p*
	M	*SD*	*M*	*SD*		
Risk taking (M number turned over cards)	14.000	5.303	27.185	3.173	−32.985	0.000
Info use (R^2)	0.425	0.202	0.338	0.235	4.448	0.000
Info use (ANOVA)	1.382	0.843	0.803	0.691	8.301	0.000
Loss amount decision weight (RIS)	0.304	0.161	0.253	0.143	3.748	0.000
Gain amount decision weight RIS	0.251	0.143	0.221	0.131	2.442	0.015
Probability decision weight (RIS)	0.446	0.186	0.527	0.211	−4.552	0.000
Loss amount INDEX (RIS * R^2)	0.120	0.084	0.068	0.048	8.339	0.000
Gain amount INDEX (RIS * R^2)	0.097	0.069	0.061	0.055	6.407	0.000
Probability INDEX (RIS * R^2)	0.208	0.153	0.209	0.207	−0.054	0.957

72% females) version of the CCT. A control analysis revealed that participants were balanced in terms of gender (χ^2 = 0.335), although cold condition participants (aged *M* = 24.77; *SD* = 5.34) were slightly older [$t_{(471.263)} = 2.060$; $p = 0.04$) than hot condition participants (aged M = 23.81; *SD* = 4.90).

RESULTS

Study 1 Results

Results for the CCT risk taking propensity measure for the whole sample are presented in **Table 4**.

On average, respondents performing the Hot task disclosed more cards (*M* = 27.185; *SD* = 3.173) than those taking part in the Cold condition (*M* = 14.000; *SD* = 5.303). Those participating in the cold condition also displayed higher information use, regardless of measure employed (**Table 4**). The R^2 measure, which we propose as a measure of information use, correlated highly with the ANOVA base ratio: $r_{(495)} = 0.613$; $p < 0.001$.

There was a difference in weights (RIS) associated with probability and payoffs at the general level (**Table 4**), indicating that Cold participants paid relatively more attention (as compared to Hot participants) to loss and gain amount importance and less to probability information.

However, taking into account the generally higher level of information use in the Cold condition, the above method of analyzing data may be misleading. It is likely that lower decision weights for probability in the Cold condition together with increased information use may constitute the same level of probability processing with an increased focus on the remaining decision characteristics. Detailed analysis supported this suspicion (**Table 4**): the probability index (RIS of probability $*R^2$) remained virtually the same for both the Hot and Cold conditions, while the loss amount index and the gain amount index were both highly increased in the Cold condition. Thus, the information use increase observed in the Cold condition was mostly caused by increased concentration on gains and losses in the Cold condition, while the focus on probabilities remained similar in the Cold and Hot conditions, supporting H1.

TABLE 5 | Correlations between CRT scores and information use (as measured by R^2 and ANOVA ratios), separately for the Cold and Hot condition.

CRT correlation with…	Study 1	
	Cold, *n* = 233	Hot, *n* = 264
Info use (R^2)	0.303**	0.062
Info use (ANOVA)	0.349**	0.048
Loss amount decision weight (RIS)	−0.032	−0.153*
Gain amount decision weight (RIS)	−0.038	−0.003
Probability decision weight (RIS)	0.058	0.106
Loss amount INDEX (RIS * R^2)	0.226**	−0.049
Gain amount INDEX (RIS * R^2)	0.202**	0.034
Probability INDEX (RIS * R^2)	0.185**	0.073

*Significance codes: **$p < 0.01$, *$p < 0.05$.*

Hypothesis H2 suggested that information use would correlate with CRT scores. For the two conditions combined, this hypothesis was confirmed in respect of both the newly proposed R^2 parameter [$r_{(495)} = 0.182$; $p < 0.001$] and the ANOVA parameter [$r_{(495)} = 0.225$; $p < 0.001$). The relationships were, however, specific to the Cold condition, and did not occur for the Hot condition (see **Table 5** for details).

As shown in **Table 6**, decision weight (RIS) correlated highly with information use: the more a decision can be explained by risk parameters, the more decision makers care about probabilities, and less about pay-offs. This confirms the role of the loss probability parameter in both cold and hot processing.

Study 1 Interim Discussion

Study 1 demonstrated that in affect-poor situations decision makers are more likely to focus on all risk parameters (and thus could rely on a compensatory process trading-off outcomes and probabilities), whereas in affect-rich choices people more often rely on a noncompensatory heuristic process (thus focusing on a single risk situation parameter—here, probability). This supports H1. One could however argue that in the current affect-rich situation (CCT Hot) people focused on probability because it was the only dynamically changing parameter. For example, having

TABLE 6 | Correlations between information use (as measured by R^2 and ANOVA 5%) and task decision weights.

RIS	Info use R^2		Info use ANOVA 5%		Info use R^2	Info use ANOVA 5%
Study 1	**Cold, $n = 233$**	**Hot, $n = 264$**	**Cold, $n = 233$**	**Hot, $n = 264$**	**All, $n = 497$**	**All, $n = 497$**
Loss amount decision weight (RIS)	−0.280**	−0.519**	−0.175**	−0.261**	−0.360**	−0.138**
Gain amount decision weight (RIS)	−0.331**	−0.444**	−0.012	−0.187**	−0.359**	−0.047
Probability decision weight (RIS)	0.497**	0.626**	0.160*	0.293**	0.514**	0.136**
Study 2	**Cold, $n = 44$**	**Hot, $n = 198$**	**Cold, $n = 44$**	**Hot, $n = 198$**	**All, $n = 242$**	**All, $n = 242$**
Loss amount decision weight (RIS)	−0.260	−0.082	0.069	−0.094	−0.128*	−0.068
Gain amount decision weight (RIS)	−0.497**	−0.293**	−0.299*	−0.257**	−0.342**	−0.275**
Probability decision weight (RIS)	0.625**	0.299**	0.161	0.282**	0.375**	0.271**

*Significance codes: **$p < 0.01$, *$p < 0.05$.*

the information that there are 2 loss cards hidden among 32 cards, one knows that the probability of turning over a loss card is initially 2/32. After turning over the next card, the probability rises to 2/31, and after the third card to 2/30, etc. The other game parameters remain constant and do not change with each turned over card, it being a widely known phenomenon that people concentrate on change and not on states (Kahneman and Tversky, 1979). To control this we conducted Study 2 with delayed feedback in the CCT Hot condition.

Study 2

Based on the above results verifying H1, we can state that probabilities are the most important risk parameter in the Hot task. Study 2 was conducted to provide better understanding of the role of probabilities while making risk decisions in the Hot task. We amended the CCT Hot procedure to freeze the probability parameter in a single round, making it constant for the whole of a round. Doing this allowed us to test whether the result of Study 1was determined by positive immediate feedback causing changes in the probability parameter each time a card was turned over.

Procedure

To address the issues raised in the previous section we used a delayed feedback procedure for the Hot condition[4] (also developed by Figner, private communication), sometimes called the "CCT warm" condition (Huang et al., 2013). In the amended task a participant points to the cards to turn over (one after another), but needs to click a special button at the end of the round to turn over all cards pointed at (they are revealed in the order that they were pointed at). With this modification, participants need to make the decision before they see the sequence of turned over cards. Thus, the probability of loss does not change over a single round, and pointing to a card to turn over does not increase the probability of turning over a loss card on the next move.

Altogether, 242 Kozminiski University and Cracow University of Economics students (62% females, aged $M = 26.87$; $SD = 4.90$) took part in Study 2. The participants performed either the CCT Cold task ($n = 44$) or the CCT Hot delayed feedback task ($n = 198$)[5]. A control analysis revealed that participants were balanced in terms of age ($p > 0.05$), however females were over-represented in the Cold condition (86%) compared to the Hot delayed condition (57%). Since the Hot condition is usually more time consuming than the Cold condition, to save participants' time, and to make the duration of the two conditions more comparable, we developed a shorter CCT Hot delayed version. This had 32 rounds: 3 probability levels (1/2/3 loss cards) × 3 gain amounts (10/20/30) × 3 loss amounts (250/500/750) = 27 rounds, plus 5 rigged rounds distributed randomly. Thus, the shortening involved only the number of task rounds (similar to Huang et al., 2013; Holper and Murphy, 2014) but not the number of levels as in Figner and Weber (2011), Panno et al. (2012), Penolazzi et al. (2012), and Buelow (2015).

Because of the amendment, the results for the Study 2 CCT Hot condition cannot be directly compared to those of Study 1. Study 2 was conducted to verify the role of the probability parameter in the Hot task, which is specifically related to H1, thus participants did not complete the CRT (Frederick, 2005) which related only to H2. As in Study 1, students participated for course credits, which depended on their total CCT performance. The students participating in studies 1 and 2 were mutually exclusive.

Results

Table 7 below presents the results of Study 2. In the Hot delayed condition, participants demonstrated comparable information use levels to the Cold condition (as measured both by ANOVA and R^2 based ratios), with no significant differences in the number of turned over cards.

The fact that the Hot delayed condition and the Cold version of the CCT do not differ significantly in terms of total information use shows that blocking positive feedback in the Hot version makes it similar to the Cold version. Although there were some differences in participants' treatment of certain risk attributes, Cold condition participants paid more attention (compared to Hot participants) to gain amount and less to probability information.

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[4] The script can be downloaded from the Inquisit Task library.

[5] The unequal group sizes were intentional given the analytical focus of the new CCT Hot delayed methodology. We employed random sampling with 1 cold participant for every 5 recruited for Study 2.

TABLE 7 | The general results of Study 2.

Study 2	CCT Cold, $n = 44$		CCT Hot delayed, $n = 198$		t-test	p
	M	*SD*	*M*	*SD*		
Risk taking (M number turned cards)	15.076	6.519	14.823	6.448	0.235	0.815
Info Use (R^2)	0.614	0.618	0.783	0.603	−1.676	0.095
Info use (ANOVA)	0.841	0.608	1.051	0.746	−1.740	0.083
Loss amount decision weight (RIS)	0.343	0.175	0.308	0.144	1.374	0.171
Gain amount decision weight (RIS)	0.297	0.139	0.251	0.129	2.105	0.036
Probability decision weight (RIS)	0.360	0.183	0.441	0.165	−2.853	0.005
Loss amount INDEX (RIS * R^2)	0.130	0.090	0.145	0.096	−0.970	0.333
Gain amount INDEX (RIS * R^2)	0.107	0.054	0.113	0.071	−0.480	0.632
Probability INDEX (RIS * R^2)	0.166	0.156	0.221	0.138	−2.322	0.021

Detailed analysis of parameter contributions toward R^2 (**Table 7**) showed that information use in the delayed Hot feedback condition grew mostly through a focus on probability (compared to the Cold condition) with a relatively similar focus on loss and gain amounts. Thus, even after desensitizing participants to permanent changes in probabilities (by replacing the Hot version with the Warm delayed feedback version), probability remained the most significant parameter. In the CCT Hot version participants concentrate on the distribution of every trial, i.e., the Bernoulli distribution, which involves the probability of success (a gain card) which is dependent on the number of cards already turned over (t), the number of loss cards (n) in the round: $\frac{32-t-n}{32-t}$, and the probability of failure (a loss card) which has a probability of $\frac{n}{32-t}$. Thus, in the CCT Hot task t changes with every turned over card, and the probabilities of success, and failure also change. In the CCT Warm version, probability is still important, but we suspect that participants consider a binomial distribution rather than a Bernoulli distribution. With every card selected, the probability of success and failure are the same, being equal to $\frac{32-n}{32}$ and $\frac{n}{32}$ respectively. A participant makes a decision about the total number of turned over cards, i.e., the number of independent Bernoulli trials in the binomial distribution, and is ultimately interested in the overall probability of turning over all success cards and no loss card.

In the more demanding Hot version of the CCT, the focus is on probabilities too. The Study 2 result cannot be attributed to changes in the risk parameters that are typical of the Hot task because in the Hot delayed condition positive feedback (which is the most important feature of the CCT Hot task) was disabled.

GENERAL DISCUSSION

A set of two experiments yielded data supporting both hypotheses. The CRT (Frederick, 2005) is considered to be a tool measuring the cognitive ability to suppress an intuitive and spontaneous (Type 1 processes) wrong answer in favor of a reflective and deliberative (Type 2 processes) correct answer. We showed that CCT information use (measured using both ANOVA and OLS based indices) correlates with CRT score only in the Cold condition and *not* in the Hot condition. This means that the ability to use Type 2 processes is a good predictor of information usage in CCT Cold, but NOT in Hot, processing. When cognition is flooded with affect (in affective tasks) the aforementioned ability is not related to information processing. Thus, H2 was supported. Moreover, the result provides an argument that the CCT Cold task requires mostly Type 2 processes, while the CCT Hot task is dominated mostly by Type 1 processes.

We have also suggested a new method of information use parameter calculation. The original method (Figner et al., 2009) is based on ANOVA and the outcome parameter is measured on a scale ranging from 0 to 3 (0 = no parameters taken into account, 3 = all three parameters taken into account). In doing this, however, the researcher cannot say—at the individual level—which risky situation parameter (probability, gain amount, loss amount) influences the decision maker most, e.g., the researcher knows that both probability and degree of loss influence a decision, but they do not know which parameter is more important for the decision maker. As a methodological insight, we employed a conjoint analysis methodology (Orme, 2010) to propose a new way of measuring information use. Thus, analyzing individual choices with OLS regression (as opposed to the ANOVA method proposed by Figner et al., 2009) provides an individual respondent-specific R^2coefficient reflecting the magnitude of information's influence on risk taking. Additionally, we have suggested further mathematical transformations of regression betas to obtain: (1) the equivalent of conjoint utilities (part-worths) for each information level and (2) the average relative importance score (referred to as decision weights, summing up to 100%) for each of the three task parameters–loss probability, gain amount, and loss amount. We can therefore compare the influence of each information type on decision making—and make comparisons between respondents. We used the new information use parameter to verify H1.

As demonstrated, in the Cold condition decision makers concentrate on each information type (gain, loss, probability), while in the Hot condition concentration on probabilities virtually monopolizes the decision making process, making loss, and gain amount almost unnoticeable. Making a decision based on one risk parameter in the Hot CCT task is simpler and more heuristic in nature than making one based on three parameters in the Cold CCT task. This supports H1.

The dominance of one parameter in the Hot task (heuristic, simplified decision making), as compared to more comprehensive information processing focusing on all available information, was an expected result. Similar dominance of one dimension of a problem over another can be found in studies of moral judgments where an individual faces a conflict between moral rules and the consequences of alternative actions. In these types of problem, people analyze the consequences more when affective arousal is low (indirect action), but when arousal is high they usually rely on their moral intuitions (direct action, direct contact: Paharia et al., 2009; Białek et al., 2014). Previous studies (Pachur et al., 2014; Suter et al., 2015) have demonstrated that in the context of outcomes laden with affective responses the traditional assumption of expectation maximization may not apply. While the current study is in line with this notion, it yielded opposite results regarding probability importance in hot vs. cold risk taking situations. While Pachur's study and other studies have shown a diminished role of probability information in the Hot task, our study ran contrary, demonstrating an increased role of probability in the Hot task. A couple of factors can explain this difference. It is worth noting that the previous studies (Rottenstreich and Hsee, 2001; Pachur et al., 2014; Suter et al., 2015) used different modality stimuli for affect-rich and affect-poor outcomes (e.g., medical vs. monetary, pain vs. monetary, etc.) to show that for affect-rich outcomes people refrain from focusing on the probability of outcomes. This result could, however, stem from both an affect load difference between conditions and domain differences (some domains are more naturally suited to concentrating on probabilities than others (Sawicki and Markiewicz, 2015). Thus, we believe that researching the effect of affect-rich and affect-poor outcomes within one domain (here: monetary) is critical. After doing this, we demonstrated that in a Hot task people act in a simplified way, concentrating on only one parameter, mostly probability. So, for affect-rich choices the process of weighing possible outcomes by their probabilities is biased.

Our results are in line with other CCT studies—e.g., Buelow (2015, p. 184) says "*It appears that participants in the CCT-cold condition paid greater attention to all three information use variables in making decisions than those in the CCT-hot condition, in which riskier performance was only associated with loss probability*."

We believe that this result can be potentially explained in two other ways related to task specificity:

1. The Hot and Cold CCT tasks employed did not only differ in the affect load of their outcomes. The greater affect load of the CCT Hot outcomes, as compared to the Cold outcomes, was obtained by providing immediate feedback to respondents in the Hot task (Loewenstein et al., 2001). This makes the whole situation more dynamic (Wallsten et al., 2005; Weber and Johnson, 2008). Thus, the real probability of loss dynamically changes after each turned over card. On the other hand, many theories (the most prominent example being prospect theory: Kahneman and Tversky, 1979) predict that people concentrate not on states, but on changes relative to a reference point. Thus, decision makers could concentrate on probability since it is the only parameter changing dynamically within a single round. However, by postponing feedback in Study 2 we demonstrated that even when the dynamic nature of the task is excluded, a similar effect of increased probability concentration in the Hot task (relative to the Cold task) is obtained.
2. Tyszka and Zaleskiewicz (2006) hypothesized that people are less sensitive to probabilities when they are faced with a single-choice situation than when they are faced with a series of lotteries with different probabilities. Thus, treating each card click in the Hot task as a separate lottery could make the whole task similar to a "series of lotteries" type of task, sensitizing decision makers to probabilities, and making probability a more salient parameter. Although Tyszka and Zaleskiewicz's (2006) study did not manage to positively verify their hypothesis, they provided a valuable theoretical justification using the "evaluability hypothesis" (Hsee, 1996; Hsee and Leclerc, 1998). In a series of studies Hsee demonstrated that attributes perceived as difficult to evaluate may become evaluable through direct comparison, such attributes eventually becoming more important in the decision process. Quite simply, the possibility of direct comparison of options differing in some feature increases the importance of the feature relative to situations where options are presented in isolation. The evaluability hypothesis can be applied to the CCT Hot task, which makes the probability parameter more salient. As noted by Tyszka and Zaleskiewicz "The probability parameter can be difficult to evaluate, particularly by people who have little experience with probabilistic judgment (...). When an individual is confronted with the same scenario several times, and the only parameter that changes is probability, the individual has a possibility to compare the target probability level with other levels of probability and to attach more weight to it" (p. 1630).

The above interpretation of the observed increase in focus on probabilities in the dynamic, repeated CCT Hot task makes a practical contribution in the area of possible corrective actions. Even if we know that decision makers often neglect probabilities for affect-rich outcomes (Sunstein, 2002), the repeated choice method seems to be a perfect tool to resensitize decision makers to probabilities. The problem of ignoring probability is important–as expressed by Suter et al. (2015) "... to the extent that people show strongly attenuated sensitivity to probability information (or even neglect it altogether) in decisions with affect rich outcomes, different decision aids may be required to help them make good choices. For instance, professionals who communicate risks, such as doctors or policy makers, may need to pay special attention to refocusing people's attention on the probabilities of (health) risks by illustrating those risks visually" (p. 19). Presently, we demonstrated that repeated choice is also an efficient way of focusing attention on probabilities. It is worth noting that the repeated choices in the CCT Hot task can be interpreted as an "experienced probability" format for presenting outcome frequencies (Weber, 2006; Tyszka and Sawicki, 2011). Studies show that, compared to using percentages or an iconographic format, such a format allows people to ascertain probabilistic information more easily, even where the situation involves affect. Tyszka and Sawicki's (2011) Study 2 "… showed that for the emotionally laden stimuli, the experience-based probability format resulted in higher sensitivity to probability variations than other formats of probabilistic information. These advantages of the experience-based probability format are interpreted in terms of two systems of information processing: the rational deliberative vs. the affective experiential and the principle of stimulus-response compatibility" (p. 1832).

We have made a methodological advance in employing a conjoint analysis methodology (Orme, 2010) as a new way of measuring information use in the CCT, demonstrating its further usefulness in judgment and decision making studies (Czupryna et al., 2014; Bialek et al., 2015). We believe that this can be potentially useful in future studies investigating decision weights for particular information types in the CCT. Previous methods of computing the information use parameter would not have allowed the present conclusions to be reached.

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Arousal and exposure duration affect forward step initiation

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Emotion influences parameters of goal-directed whole-body movements in several ways. For instance, previous research has shown that approaching (moving toward) pleasant stimuli is easier compared to approaching unpleasant stimuli. However, some studies found that when emotional pictures are viewed for a longer time, approaching unpleasant stimuli may in fact be facilitated. The effect of viewing duration may have modulated whole-body approach movement in previous research but this has not been investigated to date. In the current study, participants initiated a step forward after viewing neutral, high-arousal pleasant and high-arousal unpleasant stimuli. The viewing duration of the stimuli was set to seven different durations, varying from 100 to 4000 ms. Valence and arousal scores were collected for all stimuli. The results indicate that both viewing duration and the arousal of the stimuli influence kinematic parameters in forward gait initiation. Specifically, longer viewing duration, compared to shorter viewing duration, (a) diminished the step length and peak velocity in both neutral and emotional stimuli, (b) increased reaction time in neutral stimuli and, (c) decreased reaction time in pleasant and unpleasant stimuli. Strikingly, no differences were found between high-arousal pleasant and high-arousal unpleasant stimuli. In other words, the valence of the stimuli did not influence kinematic parameters of forward step initiation. Instead the arousal level (neutral: low; pleasant and unpleasant: high) explained the variance found in the results. The kinematics of forward gait initiation seemed to be reflected in the subjective arousal scores, but not the valence scores. So it seems arousal affects forward gait initiation parameters more strongly than valence. In addition, longer viewing duration seemed to cause diminished alertness, affecting GI parameters. These results shed new light on the prevailing theoretical interpretations regarding approach motivation in the literature, which warrants further examination in future research.

Keywords: forward gait initiation, affect, emotion, arousal, exposure duration

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INTRODUCTION

Emotion and action are strongly intertwined, but exactly how they are coupled, is not yet fully understood. Emotion theorists (Frijda, 1986; Bradley et al., 2001; Lang and Bradley, 2010; Phaf et al., 2014) argue that emotions activate or prime motivational tendencies (both defensive and appetitive), like approach and avoidance behavior.

Evidence of the emotion-action link has been found in behavioral experiments that have attempted to operationalize approach/avoidance behaviors in a variety of ways. In general, the results indicated that it is easier to organize an approach movement in response to a pleasant item, and easier to organize an avoidance movement in response to an unpleasant item, compared to alternate pairings. According to some authors, this effect constitutes evidence for the "motivational direction hypothesis" (MDH; Bradley et al., 2001) and has been consistently found in manual reaction time tasks (e.g., Chen and Bargh, 1999; Eder and Rothermund, 2008).

In most pertinent experiments, visual stimuli have been used to induce emotional states. These stimuli are typically selected from the International Affective Picture System (IAPS; Lang et al., 2005) and involve pictures varying in valence (pleasantness) and arousal, based on the assumption that emotions can be classified along these two dimensions (Lang et al., 2005). Other emotional stimuli can involve facial expressions (Stins et al., 2011) or sounds (Komeilipoor et al., 2013).

In the last decade or so, novel ways to study approach/avoidance behaviors have been adopted. Traditional responses involved pushing (avoidance) and pulling (approach) a lever (Chen and Bargh, 1999), but other responses may include discrete manual (forward/backward) responses such as keypresses (e.g., De Houwer et al., 2001), moving a doll forward or backward (e.g., Lavender and Hommel, 2007), deflecting a joystick (e.g., Eder and Rothermund, 2008), and whole-body movement paradigms (e.g., Naugle et al., 2011).

The whole-body movement paradigm has been motivated by the desire to incorporate more ecologically valid behavioral measures, that may resemble more closely actual bodily motion toward or away from an emotional cue (e.g., Koch et al., 2009), compared to one-degree-of-freedom manual responses.

Within the whole-body movement paradigm, three different but related methods are used: quiet standing (e.g., Horslen and Carpenter, 2011), (2) gait initiation involving a single step (GI; e.g., Stins and Beek, 2011), and (3) locomotion (e.g., Naugle et al., 2011). In all these paradigms evidence has been found for the proposition that postural control can be affected by emotion. In the current experiment we adopted the second method, focusing on the control of forward gait initiation. The reason is that this paradigm allows us to study most clearly directional effects of emotion, i.e., the ease with which a forward (approach) movement is organized and executed.

GI is the phase between quiet standing and walking and involves the neural control of balance and timing of muscle activation. It is generally divided in two distinct processes: a postural phase and an execution phase (Brenière et al., 1987). In forward (single step) GI, the center of pressure (COP; application point of the ground reaction forces) is initially decoupled from the center of mass (COM) and moves behind the COM, causing a forward acceleration (Brenière et al., 1987). GI consists of the actor lifting the swing leg (so that the body weight is transferred to the stance leg) and swinging it forward, using the stance leg for push off. The swing leg lands some distance anterior, and the stance leg is pulled forward and lands next to the other leg. Note that these events result in a characteristic pattern of ground reaction forces that can thus be identified in the COP trajectory.

It has been widely reported that emotional states are reflected in the COP trace, and can influence gait initiation parameters like velocity, step length, and reaction time (e.g., Gélat et al., 2011; Naugle et al., 2011; Stins and Beek, 2011; Stins et al., 2015).

Experiments within the whole-body movement paradigm with emotional stimuli have shown many interesting effects of affective cues on goal-directed movement, including effects that seem consistent with the MDH, i.e., faster whole-body movement initiation in the direction of pleasant stimuli (e.g., Stins and Beek, 2011; Yiou et al., 2014; Stins et al., 2015). The opposite effect (faster whole-body movement initiation *away* from unpleasant stimuli) has not been found to date (Stins and Beek, 2011; Stins et al., 2014; Yiou et al., 2014).

Some studies found an unexpected effect that seemed to contradict the basic tenet of the MDH, namely that it was sometimes easier to execute a forward step toward an *unpleasant* picture. Naugle et al. (2011) found, in some conditions, empirical evidence for such an effect using the GI paradigm. Stins et al. (2015) reasoned that some of the effects reported by Naugle et al. (2011) might have been due to fact that forward GI was in response to stimulus *disappearance*, i.e., at stimulus offset. In other words, participants had to withhold their step for the duration the picture was presented on the screen. Most other studies to date, in contrast, asked participants to produce a response at stimulus *onset*. To this end, Stins et al. (2015) directly compared two paradigms; GI at the offset of the cue (disappearance) and GI at the onset of the cue (i.e., stepping forward as soon as the cue appeared on the screen). Only with the onset condition the expected effect was found, namely faster forward GI with pleasant compared to unpleasant stimuli. At stimulus offset the opposite effect was found, similar to Naugle et al. (2011), which again seemed to contradict the MDH.

At present, the reason for the offset GI effect, contrasting the MDH, is unclear, but it could be the case that the effect is modulated by the viewing duration of the stimuli. Namely, one of the differences between the two conditions in the experiment of Stins et al. (2015) is the amount of time the participants were looking at the picture, before having to initiate their step. In the onset condition, viewing time before initiating the step coincided with the response time. However, in the offset condition the viewing time (i.e., duration the picture was shown on the screen) varied randomly between 3 and 5 s, prior to GI.

Viewing duration has not been directly manipulated in GI paradigms before. However, based on the studies mentioned previously and brain imaging studies on the temporal dynamics of emotional processing, viewing duration of emotional stimuli warrants further investigation within the whole-body movement paradigm. When initiating a step at onset (e.g., Stins and Beek, 2011) the viewing duration before step initiation is relatively short, namely as long as the reaction time. In these onset paradigms, pleasant and unpleasant stimuli affect GI differentially, generally in support of the MDH. This differentiation between emotional stimuli has been mirrored in studies on the temporal dynamics of emotional processing. For example, both Esslen et al. (2004) and Smith et al. (2003) found differences in early temporal activation in the brain in response to various emotional categories.

In both Naugle et al. (2011) and Stins et al. (2015), the offset conditions caused a relatively longer viewing duration of the stimuli (3–5 s in Stins et al., 2015 and 2–4 s in Naugle et al., 2011). Both studies showed differential effects of emotional stimuli in GI as well, but apparently contradicting the MDH.

This differentiation at a later time in emotional processing is comparable to unique neural signatures found later in the stages of processing related to different emotional stimuli. For example, a comprehensive study of Dan-Glauser and Gross (2011) found that viewing of IAPS pictures (pleasant, unpleasant, neutral) for 8 s induced a complex temporal response pattern, involving cognitive, subjective, physiological, and facial expressive changes. Furthermore, Sabatinelli et al. (2009) found that a late amygdala response could be observed discriminating between neutral and high-arousal stimuli.

The timing of affective processing in the brain may modulate the coupling between emotion and action. In the current experiment we sought to systematically investigate the hypothesis that viewing duration influences the mechanics of forward step initiation. Instead of directly contrasting onset and offset conditions, we used only the offset condition whereby the viewing duration was controlled (i.e., independent of individual patterns of response time like in onset manipulations). Our hypothesis was that for short durations, participants would respond faster to pleasant pictures compared to unpleasant pictures (consistent with the MDH) but that this pattern would switch with longer durations, with participants responding faster to unpleasant pictures compared to pleasant pictures. We additionally tested the effect of emotion and duration on other key GI parameters related to step execution.

MATERIALS AND METHODS

Participants

Thirty-two healthy individuals (18 females; Mean age = 23.4, SD = 3.0) participated in the experiment. The participants were screened for injuries of lower extremities and other injuries that prevented them from walking or standing properly. The experiment was approved by the local ethics committee and informed consent was signed by all participants prior to the experiment.

Materials and Methods

Posturographic data were recorded using a custom-made strain gauge force plate (1 × 1 m; sampling frequency: 100 Hz). The force plate recorded forces with eight sensors; four measuring forces in the z direction, and two sensors each for the x and y directions. The data from these sensors were converted to forces in three directions (Fx, Fy, and Fz) from which moments (Mx, My, Mz) were calculated. The COP was then calculated using Mx and My. The COP represents the point of application of the ground reaction force (for details see Brenière et al., 1987).

The images were shown on a 55-inch monitor positioned 1.5 m in front of the participant at eye-level. Image offset was detected by a photodiode attached to the monitor (not visible to the participant), which was synchronized with the force plate recording. The stimuli were chosen from the IAPS (Lang et al., 2005). Only high-arousal pictures were used since previous research has revealed that only high-arousal pictures have discernible impact on gait initiation (Stins et al., 2015). Five picture categories were chosen from the IAPS: (1) erotica and (2) extreme sports (both pleasant, high-arousal), (3) mutilation and (4) threat (both unpleasant, high-arousal), and (5) neutral. From each picture category we selected 16 unique images[1].

TABLE 1 | Mean (+SD) for SAM scores of valence and arousal of both the normative scores from the IAPS manual and the scores from the current experiment.

	Normative scores	Experiment
Valence		
Neutral	4.86 (0.28)	5.00 (0.15)
Pleasant	6.80 (0.29)	6.48 (0.26)
Unpleasant	2.22 (0.30)	2.40 (0.36)
Arousal		
Neutral	2.75 (0.50)	1.46 (0.34)
Pleasant	5.96 (0.37)	3.98 (0.43)
Unpleasant	6.64 (0.36)	5.29 (0.52)

These picture are comparable to the high-arousal pictures used in previous research on emotion and GI (e.g., mutilation, attack/threat and erotica; Yiou et al., 2014; Stins et al., 2015). To ensure that the pictures were truly highly arousing, we made sure that the high-arousal pictures all had an arousal rating greater than 5 (i.e., above the median value on the SAM scale) according to the normative ratings reported by Lang et al. (2005). The average scores for the neutral, pleasant and unpleasant categories (both normative and experimental) are shown in **Table 1**. Additionally, the four high-arousal picture categories chosen have been classified as high-arousal pleasant and unpleasant categories by Bradley and Lang (2007; e.g., Figure 2.4, p. 36). Therefore, we feel confident that the stimulus set had the desired property.

Participants filled out the 9-point Self-Assessment Manikin (SAM; Bradley and Lang, 1994) in order to rate each picture on the dimensions of valence and arousal. Higher scores on these scales indicate higher valence (i.e., pleasantness) and higher arousal. In addition, participants filled out the State-Trait Anxiety Inventory (STAI; Spielberger et al., 1983) to ensure that the group did not score high or low on anxiety, which may influence the results (Naugle et al., 2011).

Procedure

After signing the informed consent, participants filled out the STAI. Next, they stepped onto the force plate. Starting position was one of the corners, which was marked by a piece of white tape attached to the plate, in order to ensure that all participants started with their heels positioned in the same starting position. From this position participants had to initiate a step forward toward the opposite corner, which was closest to the monitor (cf. Stins et al., 2015). A 5-min practice session preceded the experiment. Each trial started with a 5 s on-screen message, instructing the participant to keep their feet at shoulder-width and look at the

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[1] IAPS pictures for each picture category:
Neutral: 2038, 2102, 2104, 2190, 2200, 2210, 2305, 2440, 7004, 7006, 7010, 7025, 7035, 7041, 7050, 7705.
Erotica: 4607, 4608, 4609, 4611, 4625, 4643, 4645, 4649, 4651, 4653, 4659, 4660, 4670, 4680, 4687, 4694.
Sports: 5626, 5629, 8021, 8031, 8032, 8033, 8034, 8040, 8041, 8050, 8080, 8090, 8161, 8170, 8180, 8341.
Mutilation: 3000, 3010, 3016, 3030, 3051, 3060, 3061, 3062, 3063, 3064, 3068, 3069, 3071, 3080, 3100, 3400.
Threat: 1120, 1201, 1300, 2683, 3500, 3530, 6022, 6200, 6210, 6230, 6250, 6313, 6350, 6510, 6550, 6560.

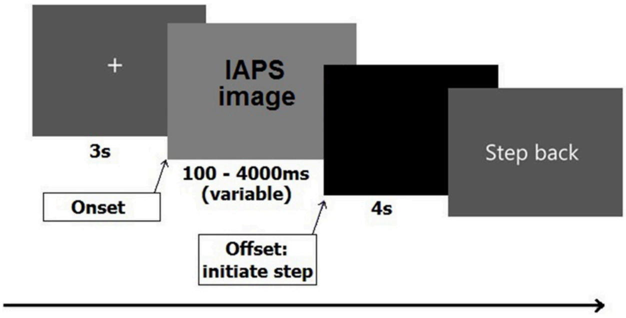

FIGURE 1 | Sequence of stimulus events for one trial.

fixation cross. The fixation cross, which appeared directly after the instruction, stayed on screen for 3 s, after which one of the IAPS pictures appeared. The duration of the picture randomly varied among seven different durations ranging from 100 to 4000 ms (100, 300, 500, 1000, 2000, 3000, and 4000 ms). Participants were instructed to stand still and look at the picture until it disappeared from the screen, and then initiate a step forward as soon as possible. No instructions were given on step size or speed. All steps had to be initiated with the right leg and participants had to wait in their new position (closer to the screen) for 4 s until the instruction "step back" appeared on the screen. Participants then had 5 s to resume their original position and await the new trial. The sequence of stimulus events is shown schematically in **Figure 1**.

Pictures of each of the five different emotion categories were presented in separate blocks, each lasting about 5 min. The reason for separating the categories into blocks, rather than showing pictures from all categories randomly, is that valence of a given picture can influence processing of the immediately following affective stimulus (Gélat et al., 2011). These authors found that the COP of a given forward step was affected differently when the previous trial was pleasant, compared to when it was unpleasant. We therefore decided to present all pictures within the same emotion category in blocked fashion.

Within each block of trials, the duration of each picture was varied randomly. Each duration combined with a unique picture was presented twice within a block, resulting in 14 steps for each category block, and thus 70 steps in total. Two catch trials were added to each block, in which a large white cross was presented immediately after picture offset, indicating that participants did not have to step at all. These trials were included to keep participants alert. Between each block, participants were given the opportunity to rest and/or stretch their arms and legs, before continuing with the next block. The neutral block was shown first to all participants, and then the four subsequent emotional blocks were presented pseudo-randomly, ensuring that each block was presented an equal number of times in each order across participants. The number of trials per condition are shown in **Table 2**.

After the experiment, participants completed the SAM scale for all 80 pictures shown during the experiment. The pictures for the SAM scale were shown in a random order on a monitor and participants used paper and pencil for the ratings.

TABLE 2 | Number of trials per participant for each Duration × Emotion category condition.

	Short	Medium	Long
Neutral	6	4	4
Pleasant	12	8	8
Unpleasant	12	8	8

Short: 100, 300, and 500 ms. Medium: 1000 and 2000 ms. Long: 3000 and 4000 ms. Pleasant: erotica and sports picture categories. Unpleasant: mutilation and threat picture categories.

Data Reduction

The COP time series and the raw force traces were rotated by 45° (due to the rotation of the force plate; see Stins et al., 2015), generating a new time-series with an anterior-posterior (AP) component in the direction of the screen, and a medio-lateral (ML) component for sideway excursions of the COP. The data were filtered using a 5-point moving average. The following GI parameters were analyzed (similar to Stins et al., 2015).

Reaction Time

The reaction time was determined as the time interval between picture offset (cue for GI) and the moment at which the force in the posterior direction exceeded 5 N.

APA Amplitude

The anticipatory postural adjustment (APA) was quantified as the distance in AP-direction between the initial position of the COP and the most posterior and lateral displacement of the COP in the direction of the right leg (sometimes labeled "S1"; see Naugle et al., 2011). The APA is related to the generation of forward momentum of the body to generate the desired step velocity by the end of the first step (Lepers and Brenière, 1995). Sixteen APA values were discarded due to an atypical initial displacement in the anterior direction instead of the posterior direction.

Step Size

The difference along the AP-axis between the initial position of the COP and the final position after completing the step was determined as the step size.

Peak Velocity

The peak velocity was quantified as the value of the maximum velocity of the COP trace during forward step. This generally coincides with the mid-swing phase of the swing leg (i.e., the right leg). Velocity was determined by numeric differentiation of the COP trace in the AP-ML plane.

Calculation of these four values is shown schematically in **Figure 2**, which displays a representative step.

Statistical Analysis

The pleasant categories (extreme sports and erotica) and unpleasant categories (threat and mutilation) were grouped together, creating three different emotion conditions: neutral, pleasant and unpleasant. Furthermore, the seven different durations were averaged and grouped as short (100, 300, and 500 ms), medium (1000 and 2000 ms) and long (3000 and

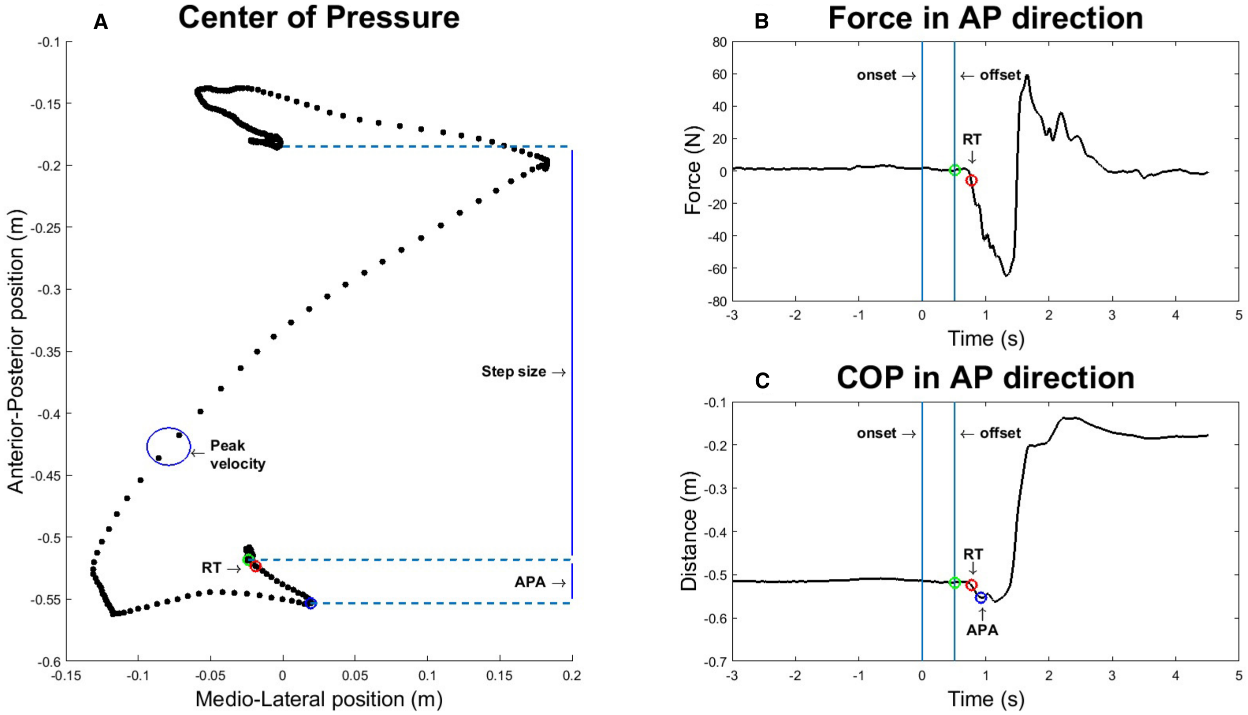

FIGURE 2 | Graphic representation of how the four dependent variables are extracted from a representative step after a stimulus duration of 500 ms. **(A)** Center of Pressure (COP) in anterior-posterior (AP) and medio-lateral (ML) direction over time. **(B)** Force exerted by the participant in AP direction. **(C)** COP in AP direction over time.

4000 ms) durations. The short and long groups are in accordance with the study by Stins et al. (2015), which examined stimulus duration indirectly (onset/offset: 3000–5000 ms).

All data analysis was done using IBM SPSS Statistics version 21. The four dependent GI variables were analyzed using a 3 (duration: short, middle, and long) × 3 (emotion: neutral, pleasant, and unpleasant) multivariate repeated measures analysis of variance (MANOVA) to control for type-I error (see Naugle et al., 2011; Stins et al., 2015). If significant, follow-up analyses of the four dependent variables were performed using separate 3 × 3 repeated measures analyses of variance (ANOVAs). Greenhouse-Geisser correction was used if the assumption of sphericity was violated. Significant effects were examined using *post hoc* paired samples *t*-tests with Bonferroni correction. Separate ANOVAs (emotion: neutral, pleasant, unpleasant) were performed on both the arousal and the valence SAM scores. Alpha was set to 0.05.

With respect to effect sizes, we report the partial eta squared (η_p^2) for the MANOVA results. Additionally, for the ANOVAs we report not only the common η_p^2, but also the generalized eta squared (η_G^2). This latter measure is not yet widely adopted, but authors such as Lakens (2013) claim that it is a more robust measure than partial eta squared. For details on calculation and theory, see Bakeman (2005), Olejnik and Algina (2003), and Lakens (2013).

Effect sizes are also reported for the *post hoc* paired-samples *t*-tests. The recommended effect size for the *post hoc* paired-samples *t*-tests is Hedges' $g_{average}$ (g_{av}; see Lakens, 2013 for details on theory and calculation). A common language (CL) effect size, introduced by McGraw and Wong (1992), is also presented to provide a more intuitive metric of effect size (Lakens, 2013). CL can be interpreted as the probability (%) that a person scores higher on one mean compared to the other, after controlling for individual differences.

TABLE 3 | Mean (+ SD) of participant characteristics.

Age	23.3 (3.0)
STAI-trait	34.9 (6.2)
STAI-state	30.2 (5.7)

RESULTS

We removed 121 trials (out of 2240; 5.4%) from the analysis for the following reasons: (a) stepping with the left leg, (b) excessive COP movement during picture presentation. This was based on visual inspection of the histogram of the SD of the movement in AP direction. The cutoff was set at 10 mm, which resulted in the removal of 1.4% of all trials, (c) stepping too early ($RT < 150$ ms), and (d) stepping too late ($RT > 1000$ ms).

Questionnaires

The mean scores for all questionnaire measures are reported in **Table 3**. The scores for both the STAI trait and state anxiety scores were comparable to those reported by Naugle et al. (2011), indicating that our sample was similar in that regard. We did not separate the scores for males and females, as previous research

TABLE 4 | Mean (+SD) of the GI variables for all three duration and emotion categories.

		Short	Medium	Long
RT (ms)	Neu	300 (77)	305 (105)	336 (110)
	P	346 (89)	335 (93)	316 (87)
	U	357 (103)	335 (109)	338 (117)
APA (cm)	Neu	3.64 (1.42)	3.39 (1.38)	3.43 (1.48)
	P	3.20 (1.48)	3.23 (1.46)	3.06 (1.36)
	U	3.23 (1.43)	3.21 (1.41)	3.15 (1.53)
Step size (cm)	Neu	42.29 (10.97)	41.83 (10.68)	41.38 (11.03)
	P	45.31 (11.58)	44.81 (11.97)	44.10 (11.51)
	U	45.27 (12.00)	44.79 (11.84)	44.03 (11.87)
Peak velocity (m/s)	Neu	2.23 (0.77)	2.19 (0.78)	2.17 (0.82)
	P	2.27 (0.82)	2.19 (0.80)	2.16 (0.77)
	U	2.26 (0.84)	2.23 (0.88)	2.18 (0.81)

Neu, neutral; P, pleasant; U, unpleasant.

has found that gender does not influence kinematic parameters (Naugle et al., 2011).

SAM; Valence

There was a main effect of emotion category, $F(1.29,39.87) = 415.02$, $p < 0.001$, $\eta_p^2 = 0.93$, $\eta_G^2 = 0.91$. *Post hoc* analysis showed that valence was significantly different for all three categories, with unpleasant pictures being scored lower (less pleasant) than both neutral [$t(31) = 21.59$, $p < 0.001$, Hedges $g_{av} = 5.36$, CL effect size = 99%] and pleasant pictures [$t(31) = 21.57$, $p < 0.001$, Hedges $g_{av} = 6.33$, CL effect size = 99%]. Pleasant pictures were scored as significantly more pleasant than neutral pictures [$t(31) = -13.84$, $p < 0.001$, Hedges $g_{av} = 2.97$, CL effect size = 99%]. These valence scores show a similar pattern to the ones reported by Yiou et al. (2014).

SAM; Arousal

There was a main effect of emotion category, $F(2,62) = 153.73$, $p < 0.001$, $\eta_p^2 = 0.83$, $\eta_G^2 = 0.64$. Follow-up analysis showed that the three emotion categories differed significantly with respect to arousal, with neutral stimuli being significantly lower compared to both pleasant stimuli [$t(31) = -10.91$, $p < 0.001$, Hedges' $g_{av} = 2.19$, CL effect size = 97%] and unpleasant stimuli [$t(31) = -18.14$, $p < 0.001$, Hedges' $g_{av} = 3{,}48$, CL effect size = 99%]. Ratings of pleasant stimuli were significantly lower than ratings of unpleasant stimuli as well [$t(31) = -5.851$, $p < 0.001$, Hedges' $g_{av} = 0{,}90$, CL effect size = 85%]. These arousal scores are similar to those reported by Yiou et al. (2014), with unpleasant pictures showing a higher arousal compared to pleasant pictures. For an overview of all SAM scores, see **Table 1**.

Gait initiation Parameters

The MANOVA revealed a significant effect of emotion, $F(8,24) = 5.69$, $p < 0.001$, $\eta_p^2 = 0.66$, a significant effect of duration, $F(8,24) = 3.08$, $p < 0.05$, $\eta_p^2 = 0.51$, and a significant interaction of duration and emotion, $F(16,16) = 3.02$, $p < 0.05$, $\eta_p^2 = 0.75$. Means and standard deviations for all variables and conditions are reported in **Table 4** and the means (+ Standard Errors) are plotted in **Figure 3**.

Reaction Time

Reaction time is plotted in **Figure 3A**. The effect of emotion on RT, $F(2,62) = 8.144$, $p < 0.01$, $\eta_p^2 = 0.21$, $\eta_G^2 = 0.015$, indicated a difference in reaction time for the various emotion categories. This effect was superseded by the interaction between duration and emotion, $F(4,124) = 9.25$, $p < 0.001$, $\eta_p^2 = 0.23$, $\eta_G^2 = 0.015$. *Post hoc t*-tests showed multiple effects. First, the RT in response to neutral stimuli became significantly longer over time; RT in response to short duration neutral pictures was significantly smaller compared to long duration neutral pictures [$t(31) = -2.86, p < 0.\ 01$, Hedges $g_{av} = 0.36$, CL effect size = 69%].

In contrast to neutral stimuli, in response to both pleasant and unpleasant stimuli, the RT decreased over time. In unpleasant stimuli the RT decreased when comparing short to medium viewing duration [$t(31) = 3.51$, $p < 0.01$, Hedges $g_{av} = 0.20$, CL effect size = 73%] and in pleasant stimuli the RT decreased when comparing short to long viewing duration [$t(31) = 4.23, p < 0.001$, Hedges $g_{av} = 0.32$, CL effect size = 77%].

Furthermore, when viewing a picture for a short duration, participants responded significantly faster to neutral pictures compared to both pleasant [$t(31) = -4.80$, $p < 0.001$, Hedges $g_{av} = 0.53$, CL effect size = 80%] and unpleasant [$t(31) = -5.05$, $p < 0.001$, Hedges $g_{av} = 0.60$, CL effect size = 81%] stimuli. When viewing a picture for a medium duration, participants only responded faster to neutral pictures compared to unpleasant pictures [$t(31) = -2.61$, $p < 0.05$, Hedges $g_{av} = 0.27$, CL effect size = 68%]. After viewing a picture for a long time, there was no difference in RT for the different emotion categories.

Anticipatory Postural Adjustment

The APA values are plotted in **Figure 3B**. The ANOVA showed a main effect for emotion, $F(1.27,39.31) = 5.67$, $p < 0.05$, $\eta_p^2 = 0.77$, $\eta_G^2 = 0.15$, indicating a difference in APA amplitude between different emotion categories, regardless of duration. The comparison between neutral and pleasant stimuli and the comparison between neutral and unpleasant stimuli (with the Bonferroni-corrected alpha set at 0.05/3 = 0.01667) were both marginally significant [$t(31) = 2.54$, $p = 0.017$, and $t(31) = 2.41$, $p = 0.022$, respectively]. Looking at the data, a general trend appeared to exist in that neutral stimuli resulted in larger APAs compared to both pleasant and unpleasant stimuli.

Step Size

Step size is plotted in **Figure 3C**. The main effect of emotion, $F(1.49,46.14) = 9.09$, $p < 0.01$, $\eta_p^2 = 0.23$, $\eta_G^2 = 0.014$, revealed a significant difference in step size for different emotion categories, regardless of duration. Pairwise comparisons showed that, compared to neutral stimuli, step size was significantly larger for both pleasant [$t(31) = -3.23$, $p < 0.01$, Hedges $g_{av} = 0.25$, CL effect size = 72%] and unpleasant [$t(31) = -3.27$, $p < 0.01$, Hedges $g_{av} = 0.25$, CL effect size = 72%] stimuli. The data also showed a main effect for duration [$F(2,62) = 11.27$, $p < 0.001$, $\eta_p^2 = 0.26$, $\eta_G^2 = 0.0016$], showing a difference in step size for the different durations. Pairwise comparisons showed that step size was significantly larger for short durations compared to both medium [$t(31) = 2.58$, $p < 0.05$, Hedges $g_{av} = 0.042$, CL effect

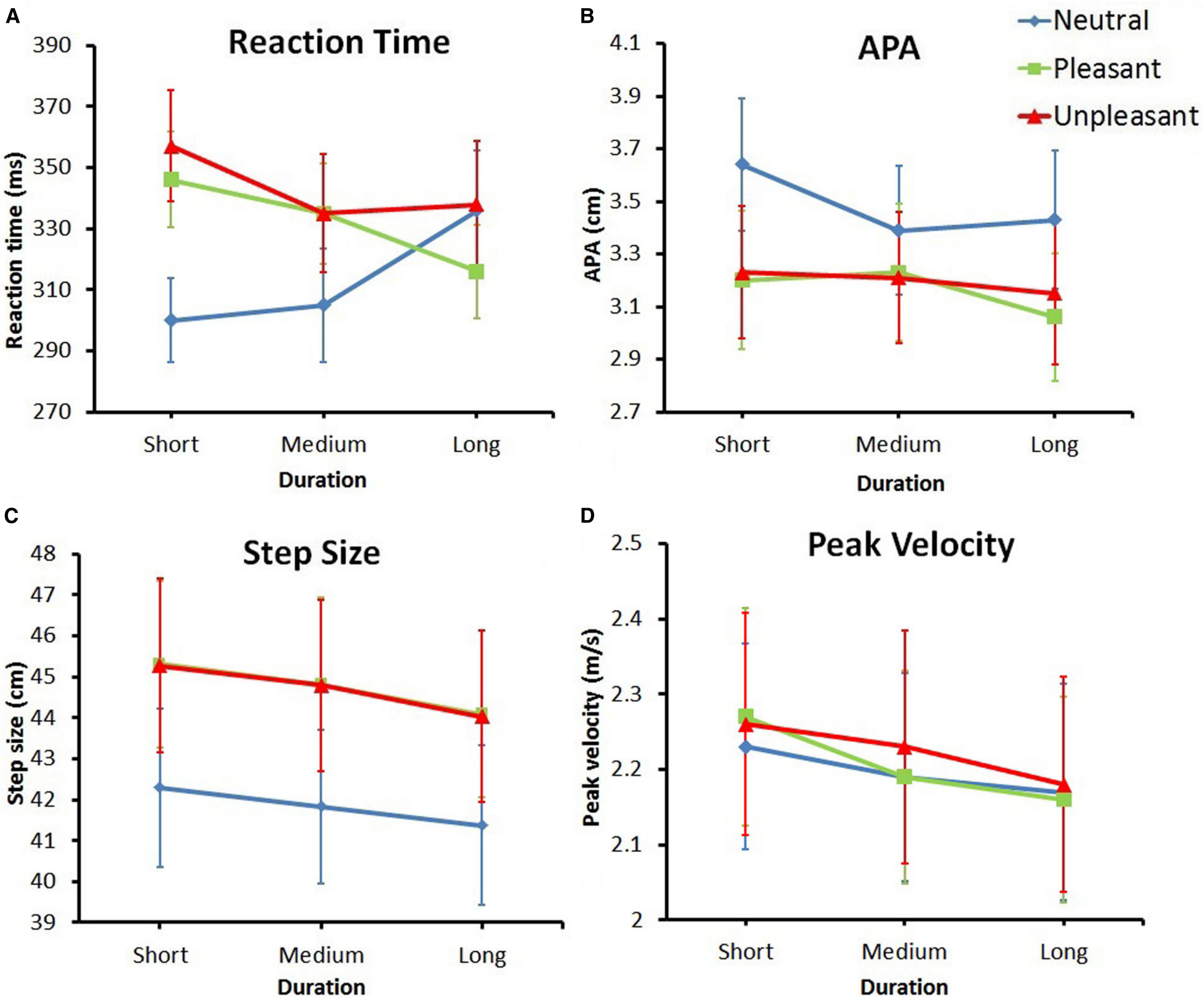

FIGURE 3 | Plotted means (+ Standard Errors) for all dependent variables. (A) Reaction time. **(B)** Anticipatory Postural Adjustment. **(C)** Step size. **(D)** Peak velocity.

size = 68%] and long [$t(31) = 4.34$, $p < 0.001$, Hedges $g_{av} = 0.10$, CL effect size = 79%] durations.

Peak Velocity

Peak velocity is plotted in **Figure 3D**. The ANOVA showed a main effect for duration, $F(1.55,47.94) = 7.62$, $p < 0.01$, $\eta_p^2 = 0.20$, $\eta_G^2 = 0.0019$, indicating a difference in peak velocity for the different picture durations, regardless of emotion. The pairwise comparison between the peak velocity for short and long durations was significant [$t(31) = 3.23$, $p < 0.01$, Hedges $g_{av} = 0.11$, CL effect size = 72%], with the longer duration resulting in a lower peak velocity in the step.

DISCUSSION

The aim of the present experiment was to examine the combined effects of stimulus duration and emotional content on the control of forward gait initiation. To this end, we analyzed a collection of kinematic variables that characterize key events in the COP trace with forward GI. Duration affects GI parameters of forward step initiation in multiple ways. Step size showed a clear effect; longer duration resulted in smaller steps, regardless of emotional content. In addition, we found an effect of viewing duration on the peak velocity, with shorter duration inducing higher peak velocity compared to longer duration. APA values appeared unresponsive to stimulus duration. However, there was an interesting interaction between duration and emotional content on the RTs. With increasing viewing duration RTs became longer in response to neutral images, but shorter in response to pleasant and unpleasant images. Furthermore, with short viewing durations, RT in response to neutral pictures was faster compared to both unpleasant and pleasant categories. With medium viewing time, RT in response to neutral pictures was only faster compared to unpleasant pictures. And finally, in the long viewing condition, there was no difference in RT between neutral, pleasant and unpleasant images. This showed that significant differences between pleasant and unpleasant (high-arousal) and neutral (low-arousal) stimuli were found when viewing these images for a short duration, but that these differences disappeared entirely when viewing them for a long duration.

The above effects of duration can potentially be explained by a mechanism whereby prolonged picture viewing leads to less forceful (smaller and slower) steps, which could be caused by a gradual loss of alertness with respect to the task. Reaction times in response to neutral pictures showed a slowing over time (which is consistent with the idea of loss of alertness to the task over time). However, for RT, the opposite pattern was found for both pleasant and unpleasant stimuli (i.e., significantly slower responses compared to neutral stimuli for short duration, while over longer durations the RT decreased to become faster and similar to neutral stimuli). It could be that in the short viewing duration, the emotional content (compared to the neutral content) captivated attention to such a degree that it interfered with the process of gait initiation (i.e., elevated RTs compared to neutral stimuli). When viewing time increased, however, the impact of the emotional content seemed to diminish, and thus interfered less and less with the GI process, becoming comparable to neutral stimuli.

Besides viewing duration, emotional content affected the GI parameters as well. Step size showed significant effects for different picture categories. Step size was smaller for neutral stimuli compared to both pleasant and unpleasant stimuli, regardless of viewing duration. APA amplitude showed a marginally significant trend in the data, with a larger amplitude for neutral stimuli compared to both pleasant and unpleasant stimuli, regardless of viewing duration.

An important observation is that for all four dependent variables, no significant differences were found in the direct comparison between pleasant and unpleasant stimuli. However, differences *were* found between these two emotion conditions and the neutral condition. When comparing the kinematic results to the subjective SAM ratings for both valence and arousal, it seems that arousal, but not valence, may explain this pattern found in the experiment.

With respect to valence, there were clear differences in valence ratings across the three emotion categories. Predictably, pleasant images were rated as most pleasant, unpleasant images were rated as most unpleasant, and neutral images occupied an intermediate position. However, these differences in subjective ratings were not mirrored in the GI parameters. Pleasant and unpleasant pictures yielded no statistically different effects on GI, whereas the neutral pictures differed significantly from both emotion categories.

With respect to arousal, a different picture emerged. There were again differences in arousal ratings across the three emotion categories; the neutral condition was clearly different from the two emotional conditions, in the presence of a small difference in arousal between the pleasant and unpleasant picture categories. These differences were manifest in three out of four GI parameters.

Although most studies within the field of whole-body emotional paradigms have highlighted the effects of valence on GI (e.g., Yiou et al., 2014; Stins et al., 2015), arousal seems to be a more crucial factor in explaining the current findings than valence. Returning to the results, regardless of viewing time, arousing stimuli appeared to cause larger step sizes (comparing neutral to pleasant and unpleasant stimuli) and marginally smaller APA amplitudes. Furthermore, the effect of duration on RT that was found in neutral stimuli (slower RTs over time) was completely opposite with the high-arousal emotional categories (faster RTs over time).

Hence, in contrast to most studies within this domain (e.g., Stins and Beek, 2011; Yiou et al., 2014), we found that arousal, but not valence, affects gait parameters of forward step initiation. Interestingly, similar results with regard to arousal were obtained by Naugle et al. (2011) and Horslen and Carpenter (2011).

Naugle et al. (2011) found, besides effects of valence, similar effects of arousal as observed in our data. Participants viewed neutral and both high and low arousal pleasant and unpleasant pictures. At picture offset (2–4 s after picture onset), participants walked forward on a walkway. Neutral pictures were only used to calculate percentage-wise-change scores, but the high arousal pleasant and unpleasant results were comparable to the present results. The authors found no difference between high arousal pleasant and high arousal unpleasant stimuli for any of the gait parameters, similar to the pattern in our results. The only exception was RT, which was different between the two high arousal categories, with a faster RT toward unpleasant compared to pleasant stimuli (similar to Stins et al., 2015; offset-condition).

Horslen and Carpenter (2011) performed a quiet standing task where participants were asked to observe pictures on a screen while standing on a force plate. Again, neutral pictures and both high and low arousal pleasant and unpleasant pictures were shown. The authors did not find an effect of valence on postural sway, nor an interaction between valence and arousal. However, they did find an effect of arousal: frequency of sway in the AP plane was higher in the high-arousal conditions compared to the low-arousal conditions. The authors described several physiological mechanisms that may explain the effect of arousal on postural control, e.g., a change in lower limb proprioceptive sensitivity.

Scrutinizing the literature reveals that in some cases behavioral effects may be driven by arousal instead of, or in addition to, valence. For example, Stins and Beek (2011) performed a study in which participants were instructed to step forward or backward on a force plate, depending on the valence of the picture. However, SAM ratings revealed that arousal and valence ratings were not independent. Not only were the arousal ratings of pleasant stimuli lower than those of unpleasant stimuli, valence and arousal ratings were also moderately correlated ($r = -0.39$), implying that unpleasant stimuli were also more arousing compared to pleasant stimuli. So, arousal may explain additional variance. That is, the higher RTs in response to stepping toward an unpleasant picture may in fact be caused by the arousing properties of the stimulus.

Besides highlighting the effect of arousal and duration on forward gait initiation, the present results in combination with those reported by Stins et al. (2015) brought an important methodological parameter to the fore, namely that the nature of the cue for GI may be more important than previously thought. The aim of the current experiment was to investigate the effect of viewing duration on gait initiation, under the hypothesis that evidence would be found for the MDH (faster response toward pleasant compared to unpleasant pictures) for short durations (onset condition) but that this effect would reverse for longer durations (offset condition; in line with the results of Stins et al., 2015). However, no such effect of duration was found. The general trend of the effect of viewing duration could reflect a mechanism of decrease of alertness with respect to the task, causing step size and velocity to decrease and RT in neutral stimuli to increase. Future studies should attempt to independently assess the level of attentional deployment to the stimulus, e.g., using a dual task or using unexpected auditory cues.

In addition to viewing duration, there was another difference between the onset and offset condition in the study by Stins et al. (2015). In the onset conditions, participants initiated their step at the moment the picture appeared, viewing the picture during their step initiation as well. In contrast, in the offset condition participants stepped toward a black screen after the picture had disappeared. One can imagine that participants would prefer to see a black screen compared to a mutilated face, making the black screen in fact a rewarding stimulus, potentially facilitating forward GI. If so, this would suggest that participants were engaged in a process of cognitive restructuring, whereby the black screen obtained positive properties. Future studies using the offset paradigm should take this alternate explanation into account.

On a more theoretical note, the current experiment showed that approach responses were not faster with pleasant or unpleasant stimuli for any of the viewing durations. Stins et al. (2015) only found evidence in line with the MDH in their onset condition, while their offset condition was almost identical to our long viewing duration condition. So, both viewing duration and cue appeared to modulate approach-avoidance tendencies. Note that approach and avoidance behavior has also been linked to arousal by some authors (e.g., Maki and McIlroy, 1996). These authors adopted a quiet standing paradigm, and found evidence for arousal causing forward leaning, which could be a prelude to a fight-flight response. More research is needed to test the conditions under which the MDH is applicable.

In sum, we found that both viewing duration and arousal, but not valence, influence forward step initiation parameters. There is no doubt that emotion and action are intertwined, and possibly coupled on a cognitive level, but more research is needed to uncover the mechanisms underlying these effects.

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Distinct effects of contrast and color on subjective rating of fearfulness

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Natural scenes provide important affective cues for observers to avoid danger. From an adaptationist perspective, such cues affect the behavior of the observer and shape the evolution of the observer's response. It is evolutionarily significant for individuals to extract affective information from the environment as quickly and as efficiently as possible. However, the nearly endless variations in physical appearance of natural scenes present a fundamental challenge for perceiving significant visual information. How image-level properties, such as contrast and color, influence the extraction of affective information leading to subjective emotional perception is unclear. On the one hand, studies have shown that visual perception and emotional perception seem to interact with each other at the earliest stages in cortical processing. On the other hand, it is important for high-level subjective ratings to be invariant to low-level visual properties. Using a psychophysical approach and signal detection theory (SDT), we tested how contrast and color influenced fearfulness ratings of a set of natural scene pictures that varied in contents and in levels of fearfulness. Image contrast influenced perceptual sensitivity but not the decision criterion of fearfulness rating, whereas color affected the decision criterion but not perceptual sensitivity. These results show that different low-level visual features contribute independently to sensitivity or decision criterion in affective perception, suggesting distinct interactions between visual cognition and affective processing. Specifically, our naturalistic approach using a novel stimulus set, combined with SDT, has demonstrated two dissociable types of cognitive mechanisms underlying how image-level properties leverage the extraction of affective information in natural vision.

Keywords: contrast, color, emotion, signal detection theory, psychophysics

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Introduction

Affective information in a natural scene mediates transactions in the environment that either promotes or threatens survival (Lang et al., 1997); for example, by rendering fight-or-flight responses (Whalen et al., 1998; Phan et al., 2002; Adolphs, 2013). According to the theory of biological communication, such affective cues influence the behavior of the observer and shape the evolution of the observer's response (Scott-Phillips, 2008). It is therefore pivotal for individuals to extract affective information from the environment as fast and efficiently as possible. Many aspects of a natural scene may provide diagnostic cues to inform a dangerous situation. Contrast patterns could be highly characteristic of a poisonous spider (e.g., stripes on its back); a visually salient color (e.g., red) could be highly predictive of a violent scene (e.g., a bloody murder). The evolutionary forces (to survive) acted on the signaler (spider) to give a particular type of signal (stripes means poisonous), and also acted on the receiver to respond to that signal (to avoid being poisoned). Such "strategic design" influenced the evolution of biological communication (Guilford and Dawkins, 1991). However, it is also of interest how image-level properties of a scene would modulate our subjective evaluation of affective information extracted from diagnostic cues. For instance, would a poisonous spider with stripes on its back be evaluated as scarier in a bright-lit condition than a dim-lit condition? Dangerous stimuli (e.g., a spider or a snake) may have large variations in physical appearances under various viewing conditions. One possibility is that early perceptual processing may rely heavily on low-level visual properties to make an early judgment about the valence of a stimulus (affective prediction hypothesis; Barrett and Bar, 2009). Alternatively, affective representation may not rely on visual analyses of any particular dimension of the image-level properties as long as these properties, such as luminance, contrast, and spatial resolution, are above certain detection thresholds for serving as diagnostic cues.

Correspondingly, the literature on this issue shows mixed findings. On the one hand, visual perception and emotional perception seem to interact with each other at early stages in vision (Lebrecht et al., 2012) in that low-level visual features directly impact affective judgment. Several studies have investigated the relation between spatial frequencies and emotions using a variety of methods, stimuli, and rationales (De Cesarei and Codispoti, 2013). When comparing low-pass filtered images to intact images, low-pass filtered images were rated less arousing and less pleasing (De Cesarei and Codispoti, 2008). Moreover, when pictures were blurred at different degree (intact, intermediate blurring, maximum blurring), a reduced modulation of skin conductance was found corresponding to the degree of blurring, suggesting that emotional reactions might be modulated by image-level visual properties (De Cesarei and Codispoti, 2010). Support for the use of color in valence judgment has also been found, where positive images elicited larger P300 amplitude than negative or neutral images only for color pictures and not gray-scale pictures (Cano et al., 2009).

On the other hand, it seems important for high-level subjective ratings to remain robust to variance in low-level visual features such as position, scale, pose, and illumination (DiCarlo and Cox, 2007). Consistent with this functional necessity of surface-feature invariance for emotional perception, some research demonstrated that image-level properties of affective pictures, such as picture size, spatial frequency, brightness and complexity, did not change affective responses measured by event-related potentials (ERPs) (Junghofer et al., 2001; De Cesarei and Codispoti, 2006, 2011a,b). In addition, removing color information shows no influence on the valence modulation of the late positive potentials (LPPs), which are larger for pleasant and unpleasant pictures than neutral pictures, implying that the processing of emotional contents does not critically rely on color information (Codispoti et al., 2012; see also Junghofer et al., 2001; Weymar et al., 2009 for different paradigms with similar results). The conflicting results of these studies might be partially driven by various measurements of emotional responses used in the experiments. However, different components of emotional responses, as reflected by different measurements, might also be modulated by different low-level visual properties. For example, spatial frequency could modulate both subjective ratings and skin conductance (De Cesarei and Codispoti, 2008, 2010); but picture size, spatial frequency and color did not modulate ERP responses (De Cesarei and Codispoti, 2006, 2011a,b; Codispoti et al., 2012).

We argue that the conflicting results of previous studies could be reconciled by examining how image-level properties of stimuli would affect different aspects of the perception of emotional information. First, to simplify the investigation, we focused on the perception of fearful stimuli, because fear is a basic emotion and crucial survival mechanism that has been studied extensively (e.g., Bradley et al., 2001; Cardinal et al., 2002), although we believe that the same approach could be used to test other dimensions of affective perception. Second, to examine different aspects of perceiving fearful stimuli, signal detection theory (SDT) will be applied to the data analysis. It has been well established that SDT can be used to estimate the two different aspects of perception: sensitivity and decision criterion (Green and Swets, 1966). According to SDT, perceptual decisions are based on the strength of a perceptual signal in relation to a decision criterion, which is a continuous process of information accumulation (Wixted, 2007). Methodological approaches that apply SDT have therefore been used to examine subjective experiences of perception, such as pain assessment (Naliboff et al., 1981; Classen, 1984; Kirwilliam and Derbyshire, 2008), distinctions between one's own correct and incorrect decisions (Galvin et al., 2003), subjective confidence ratings of the correctness of a discrimination response (Zehetleitner and Rausch, 2013), subjective confidence in reporting the absence of a stimulus (Kanai et al., 2010), subjective assessment of the quality of the percept (He et al., 2009), and subjective awareness of fearful faces (Szczepanowski and Pessoa, 2007), in addition to the events defined independently of the observer. To the best of our knowledge, however, no one has previously taken a SDT approach to investigate how low-level visual properties may modulate affective ratings.

In order to apply SDT to tease apart different aspects of subjective rating of fearfulness (i.e., true perceptual effects in fearful rating resulting from visual properties), images with a wide range of levels of fearfulness are needed. International Affective Picture System (IAPS) is a very useful standardized collection of color photographs of objects and scenes across a wide range of categories (Lang et al., 2008). Typically, studies that tried to investigate relationships between visual processing and emotion often selected pleasant, neutral or unpleasant subsamples from this image database (e.g., Bradley et al., 2007). However, subsampling the fearful stimuli from this database contains only extreme fearful images, which are rarely seen in a naturalistic environment, but contains no images with intermediate levels of fearfulness between unpleasant and neutral, which only allows measurements of one extreme level of fearful ratings that cannot be used for SDT analyses. In the present study, we compiled a new stimulus set that contains images resembling what everyone may see from a daily routine of life. Importantly, this set of stimuli contains not only the most fearful stimuli but also pictures widely varied in different fearful levels, which therefore provide the opportunity for applying SDT to disentangle how image-level properties may differently influence affective perception of scene pictures in a fine-grained manner.

Specifically, by taking the SDT approach, we examined effects of contrast and color on the subjective rating of fearfulness. It is known that information in different spatial frequency bands plays significantly different roles in recognizing fearful facial expressions (Vuilleumier et al., 2003; Pourtois et al., 2005; Mermillod et al., 2009, 2010a). Given that contrast sensitivity is intrinsically modulated as a function of spatial frequencies (Wandell, 1995), we can expect that visual contrast may affect the detection of emotion information (cf. Pallett and Meng, 2013). Nonetheless, how contrast may affect the detection of emotion information in scene pictures has not been tested. Similarly, color plays a critical role at multiple levels of visual processing (Gegenfurtner and Rieger, 2000; Tanaka et al., 2001). Color can facilitate object recognition regardless of the diagnostic value of color for the identification of the object (Wurm et al., 2004). However, how color information might affect subjective evaluations of fearfulness in natural scene pictures is still unclear.

Materials and Methods

Participants

Participants were 109 students from Dartmouth College. Among them, 56 students (mean age = 19 years, 43 females, 29 Caucasians) participated in experiment 1 to test the effect of contrast. The other 53 students (mean age = 19 years, 34 females, 32 Caucasians) participated in experiment 2 to test the effect of color. The sample size was comparable with that of similar previous studies (e.g., De Cesarei and Codispoti, 2008; Nummenmaa et al., 2010; Pilarczyk and Kuniecki, 2014). The participants for both experiments were representative in the same manner of the psychology major undergraduate population at Dartmouth College with respects to age, gender and ethnicity. All participants had reported normal color vision and normal or corrected to normal visual acuity. They were not informed the purpose of the experiments in advance. They had not participated in any experiments using the same set of stimuli. Participants received course credit. All gave informed consent. This research was approved by the Committee for the Protection of Human Subjects at Dartmouth College and conducted in accordance with the 1964 Declaration of Helsinki.

Materials

One Hundred and fifty-seven colorful pictures devoid of human faces were collected from the Internet, which displayed a wide range of content and fearful levels, from animals, human body parts, objects (knives, weapons), acrophobia scenes, landscapes of cities and streets, dark lit natural scenes to burning buildings, cars and forests. First, all images with original color were converted to gray scale by eliminating the hue and saturation information while retaining the luminance information. The color and gray scale images were used as stimuli in the color experiment. Next, based on the gray scale images, two more versions were generated with either a higher level of contrast (mean luminance = 126, on the scale from 0 = black to 255 = white; Root Mean Square (RMS) contrast = 84) or a lower level of contrast (mean luminance = 126, RMS contrast = 10) than the original gray scale images, and were used in the contrast experiment. The image processing was performed using MATLAB and SHINE toolbox (Willenbockel et al., 2010). The size of stimuli is 400 × 400 pixels for all of the color, gray scale, high contrast, and low contrast images.

In order to obtain a consensual judgment for each of the 157 images, an independent group of 43 participants (mean age = 19 years, 32 females, 23 Caucasians) were tested. This group of participants was recruited in the same manner as the main experiments, representative of the psychology major undergraduate population at Dartmouth College with respects to age, gender and ethnicity. A large version (600 × 600 pixels) and a small version (200 × 200 pixels) of the stimuli in gray scale were rated for fearfulness on a 7-point scale (1 = not scary at all, 7 = extremely scary) with similar experimental procedures as the main experiments (detailed below). The ratings for each of the 157 images were averaged across large and small stimuli and then across participants as the consensual judgment for each image. Please see supplementary materials for the distribution of averaged ratings of the 157 images.

Procedure

A between-subject and within-subject mixed design was used to examine the effect of contrast or color on the judgment of fearfulness. In the contrast experiment, participants were randomly divided into two groups: (1) viewing high contrast images first and then low contrast images; (2) viewing low contrast images first and then high contrast images. Two blocks of stimuli were presented for each group with the same low-level feature (e.g., high-contrast or low-contrast) within each block. In the color experiment, stimuli were presented in a color images block and a gray images block. In all other respects, the two experiments were designed in the same manner.

Using MATLAB with Psychtoolbox (Brainard, 1997; Pelli, 1997; Kleiner et al., 2007), images were presented on a gray background at the center of a 21-inch Dell P1130 CRT monitor with a refresh rate of 85 Hz at a viewing distance of about 65 cm. Each image had 32bit color depth and spatial resolution of 1280 × 1024 pixels. For a typical block, participants were first familiarized with the stimuli by passively viewing all of the stimuli for 1 s each without any inter-stimulus interval. A red fixation cross was always presented in the center of the screen. They were then shown the images one at a time, and were asked to rate the fearfulness of the image on a scale from 1 to 7 (1 = not scary at all, 7 = extremely scary). Each image was presented once in each block and remained on screen until a rating was made. There was a 700 ms inter-trial interval. The order of presentation of the images was random and was different for each participant.

Data Analysis

We conducted conventional ANOVA for all the rating data collected in experiments 1 and 2, except that 3 trials from 1 subject in experiment 2 were excluded because of mistaken keyboard presses. Based on the consensual judgment (averaged rating) in the independent rating experiment, the 157 images were divided into 5 fearful levels with nearly matching number for each level: Level 1 included 32 images (range of mean ratings [1.38, 2.19]); level 2 included 31 images ([2.19, 2.74]); level 3 included 32 images ([2.74, 3.38]); level 4 included 32 images ([3.38, 4.08]); level 5 included 30 images ([4.08, 5.34]). In total, there were 20 conditions (5 fearful levels × 2 levels of image feature × 2 presentation orders) in each data set. Three-way (5 × 2 × 2) mixed design ANOVA was then used for analyzing the effects of fearfulness level (5 levels: 1–5) and contrast or color (two levels: low/high contrast or color/gray) as within-subject factors, and presentation order [two levels: first present low contrast (or color) and then high contrast (or gray) vs. first present high contrast (or gray) and then low contrast (or color)] as a between-subject factor. Effect size indicator, η^2 (generalized eta squared) was computed to further evaluate these effects on the subjective fearful ratings.

For the SDT based analysis, a median (3.05) was first computed using the consensual judgment (averaged rating) data of all the stimuli obtained in the independent rating experiment. Second, consensual judgment data were split using the median to fearful and non-fearful stimuli. For every fearful stimulus (signal), each rating in the color and contrast experiment was classified as either a hit, if it was higher than its consensual judgment, or a miss, if it was lower than its consensual judgment; similarly, for every non-fearful stimulus (noise), each rating in the color and contrast experiment was classified as either a false alarm, if it was higher than its consensual judgment, or a correct rejection, if it was lower than its consensual judgment. Using these hit and false alarm rates, an overall decision criterion (c) were computed for each condition and each observer.

Receiver operating characteristics (ROCs) were then constructed for the contrast and color experiment separately, by plotting p(hit) and p(FA) across variations in response criterion or confidence on the y-axis and x-axis, respectively. The p(hit) is the proportion of rating responses greater than a given criterion for fearful stimuli (signal); and the p(FA) is the proportion of rating responses greater than the criterion for non-fearful stimuli (noise). For example, the first (leftmost) data point represents the proportion of rating responses of 7 for fearful and non-fearful stimuli on the y-axis and the x-axis, respectively, which were accustomed hit and false alarm rates using the most conservative decision criterion (i.e., only ratings of 7 for fearful stimuli were counted as hits). The next data point on ROCs represents accustomed accumulative hit and false alarm rates for pictures eliciting fearfulness rating of 7 and 6, using a less conservative decision criterion (i.e., ratings of 6 and higher were counted as hits). Keep relaxing decisional criteria will eventually lead to 100% of accumulative hit and false alarm rates for pictures eliciting fearfulness rating from 1 to 7, which by convention is not plotted. Overall six data points on ROCs were plotted to represent the accumulative p(hit) and p(FA) for the 7-point rating scale by adjusting decisional criterion. The ROCs were then fit with equal-variance Signal Detection theory (EVSD) (Macmillan and Creelman, 1991) using a maximum likelihood estimation procedure (Myung, 2003). This procedure yielded one parameter, discriminability measured as d', for each condition and each observer. Overall, the EVSD model provides a good fit for the data, accounting for more than 95% of variance on average.

Results

In the contrast experiment, significant main effects of fearful level and contrast were found [$F(4,216) = 194.61$, $p < 0.001$, $\eta^2 = 0.44$; $F(1,54) = 12.01$, $p < 0.01$, $\eta^2 = 0.01$, respectively]. The interaction between presentation order (rating block) and contrast [$F(1,54) = 7.01$, $p = 0.01$, $\eta^2 = 0.01$], as well as the interaction between fearful level and contrast [$F(4,216) = 8.00$, $p < 0.001$, $\eta^2 = 0.003$] were also significant. Moreover, a significant three-way interaction was found [$F(4,216) = 4.98$, $p < 0.01$, $\eta^2 = 0.002$], which suggests that the presentation order may modulate the effect of contrast differently at various levels of fearfulness. In the color experiment, the main effects of fearful level and color/gray were found to be significant [$F(4,204) = 204.06, p < 0.001, \eta^2 = 0.43; F(1,51) = 8.77, p < 0.01$, $\eta^2 = 0.006$, respectively]. None of the two-way interactions was significant (all Fs < 2.34, all ps > 0.05). The three-way interaction was not significant either [$F(4,204) = 1.63$, $p = 0.17$, $\eta^2 = 0.0001$]. According to our signal detection hypothesis, differentiating fearful levels of the stimuli would be different for the second time viewing of the stimuli, because memories of the previously viewing of the stimuli may be informative (i.e., providing additional signals) for observers to rate the stimuli. While the discrepancy of three-way interactions between the two experiments is consistent with possible different perceptual effects of color and contrast, it might also be caused by different memory effects or a combination of perception and memory, which exceeds the scope of the present paper. To avoid any possible confounding effects due to non-perceptual factors, we focus on between-subject comparisons for data collected in the first block of each experiment (**Figure 1**).

As shown by **Figure 1A**, in the contrast experiment, a two-way ANOVA for the first rating block reveals that the main effect of fearful level was significant [$F(4,216) = 194.93$, $p < 0.001$, $\eta^2 = 0.47$]. However, the main effect of contrast was not significant [$F(1,54) = 1.22, p = 0.27, \eta^2 = 0.02$]. The interaction between contrast and fearful level was not significant either [$F(4,216) = 1.99$, $p = 0.10$, $\eta^2 = 0.009$]. Pair-wise comparisons were then conducted to examine the contrast effect at different fearful levels. Significant effects of contrast on fearful ratings were found at levels 3, 4, and 5 (all ps < 0.01, Bonferroni corrected), whereas the effect of contrast was not significant at levels 1 and

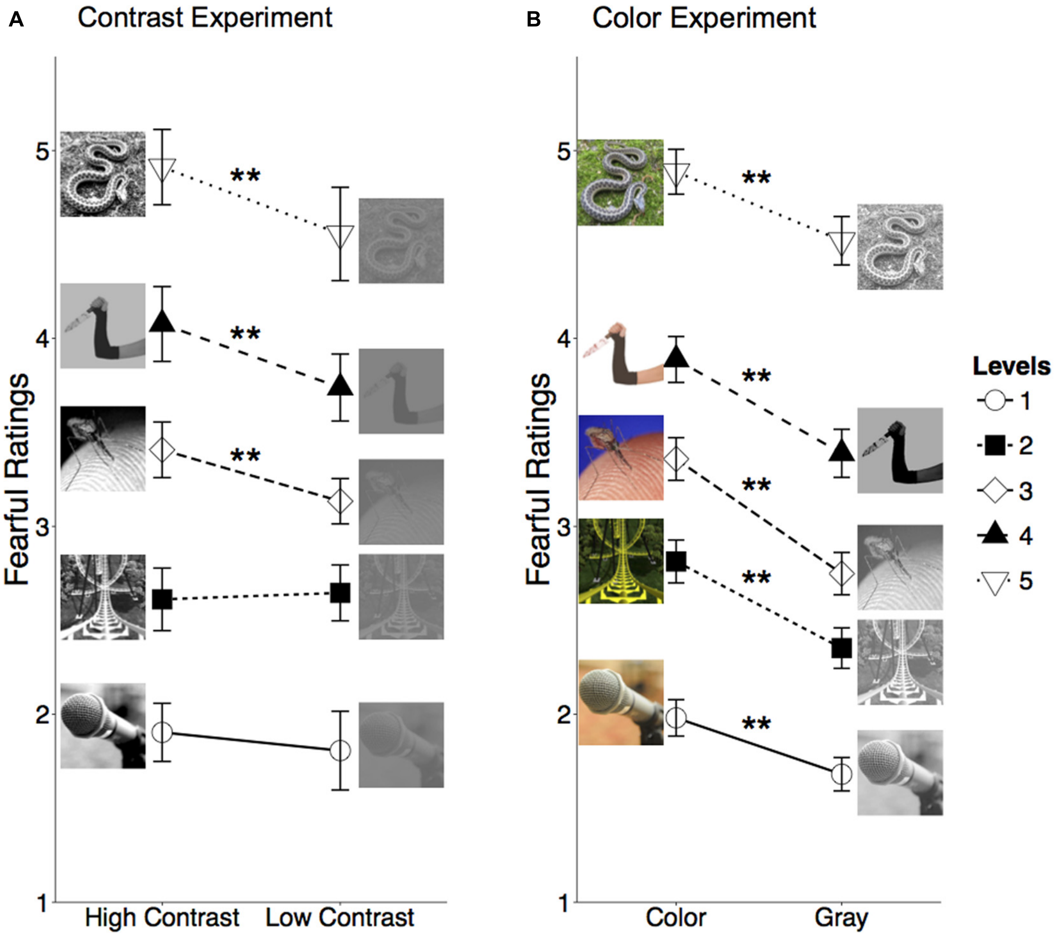

FIGURE 1 | Mean fearful ratings for (A) high contrast and low contrast images at five levels of fearfulness in the contrast experiment and (B) color and gray images at five levels of fearfulness in the color experiment. Error bars represent 95% confidence intervals. Examples of stimuli at each level of fearfulness are shown next to the corresponding data point for each experimental condition. **indicates $p < 0.01$, Bonferroni corrected.

2 ($ps > 0.4$, Bonferroni corrected). As shown by **Figure 1B**, in the color experiment, a two-way ANOVA for the first rating block reveals that the main effect of fearful level was significant [$F(4,204) = 191.57$, $p < 0.001$, $\eta^2 = 0.45$]. The main effect of color was also significant [$F(1,51) = 5.26$, $p = 0.03$, $\eta^2 = 0.07$]. The interaction between color and fearful level was not significant [$F(4,204) = 1.07$, $p = 0.37$, $\eta^2 = 0.005$]. Pair-wise comparisons were then conducted to examine the color effect at different fearful levels. The effects of color on fearful ratings were found to be significant at all five fearful levels (all $ps < 0.01$, Bonferroni corrected).

Figure 2 shows the results of the SDT analyses. The ROC curve for the low contrast condition fell below that of the high contrast condition (**Figure 2C**), suggesting that overall discrimination of fearfulness was greater for the high contrast stimulus. This was confirmed as significantly higher d' for the high contrast stimuli compared to low contrast stimuli ($t(54) = 1.874$, $p = 0.03$, 95% confidence interval for the difference between means [0.01, 0.30], **Figure 2A**). No significant difference was found in overall decision criterion, c ($t(54) = 0.75$, 95% confidence interval for the difference between means [−0.43, 0.20]). In sharp contrast, each data point on the ROCs showed a rightward shift for the color condition compared to corresponding data point for the gray condition (**Figure 2D**). This was confirmed as significantly higher overall decision criterion, c, for the color stimuli compared to gray stimuli (t (51) = 2.31, $p = 0.01$, 95% confidence interval for the difference between means [−0.68, −0.05], **Figure 2B**). No significant difference was found in d' (t (51) = 0.22, 95% confidence interval for the difference between means [−0.15, 0.19]).

Discussion

The nearly endless variations of visual properties in natural scenes present a fundamental challenge for abstracting and perceiving coherent relevant information in the environment. To maintain representational constancy, object and scene perception should be robust to variations in image-level properties (DiCarlo and Cox, 2007; Gilchrist, 2012). However, some of these variances

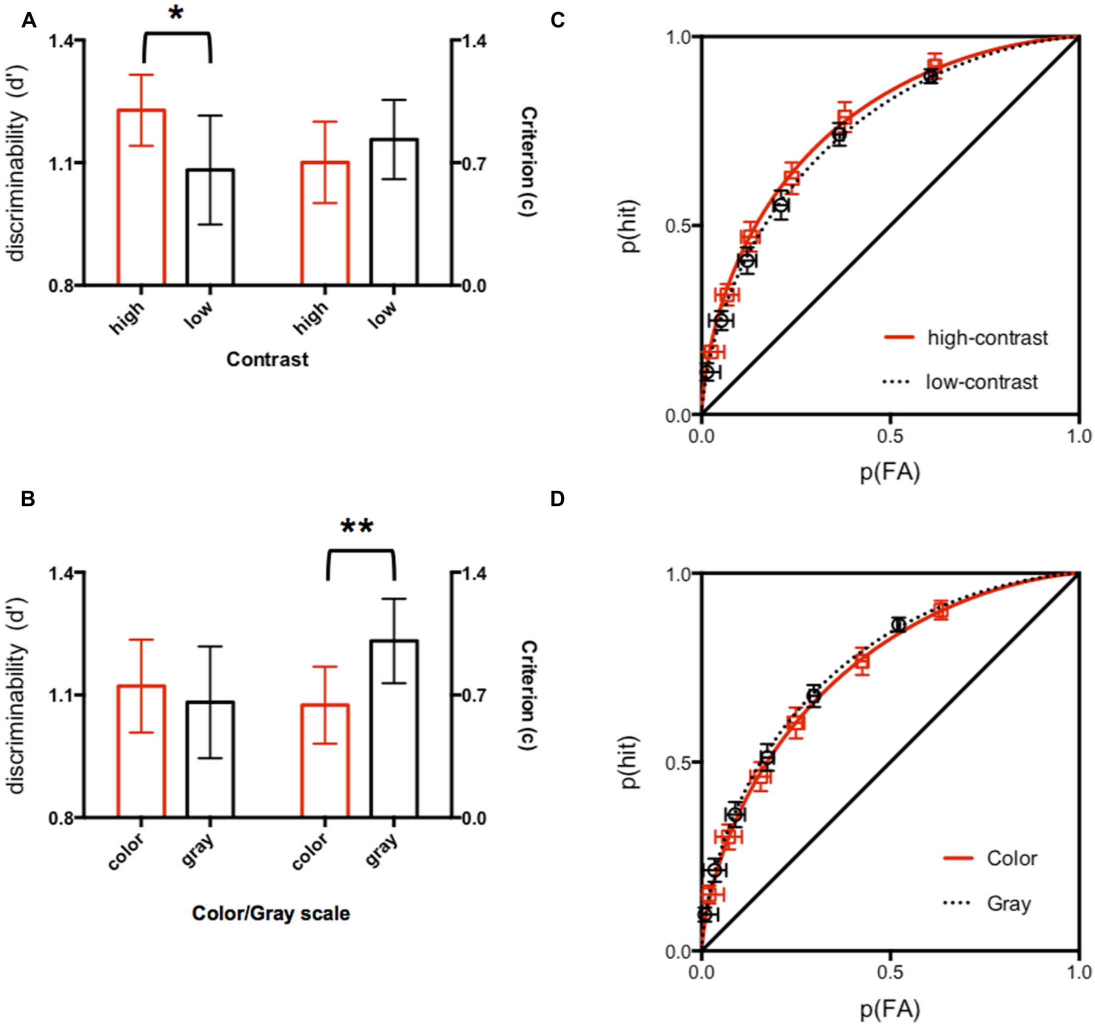

FIGURE 2 | (A,B) The discriminability (plotted on left *y*-axis) and criterion (plotted on right y-axis) extracted from ROCs **(C,D)** from aggregated data for the two experiments. *indicates $p < 0.05$, **indicates $p < 0.01$.

in natural stimuli are pivotal for detecting emotional information. Our results indicate that both image contrast and color modulate subjective fearfulness ratings of scene pictures. This is consistent with previous studies suggesting that affective perception is not isolated from early visual processing of color, size, resolution, brightness, spatial frequency of the stimuli pictures (Vuilleumier et al., 2003; Pourtois et al., 2005; De Cesarei and Codispoti, 2006, 2008, 2010; Mermillod et al., 2010b; Codispoti et al., 2012; Lakens et al., 2013). Yet why would image-level visual properties influence ratings of fearful scenes? The present results suggest that different mechanisms could support the effects of visual features on fear perception.

As suggested by our SDT analyses, contrast influences perceptual sensitivity but not decision criterion of rating fearfulness in the scene pictures. By contrast, color shifts the decision criterion without affecting perceptual sensitivity for rating fearfulness in natural scene pictures, suggesting that color information is less effective in modulating the sensitivity of fearful perception than stimulus contrast. However, this does not necessarily mean that color is less effective in influencing subjective rating. In fact, the criterion effect of color increased overall fearfulness rating. Note that we would have not found these differences, had we only conducted conventional ANOVAs. Results of ANOVAs suggest that both contrast and color information affected fearful ratings. When rated for the first time, the effect of contrast was stronger for the images of medium to high levels of fearfulness (levels 3–5 in our study) than for the neutral (level 1) or nearly neutral images (level 2). When rated for the first time, the effect of color was highly significant at all levels of fearfulness. These results are consistent with what our SDT analyses revealed. However, without applying the SDT, it would have been difficult to understand how these different effects were caused by sensitivity or detection criterion differences.

Our findings also reconcile previously reported mixed results regarding the role of color on affective perception (Cano et al., 2009; Codispoti et al., 2012). On the one hand, color does not improve the sensitivity of discriminating fearful and non-fearful stimuli, thus leading to little effect on the neural marker of valence modulated LPP (Codispoti et al., 2012). On the other hand, changes in decision criterion due to color can still be accompanied by changes in P300, which is an ERPs component elicited in the process of decision making (Cano et al., 2009). Note that the effect of color on decision criterion observed in the present study does not exclude possible modulations of perceptual sensitivity in discriminating emotional stimuli under extreme cases. For example, the presence of a red splash of blood in an image could lead to rapid detection of danger. When color is diagnostic of a scene category, it mediates express scene recognition (Oliva and Schyns, 2000), e.g., red may signify blood. Therefore, in this case, color plays a diagnostic role in the operation of high-level vision: categorizing a scene into fearful or not fearful (Tanaka et al., 2001). However, such effect of color for particular diagnostic contents of images may be negligible in the present study because a wide range of contents with large variance in the level of fearfulness, from animals, human body parts, weapons/objects to various scenes, including street and city which are not color-diagnostic (Oliva and Schyns, 2000), were used. Therefore, the present results are more representative for interactions between emotional perception and visual perception in natural vision, regardless of the specific diagnostic value of color for scene recognition in any given stimulus.

The dissociable effects of image color and contrast on fearfulness rating may arise from interactions between perception and metaphor. A recent study demonstrated that stimulus brightness could influence affective rating in that brighter images tended to be rated more positive whereas dimmer images tended to be rated more negative (Lakens et al., 2013). Similarly, interactions between metaphoric understanding and embodied cognition (Gibbs, 1994; Gibbs et al., 2004; Xie and Zhang, 2014) can lead to a metaphoric association between stimulus contrast and affective perception. That is, high-contrast and low-contrast can metaphorically correspond to being more fearful and less fearful, respectively. By contrast, given the lack of any metaphoric association between stimulus color and affective judgment, the effects of color on affective judgment are largely driven by the change of decision criterion.

Besides extending our understanding of the influences of visual properties on affective perception, the current study has provided some methodological tools for research on affective perception. The fearful stimulus set developed in the present study has a wide range of fearfulness levels and can be controlled on certain low-level properties. With this set, SDT methods can be used to tease apart sensitivity and decision criterion, two independent factors contributing to fear perception. The dissociable effects on these two factors would have been impossible to see if we had only compared images that are either very fearful or not fearful at all. SDT methods may be used to resolve the variety of previous findings on whether certain visual properties, such as spatial frequency information, influence affective processing (Vuilleumier et al., 2003; De Cesarei and Codispoti, 2008). Future studies using SDT approaches can extend current findings by applying type 2 task and parametric manipulations of image-level properties to further investigate how metacognitive (type 2) sensitivity (e.g., Maniscalco and Lau, 2012) to affective information would be modulated by graded levels of image-level properties. Moreover, it is important to note that subjective rating used in the present study is prone to biases from beliefs and expectation. Therefore, it would be interesting for future studies to generalize the present findings with more objective measures of emotional responses, such as skin conductance response and neural activities in amygdala using functional imaging. Nevertheless, by showing that low-level properties such as contrast and color affect different aspects of the subjective rating of fearful scenes, our findings provide a premise for future studies to investigate how danger may be detected from natural scenes based on cognitive algorithms computing the visual properties of stimuli.

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Supplementary Material

The Supplementary Material for this article can be found online at: http://journal.frontiersin.org/article/10.3389/fpsyg.2015.01521

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Modulation of executive attention by threat stimulus in test-anxious students

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The study examined whether test anxiety (TA) is related to impaired attentional networks under emotional distraction. High and low test-anxious students completed a modified version of the attention network test (ANT) in which emotional distracters, specifically threat-related or neutral words, were embedded in centrally presented hollow arrows in Experiment 1. Results showed a significant reduction in efficiency of the executive attention in test-anxious students compared to controls when the fillers were threat/test-related words. To evaluate the effect of the test adaptation, the original ANT, which utilized no emotional distracter, was employed as a control task in Experiment 2. We then consolidated the data on efficiency of attentional networks, which were derived from both tasks. Contrasting the two tasks showed that TA reduced executive attention in the revised task only, suggesting an enhanced sensitivity provided by the adaptation from the original task. Taken together, these findings indicate that the attentional deficit in test-anxious individuals represents a situation-related defect of a single component of attention rather than an underlying structural and universal attentional deficit. The results support the hypothesis of attentional control theory and contribute to the understanding of attentional mechanisms in individuals with TA.

Keywords: test anxiety, emotional distraction, attention network test, executive attention, modulation

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Introduction

Test anxiety (TA) has been described as a set of phenomenological, physiological, and behavioral responses that accompany concerns about possible negative consequences or failure in an exam or similar evaluative situations (Zeidner, 1998). It has been found that TA was related to susceptibility or attentional bias to threat distraction (Mathews, 1993; Keogh and French, 2001; Putwain et al., 2011). Hence, TA was deemed to induce a type of information processing (Zeidner, 1998), concretely, attentional deficit (Calvo et al., 1994). Considering that attention has been researched as a unitary idea in the past (Raz and Buhle, 2006), it is not entirely clear whether susceptibility or bias to threat-related distracters is due to underlying structural and universal deficits of attention or due to situational defect of a single component of attention.

It is important to note that attention characteristics in test-anxious individuals have been examined in a variety of studies using different paradigms, such as the dot probe task

(Putwain et al., 2011), cue-target task (Keogh and French, 2001; Liu et al., 2015), central cue task (Chen et al., 2011), negative priming task (Shi et al., 2014), Stroop task (Hopko et al., 2002; Kofman et al., 2006; Lawson, 2006; Bradley et al., 2010; Geen and Kaiser, unpublished manuscript), and switching task (Kofman et al., 2006). The results from these tests are hard to compare directly due to different aspects of attention that were tested by the different tasks (Miyake et al., 2000; Joormann, 2004; Derrfuss et al., 2005; Mottaghy et al., 2006; Mogg et al., 2008; Finucane et al., 2010). Therefore, it is critical to employ a comprehensive and systematic measurement to inspect potential attentional deficits in test-anxious people thoroughly.

Among the various instruments to assess attention characteristics, the attention network test (ANT) is a popular tool that was designed as a quick and simple computerized task based on a neural network model of attention (Posner and Petersen, 1990; Fernandez-Duque and Posner, 2001; Posner et al., 2007; Petersen and Posner, 2012). According to this model, the attention system of the human brain can be divided into three functionally and anatomically independent networks, each with corresponding functions. For example, the alerting network allows producing and maintaining optimal vigilance; the orienting network is focused on the ability to prioritize sensory input by selecting a modality or location; and the executive control network allows for the monitoring and resolution of conflict between responses. These networks used to be analyzed separately until a single task (ANT) was created through the combination of a flanker paradigm and cueing task with fully randomized conditions within blocks (Dennis et al., 2008; Macleod et al., 2010). Participants were instructed to press either the left or right key of the keyboard (or mouse) depending on whether the target, a central arrow presented above or below the fixation point, pointed to the left or the right, respectively. Through the integration of separate chronometric analyses for each attention network, the ANT can tap into early and late stages (components) of information processing (Raz and Buhle, 2006; Galvao-Carmona et al., 2014). It has been widely accepted as a useful, accurate, and reliable measure of function of the three attentional subsystems in light of the evidence from various behavioral and brain imaging studies (Petersen and Posner, 2012). The ANT was also applied to explore individual differences in Caucasians (Matthews and Zeidner, 2012), and Chinese (Du et al., 2006).

Recently, four versions of the emotional ANT have been developed to explore the effects of emotional distracters on attentional functions. In earlier versions, each trial was preceded by an emotional picture presented for 50 ms (Dennis and Chen, 2007), or every sixth trial was preceded by an emotional picture presented for 6 s (Finucane et al., 2010). In more recent versions, the cues (asterisks) were replaced by emotional pictures (Cohen et al., 2011) or words (Gómez-Íñiguez et al., 2014). All of these tasks are useful, as they provide insight into the effect of emotion on attentional processing. However, we are skeptical of their sensitivity to differentiate between high and low test-anxious people under emotional distraction. The main reason for this insensitivity may lie in the time lag between emotional and target processing, which can help test-anxious people to summon extra resources and thus compensate for potential performance impairments caused by the resource preemption of emotional processing (Eysenck et al., 2007). More concretely, the extra resources may compensate for depleted self-control resources which help test-anxious people regulate the disruptive effects of emotional stimuli on subsequent cognitive processes (Cohen et al., 2011; Bertrams et al., 2013).

In the present study, we developed a novel version of the ANT by embedding a task-irrelevant distracter (Chinese two-character word differing in valence and relevance to the examinations) into the target (central hollow arrow). Due to the new, yet the same, perceptual object which was formed by the distracter and target (Berti and Schröger, 2001), participants were forced to attend to the distracter which was presented in the whole object (Leiva et al., 2015); consequently, visual distraction effects were obtained (Berti and Schröger, 2004). The adaptation allows us to induce simultaneous competition for attention resources between the target and emotional distracter and serves as a possible source of emotional interference (illustrated in **Figure 1**). More importantly, TA individuals had no supplemental resources in our modified ANT compared to the previous revised ANTs, due to the simultaneous presentation of distracters and targets, to compensate for their potential performance impairments caused by the emotional distraction. Hence, our modified ANT might tap into the effect of TA on attentional functions.

The aim of this study was twofold. First, we examined whether TA is related to impaired attentional networks under emotional distraction. In Experiment 1, we employed the revised ANT to explore the effects of emotional distraction on attentional functions. Second, we assessed the validity of this revised task to measure attentional networks in high versus low test-anxious students. For this purpose we proceeded in two steps: (i) replicating the original ANT in Experiment 2, and (ii) comparing the data on efficiency of attentional networks, which were recorded in the two different situations, that is, derived from the original (conditions free from emotional distracters) and revised tasks (conditions under emotional distracters).

Hypothesis 1: Threat/test-related distracters embedded in targets are expected to induce stronger attention interference effects (i.e., lower efficiency of alerting, orienting, and executive attention) in contrast to neutral distracters in high versus low test-anxious students.

Experiment 1

Methods

Participants

Forty (19 males) college students (see **Table 1**) were selected from a total of 422 (197 males), aged 18–26 years ($M = 20.38$, $SD = 1.12$), according to their scores of the Chinese version of the Test Anxiety Inventory (TAI; Spielberger, 1980; Wang, 2003). Those falling into the highest and lowest quarters of the score distributions were selected as the 40 candidates (high-anxious students and controls, respectively). All participants (native Chinese speakers) reported normal or corrected-to-normal vision and right-handedness. None of them suffered from

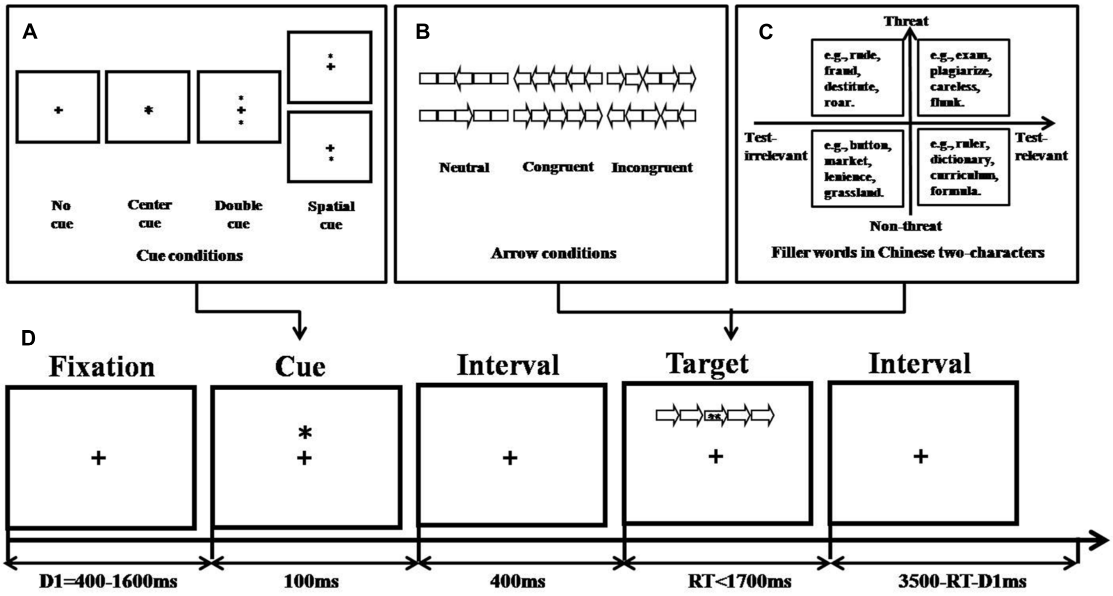

FIGURE 1 | Experimental procedure of revised ANT (based on Fan et al., 2002). (A) Cue conditions, **(B)** Arrow conditions, **(C)** Filler word conditions, and **(D)** An example of the procedure.

TABLE 1 | Demographic characteristic of subjects in the two experiments.

Task	Group	Gender (N)		Age *M* (*SD*)	TA *M* (*SD*)	Trait anxiety *M* (*SD*)	State anxiety *M* (*SD*)	Depression *M* (*SD*)
		Male	Female					
(A) Revised ANT	Control	10	10	20.45 (0.95)	25.10 (2.51)	38.70 (8.02)	35.50 (5.31)	3.50 (3.36)
	Experiment	9	11	20.20 (1.06)	47.75 (5.88)	49.60 (6.92)	44.85 (7.31)	9.60 (4.94)
(B) Original ANT	Control	9	10	19.89 (0.88)	25.39 (2.64)	38.37 (7.93)	33.63 (7.31)	2.79 (2.02)
	Experiment	10	11	19.90 (0.94)	49.65 (8.25)	50.71 (7.71)	42.33 (7.37)	10.67 (5.09)

psychosis, neuropathy or had experienced drug abuse. They took no medications or alcohol in the 3 days before the experiment. All participants signed the written informed consent, and they were paid for their participation. The study was approved by the local ethics committee.

Measures

Test anxiety

The Chinese version of the 20-items TAI (Wang, 2003), including the two concepts worry and emotionality, was used to measure TA. On a four-point scale, participants rated the frequency with which they experienced specific symptoms of anxiety before, during, and after exams. Cronbach's alpha of the Chinese Version of the TAI (total) in this study (0.90) was comparable with that (0.92) reported in a previous study (Spielberger, 1980); the corresponding values for the worry and emotionality subscale were 0.80 and 0.84, respectively (Wang, 2003).

State anxiety and trait anxiety

The State-Trait Anxiety Inventory (STAI; Spielberger, 1983), including the A-Trait and A-State subscale, was used to measure trait and state anxiety separately. On a four-point scale, participants rated the frequency of specific symptoms they experienced before in the A-Trait subscale or rated the correspondence between the descriptions and their current feelings in the A-State subscale. A score of 20 indicates the absence of anxiety and a score of 80 indicates high anxiety in each subscale. The Chinese version of the STAI (Tsoi et al., 1986), showing high internal consistency, was used in the present study. Shek (1988) reported that the Cronbach's alpha was 0.90 and 0.81 for A-State and A-Trait subscale, respectively.

Depression

The short form of the Beck Depression Inventory (BDI; Beck et al., 1974, 1988) was used to measure the respondent's current depressive state on a four-point scale. The inventory taps symptoms and attitudes frequently displayed by depressed psychiatric patients and relatively infrequently by non-depressed psychiatric patients (Beck et al., 1961). The Chinese version of the BDI (Chan and Tsoi, 1984) was used in the present study. The overall Cronbach's alpha was 0.86 (Shek, 1990), indicating good reliability.

Vocabulary assessment

One thousand and forty-six two-character Chinese words (including 476 nouns, 359 verbs, and 211 adjectives) with frequency counts below 1000 were chosen from a frequency list of a 20-million word corpus of the Chinese Linguistics Data [DB/OL] (Institute of Applied Linguistics, 2009) by three candidates for the doctoral degree in psychology. These words were divided into four groups with approximately the same amount of words, and the 422 previously mentioned participants completed the assessment at different times. A list of words was presented on the screen one-by-one (programmed in E-prime 1.1), and the participants assigned a value from 1 to 7 according to the word's threat potential and relevance to examinations. Higher values indicate that the words were more threatening (or relevant).

These words were then ranked according to their values on threat and exam relevance. Those falling into the highest and lowest 10% of their respective score distributions were selected as candidate items. After controlling for frequency and stroke, we obtained 64 two-character Chinese words. The various questionnaires listed previously were performed in the 3 weeks before the final exams, except for the measurement on state anxiety. In order to assess the test–retest reliability of the 64-items vocabulary, a sample of 79 college students (26 males), aged 18–23 years ($M = 19.96$, $SD = 1.13$), returned to complete the assessment of the words after 2 weeks.

The Modified ANT

Stimuli, apparatus, and design

The stimuli consisted of a row of five visually presented horizontal rectangles, with arrowheads pointing leftward or rightward. The combination of arrowheads and rectangles yielded hollow arrows. The central arrow (leftward or rightward) was considered the target and was flanked by two arrows on each side that could point in the same direction as the target (congruent trials) or in the opposite direction (incongruent trials) or by rectangles (neutral condition; see the three flanker conditions in **Figure 1B**). These five-items combos covered an area of 10 mm × 6 mm. The efficiency of executive attention was indexed by deterioration in reaction time (RT) in incongruent trials compared to congruent trials.

Within the centrally presented hollow arrows, one of the 64 two-character Chinese words, which varied in terms of valence (threat versus non-threat) and relevance to examinations (relevant versus irrelevant), was presented as filler (see **Figure 1C** and **Table 2**). For example, "sweater" was considered an irrelevant and non-threat filler; "ferocious," "dictionary," and "exam" were considered irrelevant and threat, relevant and non-threat, and relevant and threat fillers, respectively. The filler word was set in Song typeface with a font size of 9 points and changed randomly between trials.

In some trials, there were asterisk cues before the stimulus presentation, indicating when or where the target would occur, thereby providing a basis for the participant to direct attention to the cued location (Posner, 1980). The cue conditions (no-cue, central-cue, double-cue, and spatial-cue condition) which have been described in Fan et al. (2002), are illustrated in **Figure 1A**. For the no-cue (no asterisk appeared, participants saw only the fixation point for 100 ms), center-cue (asterisk appeared superimposed over the fixation point), and double-cue trials (asterisks appeared both above and below the fixation point), the target locations were always uncertain. The cue was only valid for the spatial-cue trials (asterisk appeared either above or below the fixation point), which meant that it was at the target position. The efficiency of alerting attention was indexed by improvement in mean RT in double-cue trials compared to no-cue trials. The efficiency of orienting attention was indexed by improvement in mean RT in spatial-cue trials compared to center-cue trials.

Forty-eight conditions (4 cue conditions × 3 flanker types × 2 relevance conditions × 2 threat conditions) were assigned to the repeated testing conditions, with the assignment counterbalanced between experimental (high-anxiety participants) and control group. All four cue conditions were equally probable in the task, as were all three flanker types. Targets appeared above and below the fixation point with equal probability. The words varying in valence and relevance and were randomly distributed among the different cue conditions and flanker types. Group condition was the between-subject factor; the within-subject factors included cue, flanker, and filler conditions. The generation of the stimuli and collection of responses were controlled using the E-prime 1.1 software (Schneider et al., 2002) running under Windows XP on a PC with a 1.6 GHz processor and displayed on a 17-inch flat-panel screen (resolution of 1024 × 768 pixels and refresh rate of 85 Hz).

Procedures

Subjects sat about 90 cm away from the screen in a silent and dimly illuminated room, and their heads were stabilized by the headrest of an armchair. Each trial began with a fixation point presented for 400–1,600 ms in the center of the screen. A cue was presented for 100 ms, and 400 ms later, a stimulus-combination was presented. Subjects were asked to identify the direction of the central arrow by pressing the left mouse button for the left direction and the right mouse button for the right direction. They were instructed to respond as quickly and accurately as possible.

The stimulus-combination was presented for up to 1,700 ms, or until the subject responded. The total duration of each trial was 4,000 ms. The fixation point appeared at the same location during the whole trial. The stimulus-combination, which subtended an area of 3.18° × 0.38° of visual angle, was presented 0.25° above or below the fixation point. The cue was presented at similar locations except for the central cue condition. The experimental process is shown in **Figure 1D**. The experiment consisted of a 24-trial full-feedback practice block (RT, whether answer was correct, and cumulative success rate) followed by three blocks of 96 feedback-free trials each (4 cue conditions × 2 combo locations × 2 target directions × 3 flanker types × 2 repetitions), with a 2-min break between blocks. The A-State subscale of the STAI was completed either before or after the revised ANT, with the order counterbalanced between groups. The tasks were completed individually 1 week before the final exams and usually lasted about 40–50 min.

Analysis

The questionnaire scores were compared between groups using Fisher's exact test. The data for the 64 words were analyzed by a 2

TABLE 2 | Characteristics of the filler words (mean and SD).

Emotionality (*N*)	**Nouns (*N*)**	**Verbs (*N*)**	**Adjectives (*N*)**	**Relevance**	**Threat**	**Frequency**	**Strokes**
Irrelevant and non-threat(16)	11	2	3	1.55 (0.18)	1.29 (0.20)	33.50 (22.33)	17.38 (3.91)
Irrelevant and threat(16)	3	4	9	1.77 (0.18)	2.86 (0.24)	33.50 (21.62)	17.31 (5.56)
Relevant and non-threat(16)	9	5	2	3.48 (0.40)	1.37 (0.18)	33.25 (28.63)	17.12 (4.23)
Relevant and threat(16)	3	10	3	3.65 (0.58)	2.94 (0.28)	33.62 (35.09)	17.81 (4.64)

(relevance condition) × 2 (threat condition) analysis of variance (ANOVA) with relevance-rating and threat-rating scores serving as dependent variables. In addition, a classical one-way ANOVA of word frequency and stroke was carried out on these different word groups.

We followed the method of Fan et al. (2002) to analyze the effects of cues, flankers, and groups on choice RTs. Two participants were excluded from the analysis for outlier RTs in more than 20% trials (Z-score > 3). Subsequently, 38 participants were screened to remove trials (1.58%) with responses faster than 200 ms and trials with RTs 3 SD greater than an individual's mean. The remaining RT data from the correct trials (95.56%) were pooled as a function of cue and flanker condition. We carried out a 2 (group condition) × 4 (cue condition) × 3 (flanker type) × 4 (filler-emotion condition) mixed ANOVA of the RT data.

To examine the effect of emotions on attention, we reconstructed the current formula for calculating the efficiency of the attentional network (Fan et al., 2002) by computing the RT difference between the emotional targets and neutral targets (i.e., targets contained irrelevant and non-threat words). The formulae for calculating the alerting effect under different emotional conditions were as follows: $\text{Alerting}_{\text{neutral}} = \text{RT}_{\text{no-cue,neutral}} - \text{RT}_{\text{double-cue,neutral}}$ representing the benefit of the target response speed because of presence versus absence of cues without spatial information in neutral trials. $\text{Alerting}_{\text{irrelevant and threat}} = \text{RT}_{\text{no-cue,neutral}} - \text{RT}_{\text{double-cue,irrelevant, and threat}}$ representing the benefit of the target response speed because of alerting in irrelevant and threat trials compared to neutral trials. $\text{Alerting}_{\text{relevant and threat}} = \text{RT}_{\text{no-cue,neutral}} - \text{RT}_{\text{double-cue,relevant, and threat}}$ representing the benefit of the target response speed because of alerting in relevant and threat trials compared to neutral trials. $\text{Alerting}_{\text{relevant and non-threat}} = \text{RT}_{\text{no-cue, neutral}} - \text{RT}_{\text{double-cue, relevant, and non-threat}}$ representing the benefit of the target response speed because of alerting in relevant and non-threat trials compared to neutral trials.

The formulae for calculating the orienting effect under different emotional conditions were as follows: $\text{Orienting}_{\text{neutral}} = \text{RT}_{\text{central-cue,neutral}} - \text{RT}_{\text{spatial-cue,neutral}}$ representing the benefit of the target response speed because of presence versus absence of cues with spatial information in neutral trials. $\text{Orienting}_{\text{irrelevant and threat}} = \text{RT}_{\text{central-cue,neutral}} - \text{RT}_{\text{spatial-cue,irrelevant, and threat}}$ representing the benefit of the target response speed because of orienting in irrelevant and threat trials compared to neutral trials. $\text{Orienting}_{\text{relevant and threat}} = \text{RT}_{\text{central-cue,neutral}} - \text{RT}_{\text{spatial-cue,relevant, and threat}}$ representing the benefit of the target response speed because of alerting in relevant and threat trials compared to neutral trials. $\text{Orienting}_{\text{relevant and non-threat}} = \text{RT}_{\text{central-cue,neutral}} - \text{RT}_{\text{spatial-cue,relevant, and non-threat}}$ representing the benefit of the target response speed because of alerting in relevant and non-threat trials compared to neutral trials.

The formulae for calculating the conflict effect under different emotional conditions were as follows: $\text{Conflict}_{\text{neutral}} = \text{RT}_{\text{incongruent,neutral}} - \text{RT}_{\text{congruent,neutral}}$ representing the cost of the target response speed because of incongruence versus congruence in neutral trials. $\text{Conflict}_{\text{irrelevant and threat}} = \text{RT}_{\text{incongruent,irrelevant, and threat central}} - \text{RT}_{\text{congruent,neutral}}$ representing the cost of the target response speed because of conflict in irrelevant and threat trials compared to neutral trials. $\text{Conflict}_{\text{relevant and threat}} = \text{RT}_{\text{incongruent,relevant, and threat}} - \text{RT}_{\text{congruent,neutral}}$ representing the cost of the target response speed because of conflict in relevant and threat trials compared to neutral trials. $\text{Conflict}_{\text{relevant and non-threat}} = \text{RT}_{\text{incongruent,relevant, and non-threat}} - \text{RT}_{\text{congruent,neutral}}$ representing the cost of the target response speed because of conflict in relevant and non-threat trials compared to neutral trials. These differences indicate that the higher the value of the alerting and orienting effect, the more efficient the attentional network is. When it comes to the conflicting effect, the reverse is true (Fan et al., 2002).

We suspected that there might be a close relationship between anxiety sensitivity and depression (Goldenberg et al., 1996; Taylor et al., 1996; Weems et al., 1997), and that trait and state anxiety levels might modulate individual attentional network efficiency (Pacheco-Unguetti et al., 2010). We hence carried out three separate 2 (group condition) × 2 (filler relevance condition) × 2 (filler valence condition) analyses of covariance (ANCOVAs) by entering all three covariates (trait anxiety, anxiety, and depression scores), with alerting, orienting, and conflicting effects as dependent variables. All the data were analyzed using SPSS 16.0 for Windows.

Results and Discussion

Questionnaire Results

As shown in **Table 1A**, test-anxious subjects in the revised ANT had significantly greater TA [$t_{(39)} = 15.09$, $p < 0.001$] than controls. The same result was obtained for the subscales of the STAI [trait $t_{(39)} = 4.54$, $p < 0.001$; state $t_{(39)} = 4.49$, $p < 0.001$]. These findings are consistent with the notion that describes TA as a situation specific anxiety (Spielberger and Vagg, 1987). Furthermore, test-anxious subjects had significantly greater depression levels than controls [$t_{(39)} = 4.77$, $p < 0.001$]. This result confirmed the close relationship between anxiety sensitivity and depression (Goldenberg et al., 1996; Taylor et al., 1996; Weems et al., 1997).

Filler Word Results

The results of the vocabulary assessment are shown in **Table 2** and reveal a main effect of relevance [$F_{(1,420)} = 415.07, p < 0.001, \eta_p^2 = 0.87$], with rating levels significantly greater for test-relevant than test-irrelevant words, as well as a main effect of valence [$F_{(1,420)} = 759.76, p < 0.001, \eta_p^2 = 0.93$], with rating levels significantly greater for threat than non-threat words. Thus, the four different word groups indeed varied in either relevance or valence. It is also important to note that there were no significant differences in word frequency [$F_{(1,421)} = 0.00, p = 1.00$] and stroke [$F_{(1,421)} = 0.06, p = 0.98$] between the different word groups.

The intra-scale reliability of each conceptual domain was determined by computing Cronbach's alpha coefficients. Values of 0.94 (for relevance) and 0.94 (for valence) were taken as indicating satisfactory reliability. Test–retest repeatability correlation coefficients for the two domain scores were highly significant ($p < 0.001$). Cronbach's alpha coefficients were 0.81 and 0.83 for the relevance and valence subscale, respectively.

Effects of Cues, Flankers, and Fillers on Choice Reaction Times

Table 3 summarizes RT data pooled from correct trials as a function of cue, flanker, and filler-emotion condition. The results replicated the findings of Fan et al. (2002). Statistically significant differences were found for the cue [$F_{(3,34)} = 122.52, p < 0.001, \eta_p^2 = 0.77$] and flanker [$F_{(2,35)} = 508.98, p < 0.001, \eta_p^2 = 0.93$] main effects and for their interaction [$F_{(6,31)} = 5.04, p < 0.001, \eta_p^2 = 0.12$; see **Figure 2**]. The simple effect analysis suggested that, regardless of the cue condition, subjects took more time to react under incongruent flankers, and this effect was enhanced under the alerting cue conditions (central and double cues). Considering that both cue and flanker effects are in line with the principles of the ANT design, attentional network functions can be thus formulated (Fan et al., 2002).

The results of the ANOVA showed no significant main effect of group [$F_{(1,36)} = 0.91, p = 0.35$]. However, the ANOVA revealed a significant filler-emotion main effect [$F_{(3,34)} = 10.89, p < 0.001, \eta_p^2 = 0.23$]. This effect was qualified by a significant group × filler-emotion interaction [$F_{(3,34)} = 12.58, p < 0.001, \eta_p^2 = 0.26$]. Contrasting high and low TA groups showed that targets embedded with emotional (i.e., irrelevant and threat, relevant and non-threat, and relevant and threat) versus neutral words prolonged the RT only in the TA group, suggesting that controls were free from the emotional interference. The effect of filler-emotion was also qualified by a significant group × filler-emotion × cue × flanker interaction [$F_{(18,19)} = 1.70, p < 0.05, \eta_p^2 = 0.05$]. Further analysis showed that students with TA took more time for dealing with targets embedded with irrelevant and threat words in conflict trials under center-cue [$F_{(1,36)} = 6.63,$

TABLE 3 | Reaction time (RT) data (mean and SD) under each condition.

Flanker	Filler emotion	Group	Cue condition				
			No cue	Center cue	Double cue	Spatial cue	Total
Congruent	IRNT	Control	439 (48)	436 (33)	390 (49)	384 (53)	411 (43)
		Experiment	448 (54)	413 (36)	394 (43)	390 (49)	410 (45)
	IRT	Control	448 (50)	441 (54)	392 (56)	378 (52)	408 (48)
		Experiment	452 (59)	415 (61)	406 (57)	394 (56)	416 (50)
	RNT	Control	444 (60)	443 (44)	396 (57)	376 (50)	407 (52)
		Experiment	450 (56)	411 (36)	411 (46)	387 (43)	414 (46)
	RT	Control	445 (46)	479 (41)	400 (54)	380 (50)	406 (46)
		Experiment	447 (41)	424 (49)	403 (50)	396 (45)	414 (40)
Incongruent	IRNT	Control	505 (54)	484 (48)	469 (49)	455 (55)	478 (52)
		Experiment	506 (56)	498 (51)	470 (41)	466 (52)	489 (49)
	IRT	Control	494 (75)	506 (63)	469 (54)	445 (68)	479 (59)
		Experiment	547 (70)	558 (62)	542 (49)	503 (60)	503 (51)
	RNT	Control	506 (63)	494 (51)	461 (54)	445 (50)	478 (52)
		Experiment	526 (63)	505 (54)	499 (47)	482 (48)	497 (45)
	RT	Control	494 (51)	444 (52)	479 (56)	461 (58)	478 (50)
		Experiment	520 (51)	527 (41)	520 (59)	502 (51)	496 (46)
Neutral	IRNT	Control	444 (52)	440 (42)	402 (46)	380 (42)	416 (44)
		Experiment	440 (46)	422 (49)	409 (33)	393 (46)	415 (41)
	IRT	Control	445 (51)	440 (45)	392 (50)	372 (45)	412 (49)
		Experiment	455 (46)	419 (54)	413 (41)	397 (45)	421 (44)
	RNT	Control	441 (47)	438 (35)	409 (47)	378 (47)	417 (42)
		Experiment	455 (45)	417 (36)	403 (36)	392 (40)	417 (37)
	RT	Control	439 (37)	414 (58)	395 (49)	376 (40)	406 (42)
		Experiment	438 (44)	416 (49)	402 (44)	386 (34)	411 (39)

IRNT, irrelevant and non-threat; IRT, irrelevant and threat; RNT, relevant and non-threat; RT, relevant and threat.

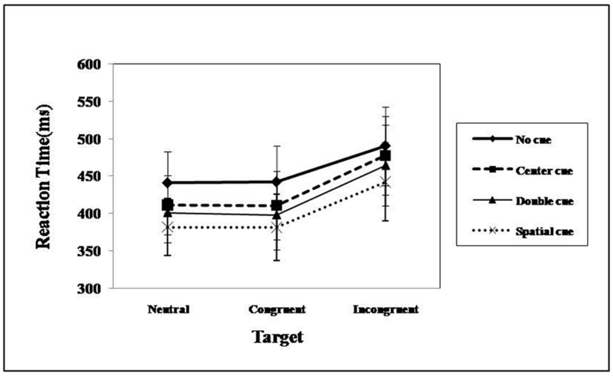

FIGURE 2 | Mean RT from correct trials as a function of cue and flanker condition under emotional distraction.

$p < 0.05$, $\eta_p^2 = 0.16$] and no-cue [$F_{(1,36)} = 5.17$, $p < 0.05$, $\eta_p^2 = 0.13$] conditions, compared to controls. The same was true for irrelevant and threat [$F_{(1,36)} = 7.52$, $p < 0.01$, $\eta_p^2 = 0.17$], relevant and non-threat [$F_{(1,36)} = 5.26, p < 0.05, \eta_p^2 = 0.13$], and relevant and threat [$F_{(1,36)} = 5.13$, $p < 0.05$, $\eta_p^2 = 0.13$] fillers in conflict trials under spatial-cue conditions. Similarly, in the double-cue conditions, the corresponding ANOVA values were as follows: $F_{(1,36)} = 18.48$, $p < 0.001$, $\eta_p^2 = 0.34$; $F_{(1,36)} = 5.23$, $p < 0.05, \eta_p^2 = 0.13$; $F_{(1,36)} = 4.91, p < 0.05, \eta_p^2 = 0.12$.

Efficiency of Attentional Networks

Table 4 shows the efficiency of subjects' alerting, orienting, and executive attention networks in these emotional tasks. There were no significant main effects of group [$F_{(1,33)} = 2.91$, $p = 0.10$], relevance [$F_{(1,33)} = 0.05$, $p = 0.82$], or valence [$F_{(1,33)} = 1.80$, $p = 0.19$] in the efficiency of alerting. No significant interactions (all four F's < 1.14) were found. We found similar results for the efficiency of orienting; the corresponding F-values for group, relevance, and valence were 1.02 ($p = 0.32$), 1.00 ($p = 0.32$), and 0.74 ($p = 0.40$), respectively. Again, there were no significant interactions (all four F's < 1.48). These results suggest that despite the emotionality of the targets, there was no difference in alerting or orienting efficiency between test-anxious and control individuals.

The ANCOVA for executive attention revealed a significant main effect of relevance [$F_{(1,33)} = 9.08$, $p < 0.01$, $\eta_p^2 = 0.22$) and a marginally significant main effect of group [$F_{(1,33)} = 3.69$, $p = 0.06$, $\eta_p^2 = 0.10$]; however, no main effect of valence was observed [$F_{(1,33)} = 0.67$, $p = 0.42$]. Importantly, these effects were qualified by a significant group × valence interaction [$F_{(1,33)} = 4.41, p < 0.05, \eta_p^2 = 0.12$] and a marginally significant group × relevance interaction [$F_{(1,33)} = 3.63$, $p = 0.06$, $\eta_p^2 = 0.10$]. The simple effect analysis revealed that the TA group ($M = 93.20 \pm 7.14$) was more impaired on executive attention than controls ($M = 64.97 \pm 6.63$) when the fillers were threat words compared with non-threat words (see **Figure 3A**). The same was true when the filler words were test-relevant ($M_{\text{TA}} = 92.42 \pm 7.13$ versus $M_{\text{controls}} = 62.53 \pm 6.14$; see **Figure 3B**). These results suggest that test-anxious individuals showed lower efficiency of executive attention than controls especially when they were exposed to a situation involving threat/test-related information.

To validate the effect of the modified ANT, we introduced Experiment 2 in which the original ANT was employed. Considering the findings from Experiment 1 and the evidence indicating that elementary cognitive operations may be intact in individuals with anxiety and depression in the conditions that are free from emotional distracters (Airaksinen et al., 2005; Pardo et al., 2006; Preiss et al., 2010), we expected that the revised task would be more sensitive to TA than the original ANT when measuring executive attention.

Hypothesis 2: Emotional distraction (i.e., revised) task is expected to reduce executive rather than alerting/orienting attention in contrast to distraction-free (i.e., original) task in high versus low test-anxious students.

Experiment 2

Methods

Participants

Another 40 (19 males) students of the subject pool of 422 original participants (see **Table 1B**) were assigned to the original ANT. The basic requirements for their participation were the same as those for Experiment 1.

Measures

Measures were the same as those in Experiment 1.

The Original ANT

Stimuli, apparatus, and design

Stimuli were different from Experiment 1, for example, black lines replaced rectangles, thus yielding solid arrows or arrow-line combinations (see **Figure 4**). In addition, no word was used as filler. The combination subtended an area of 3.08° of visual angle and appeared either 1.06° above or below the fixation point. The cue conditions and the apparatus were the same as for the revised ANT. More details are given in Fan et al. (2002).

Procedures

The procedure was the same as described by Fan et al. (2002). Briefly, participants viewed the stimuli from a distance of 65 cm under four cue conditions and two flanker conditions. They were instructed to identify the direction of the centrally presented arrow and to respond as fast and as accurately as possible. Responses were collected via two mouse buttons. A session consisted of a 24-trial practice block and three experimental blocks. Each experimental block consisted of 96 trials (48 conditions, as described in Experiment 1, with two repetitions). The presentation of trials was in a random order. Again, the A-State subscale of the STAI was completed either before or after the revised ANT, with the order counterbalanced between groups.

Analysis

Questionnaire analyses were the same as those in Experiment 1. We followed the method of Fan et al. (2002) to calculate

TABLE 4 | Alerting, orienting, and executive effects (mean RTs and SD) under emotional distraction.

Index	Alerting (ms)				Orienting (ms)				Executive (ms)			
	IRNT	IRT	RNT	RT	IRNT	IRT	RNT	RT	IRNT	IRT	RNT	RT
Control (*M*)	43.68	46.51	46.83	36.04	35.75	36.16	43.40	36.10	67.57	68.32	67.56	67.37
Control (*SD*)	27.94	28.51	29.76	23.70	26.23	33.24	26.61	30.13	24.61	26.97	25.53	21.46
Experiment (*M*)	39.05	37.92	39.09	41.59	29.74	26.26	26.87	30.90	78.94	93.77	87.62	86.24
Experiment (*SD*)	39.01	29.96	26.76	34.59	29.09	34.70	29.19	27.20	24.92	34.64	30.41	28.94

IRNT, irrelevant and non-threat; IRT, irrelevant and threat; RNT, relevant and non-threat; RT, relevant and threat.

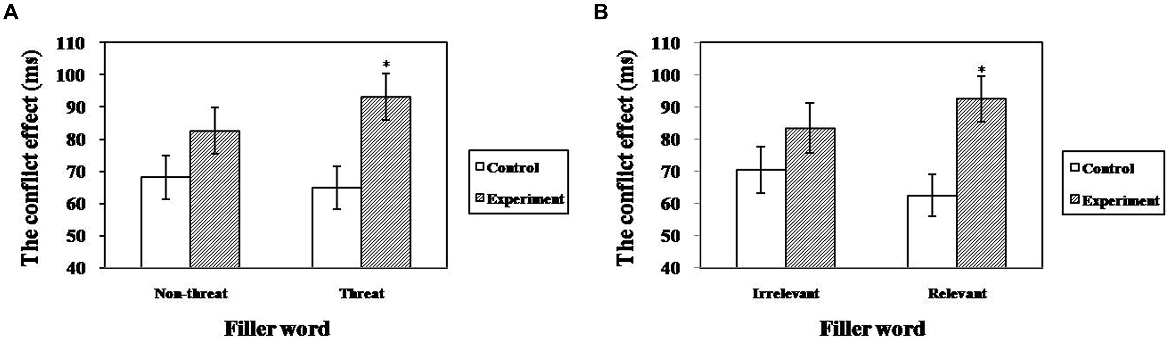

FIGURE 3 | The interaction between group and valence/relevance for executive attention in the revised ANT (*$p < 0.05$). (A) Interaction between group and valence, **(B)** Interaction between group and relevance.

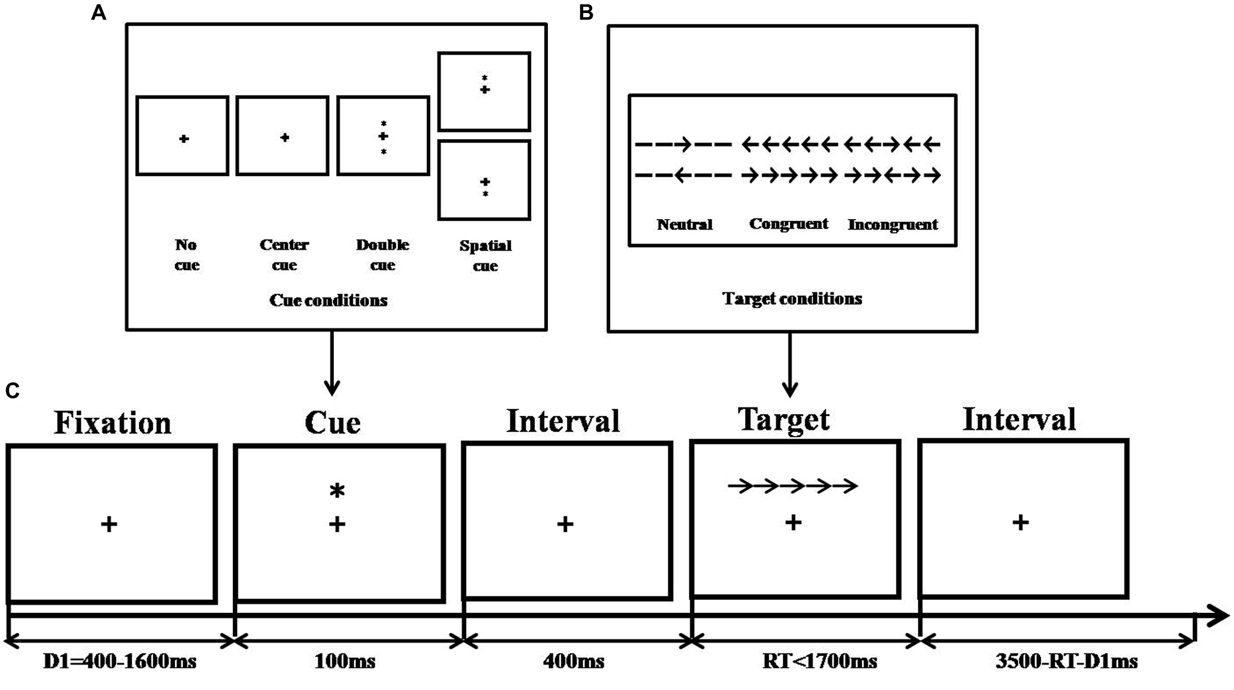

FIGURE 4 | Experimental procedure of original ANT (adapted from Fan et al., 2002). (A) Cue conditions, **(B)** Stimuli without emotion interference, and **(C)** An example of the procedure.

efficiency of executive attention based on the RT data from the original ANT. The formulae were as follows: alerting effect = $RT_{no-cue} - RT_{double-cue}$, orienting effect = $RT_{center-cue} - RT_{spatial-cue}$, conflicting effect = $RT_{incongruent} - RT_{congruent}$. After consolidating the data on efficiency of attentional networks, which derived from the original and revised ANT (Experiment

1), we then carried out three separate 2 (task type) × 2 (group condition) ANCOVAs by entering all three covariates (trait anxiety, anxiety, and depression scores), with alerting, orienting, and conflicting effects as dependent variables.

Results and Discussion

Questionnaire Results

We observed similar results in demographic characteristics of the subjects compared to those of Experiment 1. As shown in **Table 1B**, test-anxious subjects had significantly higher levels of TA [$t_{(38)} = 12.40$, $p < 0.001$], trait anxiety [$t_{(38)} = 4.99$, $p < 0.001$], state anxiety [$t_{(38)} = 3.74, p < 0.001$], and depression [$t_{(38)} = 6.30, p < 0.001$] than controls.

The Effects of the Revised ANT

Figure 5 shows the efficiency of subjects' alerting, orienting, and executive attention in the different tasks. Although no main effect of group [$F_{(1,71)} = 3.21$, $p = 0.08$] was found for the efficiency of executive attention, the ANCOVA yielded a significant main effect of task type [$F_{(1,71)} = 20.30$, $p < 0.001$, $\eta_p^2 = 0.22$] and a significant interaction between group and task type [$F_{(1,71)} = 4.20$, $p < 0.05$, $\eta_p^2 = 0.06$]. The simple effect analysis suggested that the efficiency of executive attention in high TA individuals ($M = 85.34 \pm 6.66$) was significantly lower than that of controls ($M = 59.38 \pm 6.09$) in the revised task, while no difference between groups was found in the original task ($M_{\text{TAgroup}} = 99.23 \pm 6.07$ versus $M_{\text{controls}} = 96.64 \pm 6.38$). The results indicated that the adaptation of the ANT enhanced its sensitivity to TA when measuring executive attention.

There was no significant group main effect [$F_{(1,71)} = 0.05$, $p = 0.82$] or interaction between task type and group [$F_{(1,71)} = 0.32, p = 0.57$] for the efficiency of alerting attention. The same was true when applying the analysis to the efficiency of orienting attention; the corresponding ANCOVA values were $F_{(1,71)} = 0.01$, $p = 0.92$ and $F_{(1,71)} = 0.02$, $p = 0.90$. In addition, no significant difference was found between groups when comparing the efficiency scores of executive [$F_{(1,71)} = 0.07$, $p = 0.79$], alerting [$F_{(1,71)} = 0.28$, $p = 0.60$], or orienting [$F_{(1,71)} = 0.02, p = 0.88$] attention that derived from the original task. The results indicated that performance in the original ANT was insensitive to the level of TA.

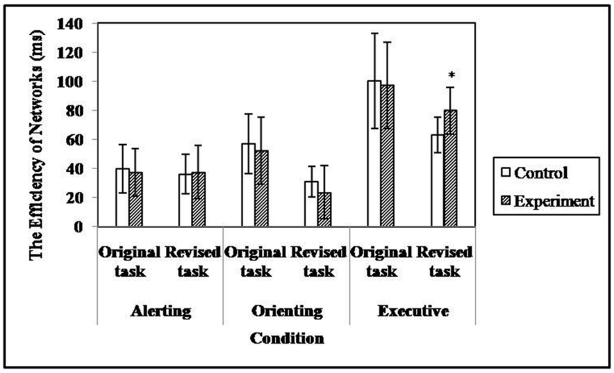

FIGURE 5 | The efficiency of attentional networks in different tasks (*$p < 0.05$).

General Discussion

As we expected, test-anxious students showed a significant deficit in the executive attention network when they were faced with threat/test-related distracters (Experiment 1). This result is consistent with event-related potential (ERP) findings, indicating that the processing of negative emotions was linked to decrements in executive attention in the high trait-anxiety group (Dennis and Chen, 2007). The current result also supports findings of a previous study using a modified Stroop color-naming task, which found that test-anxious individuals took longer to respond to test-threat words compared to controls (Lawson, 2006). In fact, various studies employing different tasks, which tapped different aspects of control processing, also reached the conclusion that threat-related information negatively affected executive function of anxious individuals (Bishop et al., 2004; Wieser et al., 2009); considering that effortful control, especially behavioral or attentional control, is strongly related to the construct of executive function (Muris and Ollendick, 2005).

Both Experiments 1 and 2 suggested that impaired executive attention in test-anxious students was only related to a specific situation, which involved emotional, in particular threat/test-related distracters. This may be due to the poor stability of the attention bias in different situations (Bar-Haim et al., 2007). For example, individuals with trait anxiety were more sensitive to threat stimuli in stressful situations (Mogg et al., 1997), and state anxiety was related to the attentional narrowing of negative affect (Rowe et al., 2007). In the present study, incongruent flanker displays represent the high-conflict condition (congruent flanker displays, in contrast, represent the low conflict conditions), and conflict is associated with stress (Mann, 1992; Dehais et al., 2012). Moreover, time pressure might also decrease the efficiency of attentional allocation (Assink et al., 2015). On these grounds, we speculate that the overlapping effects of the flanker conflict and the resource competition between targets and fillers under time pressure (upper limit of 1,700 ms) increased the stress level in conflict conditions compared with non-conflict conditions. Compared to the controls, test-anxious students perceived more stress or higher pressure, which triggered a more distinct attentional bias toward threat/test-related distracters or evoked attentional narrowing of negative emotions. This consequently caused delayed identification of the targets in conflict trials, which was reflected as executive impairment in test-anxious students compared to controls.

Another possible explanation stems from the study of Mathews and MacLeod (2005), which demonstrated that anxious people apply a top–down activation strategy due to vigilance but have difficulty inhibiting the unexpected stimulus-related bottom–up activation. On the one hand, it has been found that the goal-directed attentional system (i.e., top–down activation) could regulate the stimulus-driven attentional system, for example, a threat bias could be moderated by attentional control (Derryberry and Reed, 2002), which decreased the disruptive effect of negative cues (Cohen et al., 2011). Accordingly, the application of top–down activation strategies may have regulated the impact of threat distracters (i.e., reduced attentional bias toward threats) on alerting/orienting attention, which is primarily related to vigilance, in test-anxious students.

On the other hand, the response to multiple stress conditions (due to the design of our modified ANT) during conflict trials might not only deplete the self-control resources in test-anxious students under emotional distraction, but might make it hard to replenish resources as well, hence weakening the inhibitions for negative distraction during task performance (Cohen et al., 2011). Alternatively, the depleted self-control resources could make it difficult to suppress the "pop-out" effect induced by unintended threat distraction (Bertrams et al., 2013), as "bottom–up" sensory driven mechanisms were active at the moment. Therefore, TA subjects' target identification was delayed to a greater degree by threat/test-related distracters in incongruent trials compared with congruent trials, and compared to target identification of controls. These findings are in accordance with the attentional control theory, which proposes that anxiety decreases the influence of the goal-directed attentional system and increases the influence of threat distraction related to the stimulus-driven attentional system (Eysenck et al., 2007), and provide further evidence that "anxiety is associated with reduced top–down control over threat-related distracters" (Bishop et al., 2004, p. 184).

The results that threat/test-related distracters had no impact on alerting/orienting attention in TA students (Experiment 1) did not meet our expectations. One reason may be that anxious subjects, as we previously mentioned, apply a top–down activation strategy due to vigilance. Moreover, we speculate that processing patterns differed from those of the executive attention network when assessing alerting or orienting networks. Because two-thirds of the trials were non-conflict trials in the latter two assessment models, test-anxious students suffered less stress at this time in contrast to measuring conflict effects, thus were not more sensitive to threat stimuli than controls under these conditions. Consequently, no difference in RT data (on target identification) was observed between controls and highly test-anxious students. In fact, these results support the findings that threat distraction neither enhanced the orienting attention in a state anxiety study (Dennis et al., 2008) nor had an impact on alerting attention in a trait anxiety study (Dennis and Chen, 2007), although the precise nature of the impact of threat distraction on orienting or executive attention seemed rather complicated in the latter study. Taken together, these findings reveal the complexity of attention processing in test-anxious individuals under threatening or evaluative situations: such individuals share certain characteristics with those suffering from trait and state anxiety while maintaining certain differences; thus, confirming the concept of TA that combines attributes from both trait and state anxiety (Spielberger and Vagg, 1987; Hodapp et al., 1995).

Experiment 2 showed that the revised ANT was more sensitive to TA than the original ANT when measuring executive attention. We speculate that emotional distracters play a critical role in the regulation of executive function in TA students. One reason may be that emotional distracters provided conditions to induce an attentional bias or the preemption of resources required for emotion processing, compared to conditions without distracters. Considering that the performance on the original ANT is insensitive to the level of TA, the results from Experiment 2 indicate that the attentional deficit in test-anxious individuals represents a situation-related defect of a single component of attention, rather than an underlying structural and universal deficit of attention.

There are still many gaps in our knowledge about the stage of information processing in which attentional biases occur (Fox et al., 2000; Amir et al., 2003; Mogg et al., 2004; Koster et al., 2005; Cisler and Koster, 2010), and there are many debates about the mechanisms that mediate the biases (Cisler and Koster, 2010; Putwain et al., 2011). In the present study, threat/test-related distracters did not affect alerting/orienting attention in TA individuals, indicating that the bias may not occur at the early stage (detection). In contrast, threat/test-related distracters did affect executive attention in TA individuals, indicating that the bias may occur at the late stage (execution). The findings that threat/test-related stimuli modulate executive attention in TA individuals may tap into the mechanism of bias modulation and at least partly explain why TA individuals have difficulty to disengage attention from threat/test-related distracters (Vasey et al., 1996; Keogh and French, 2001). Considering that the bias might depend on the interaction between bottom–up activation of threat representations by a threat-detection system and top–down activation of competing representations related to other goals by an attentional control system (Mathews and MacLeod, 2005), our findings strengthen the notion that executive attention may be the key structure to the understanding of attentional biases toward threat-related material in anxious subjects (Avila and Parcet, 2002).

The present study has several limitations that need to be acknowledged. First of all, TA was measured as a factor between subjects by self-report, and this criterion may be involved in other personal characteristics such as learning ability (Zeidner, 1998), self-esteem (Lekarczyk and Hill, 1969), and social desirability bias (Tanaka-Matsumi and Kameoka, 1986). Thus, effects from these characteristics cannot be convincingly excluded. In future studies, a within-subject design, in which TA is elicited by emotional stimuli, might be introduced to control for demand characteristics across each condition. Secondly, the way we introduced emotional distraction in the revised ANT consisted of embedding emotional two-character Chinese words in hollow arrows. Although the simultaneous presentation of target and distraction in spatial terms led to a competition for attentional resources, the ecological validity of the measurement is ambiguous due to the artificial interference. The use of more ecological emotion manipulations is recommended, for instance, by integrating images with sound in a cross-modal stimulus presentation. Lastly, our findings were mainly derived from behavioral evidence. ERPs on the other hand would provide a powerful tool for capturing aspects of emotion-attention interactions that behavioral studies alone might miss (Dennis and Chen, 2007); thus, further studies should concentrate on the neural mechanisms of the impaired attentional network in test-anxious individuals.

Despite these limitations, we believe that the present study contributes to the understanding of attentional mechanisms in TA individuals. To our knowledge, the study provides the first investigation of the attentional system in test-anxious individuals under emotional distraction and adds to our knowledge of vulnerability to threat-related stimuli in test-anxious individuals. In addition, the study developed a revised ANT, in which an emotional factor was integrated into the target yielding a more sensitive measurement of TA. This adaptation offers a novel method, which can simultaneously examine the "real-time" impact of emotional processing on attention performance in multiple domains. The revised ANT may contribute to the development of future work to serve as validation assessment of cognitive training in TA.

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Supplementary Material

The Supplementary Material for this article can be found online at: http://journal.frontiersin.org/article/10.3389/fpsyg.2015.01486

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Anger fosters action. Fast responses in a motor task involving approach movements toward angry faces and bodies

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Efficiently responding to others' emotions, especially threatening expressions such as anger and fear, can have great survival value. Previous research has shown that humans have a bias toward threatening stimuli. Most of these studies focused on facial expressions, yet emotions are expressed by the whole body, and not just by the face. Body language contains a direct action component, and activates action preparation areas in the brain more than facial expressions. Hence, biases toward threat may be larger following threatening bodily expressions as compared to facial expressions. The current study investigated reaction times of movements directed toward emotional bodies and faces. For this purpose, a new task was developed where participants were standing in front of a computer screen on which angry, fearful, and neutral faces and bodies were presented which they had to touch as quickly as possible. Results show that participants responded faster to angry than to neutral stimuli, regardless of the source (face or body). No significant difference was observed between fearful and neutral stimuli, demonstrating that the threat bias was not related to the negativity of the stimulus, but likely to the directness of the threat in relation to the observer. Whereas fearful stimuli might signal an environmental threat that requires further exploration before action, angry expressions signal a direct threat to the observer, asking for immediate action. This study provides a novel and implicit method to directly test the speed of actions toward emotions from the whole body.

Keywords: emotion perception, body posture, facial expression, affect, reaction times, action preparedness

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Introduction

Humans are well adapted to quickly recognize and adequately respond to another's emotional expression. As emotional expressions are intrinsically linked to actions, it has been proposed that in our attempt to understand emotions, we should study *actions* rather than cognitions or feelings (Frijda et al., 1989). Because threatening signals are thoroughly processed (Williams et al., 2006) and rapidly detected (Hansen and Hansen, 1988; Öhman et al., 2001b; Pinkham et al., 2010), they prepare for greater action preparedness (Schutter et al., 2008; Van Loon et al., 2010; Borgomaneri et al., 2014) and for quick actions (Coombes et al., 2005). For example, fearful and angry as compared to neutral facial expressions induce larger peak amplitudes on early face-related components such as the N170 and VPP (120–220 ms post-stimulus; Williams et al., 2006; Hinojosa et al., 2015), but also boost later potentials reflecting decision making processes (Lang et al., 1990; Liddell et al., 2004). There is an extensive literature on the implicit (i.e., non-conscious) processing of facial expressions. Research showing that faces and facial expressions are still processed and yield similar actions under conditions of limited attention and awareness has contributed significantly to the view that faces have a special status (Eastwood and Smilek, 2005; Johnson, 2005; Vuilleumier, 2005; de Gelder et al., 2010, 2014).

The majority of emotion studies focus on facial expressions. However, faces are naturally encountered in the context of a whole body. Distinct expressions of emotion portrayed by body language are readily recognized even in the absence of facial and vocal cues (Bannerman et al., 2009; de Gelder et al., 2010; de Gelder and Van den Stock, 2011). Moreover, the perception of facial expressions is strongly influenced by body language and the other way around, i.e., the interpretation of a face (body) can change, depending on the emotion expressed by the body (Meeren et al., 2005; Van den Stock et al., 2007; Willis et al., 2011; Van den Stock and de Gelder, 2012, 2014; Kret et al., 2013a,b; Martinez et al., 2015). Eye-tracking studies have shown that when humans are observing whole-body images of other individuals, they generally spend more time looking at the face than at the posture (Kret et al., 2013a,b). However, when the observed individuals display conflicting messages through the face and the body (for example, a happy face above an angry body), then visual attention immediately allocates toward the threat, whether expressed by the face or by the body (Kret et al., 2013a,b). Other studies have shown that recognition of emotional bodies is facilitated (or hindered) by simultaneous presentation of task-irrelevant congruent (or incongruent) emotional facial expressions, respectively (Willis et al., 2011; Gu et al., 2013). As with facial expressions, body language can also be processed without awareness (Tamietto et al., 2009, 2015; Tamietto and de Gelder, 2010; Van den Stock et al., 2011). For example, in a study with patients with hemi-spatial neglect, fearful bodily expressions automatically summoned spatial attention toward the neglected side (Tamietto et al., 2007).

Faces and bodies are processed by similar neural networks (Van de Riet et al., 2009). However, as compared to facial expressions, bodily expressions of emotion contain a direct action component; a fearful posture is bending backward/avoiding the observer, and an aggressive posture is leaning to the front/approaching the observer. This core difference is reflected in distinct brain activity patterns. For example, it has been shown that body language activates action preparation areas more than facial expressions, especially when fear or anger is expressed, and even more so when expressed by a male versus female (Kret et al., 2011a).

Although fear and anger are both negative emotions, a fearful signal can be more ambiguous and might signal an environmental threat, whereas anger can be perceived as a direct threat toward the observer requiring immediate action (Grillon and Charney, 2011). Merely looking at fearful faces does not evoke an autonomic response (Dunsmoor et al., 2009) or subjective fear (Davis and Whalen, 2001). Rather, fearful faces are important signals for a potential threat in one's environment, leading to increased vigilance for the source of danger without concomitant defensive mobilization (Whalen, 1998; Whalen et al., 1998). Pichon et al. (2009) directly compared brain activity during the perception of fearful and angry body expressions. They observed that angry body expressions activated the premotor cortex more than fearful expressions. In addition, Kret and de Gelder (2013) showed that angry bodies were more distracting than fearful bodies in a matching-to-sample task, slowing down reaction times when the task required an action away from the angry cue (in violent offenders and control males alike). Together, these studies suggest enhanced action preparation in response to anger than fear.

Thus far, fear and anger have never been directly compared in a task that requires direct actions toward these expressions. By using a new experimental paradigm, the current study investigates the speed of movements toward angry, fearful, and neutral facial and bodily expressions by male actors. We opted for the threat related emotions fear and anger for three reasons. First, both emotions can be expressed equally well via the body and the face, contrary to for example disgust that is not well recognized from body expressions alone, and happiness that is much better expressed by the face as compared to the body (de Gelder et al., 2010). Second, fear and anger are both negative emotions, similarly arousing and contain a clear action component in the body expression, in contrast to for example a sad body expression (Pichon et al., 2008; Kret et al., 2011a) Third, anger is a more direct threat than fear. Male actors were included exclusively because previous research has shown they evoke greater affective responses than female actors, at least for the emotions fear and anger (Kret et al., 2011b)

In real life, people seldom explicitly label other's emotional expressions, yet this is what is most commonly asked during lab experiments. In explicit tasks such as emotion recognition tests, other cognitive processes such as memory and decision making can interfere with emotional processes such as action preparedness (for example, see Kliemann et al., 2013). In implicit tasks, this interference is much less of an issue. An extensively used implicit task is the emotional dot probe task which, because it requires minimal training, is often used in studies with children and non-human primates (King et al., 2012; Lacreuse et al., 2013; Parr et al., 2013).

In the classical dot-probe task two emotional stimuli are presented simultaneously and are followed by a dot that is presented on the left or right side of the screen. Typically, participants are sitting in a chair and required to click on a left or right button on a keyboard or button box. What is generally measured is an attentional bias score, i.e., the extent to which reaction times are shortened when the dot was presented at the location of the emotional as compared to the neutral image. The aim of the current study is not to measure competition between two different stimuli, but to measure the speed of an action toward expressions and in addition, to provide a novel tool for future research. For that reason, we designed a simplified version of the emotional dot probe task where one image is presented at a time, on either the left or on the right side of the screen. To increase the naturalness of the study, a touch screen was used, in front of which participants were standing. Participants were requested to *directly* tap on the image as fast as they could.

Our expectations were threefold. First, we expected faster reaction times following threatening as compared to neutral stimuli. Second, bodies contain a direct action component and

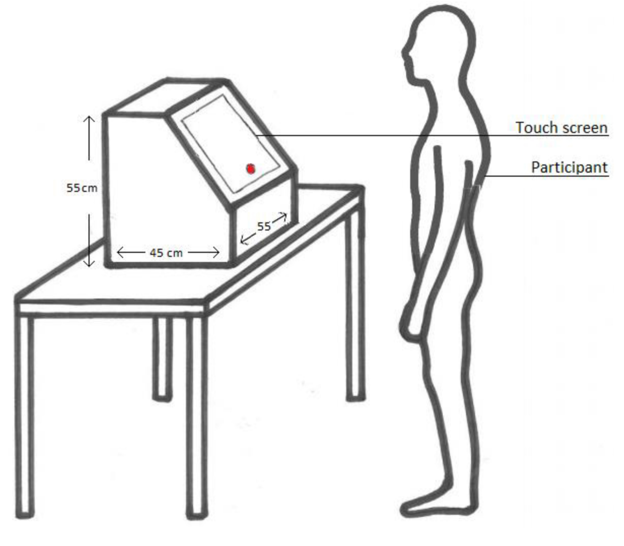

FIGURE 1 | Experimental Setup.

faces do not, which is why we expected faster responses toward fearful and angry bodies than toward faces. Third, in line with research showing greater activation of motor preparation areas in the brain and greater action preparedness following angry versus fearful stimuli, we predicted shorter reaction times following angry as compared to fearful bodies (Whalen, 1998; Davis and Whalen, 2001; Pichon et al., 2009).

Materials and Methods

Participants

Thirty-three participants (12 male) took part in the experiment. The mean age was 23.23 (SD = 4.35), with age ranging from 18 to 35 years old. The participants were recruited at the psychology laboratory from the University of Amsterdam. They filled out an informed consent and were debriefed after the experiment for which they obtained course credit or money. Participants had no neurological or psychiatric history, were right-handed and had normal or corrected-to normal vision. The study was performed in accordance with the Declaration of Helsinki and approved by the local medical ethical committee.

Procedure

After participants read the information brochure and signed the informed consent, they were given verbal instructions. In order to investigate the interference of bodily and facial expressions on the emotion task, angry, fearful, and neutral face or body expressions were randomly presented with Presentation software (Neurobehavioral Systems, San Francisco, CA, USA). Participants were asked to stand behind the touch screen (**Figure 1**). The distance between the participants and touch screen was 50 cm, a distance at which all participants could comfortably touch the screen. They were instructed to press the red dot that appeared on the screen to start the trial and to subsequently press the appearing image as quickly as possible.

A trial started with the presentation of a dot in the middle, lower side of the screen, on which participants had to tap with their right hand. Because participants had to visually guide their hand action, this guaranteed that their eye fixation was on the location of the dot and that the hand did not occlude the upcoming stimulus. Immediately after participants touched the dot, the emotional picture was randomly presented on the left or on the right side of the screen. Participants were instructed to tap as fast as they could directly on the image, after which the image disappeared. Participants completed 192 trials which took about 5 min. Reaction times were measured from the moment the participant pressed the red dot in the center of the screen to the moment the participant pressed the image. See **Figure 2** for a trial outline.

Materials

Pictures consisted of angry, fearful, and neutral body postures and facial expressions. The bodies were taken from the BEAST stimulus data base (de Gelder and Van den Stock, 2011) and the faces from the NimStim set (MacArthur Research Network on Early Experience and Brain Development, 2002). All face and body stimuli were from male actors. For the body stimuli, the facial features were blurred so that the emotional signal could only be perceived from the posture. The images were turned to grayscale and had an average gray background color. The luminance of each image was set to the average of all stimuli. Bodies and faces of 16 different identities of men (32 in total) were used, each of which expressed fear or anger or which showed a neutral expression (96 trials in total). These stimuli and their mirror images were repeated twice (192 trials in total). The diameter of the dot was 2.5 cm. The size of the images of both faces and bodies was 17 cm (width) by 25 cm (height), but see the stimulus examplars in **Figures 2** and **3** for the proportions.

Experimental Design

The study had a two within subjects (source: body/face) by three within subjects (emotion: anger, fear, or neutral) design.

Data-Analysis

The reaction time data was skewed (skewness = 12.813, SE = 0.032) and had outliers (maximum reaction time = 9930 ms, mean reaction time = 470 ms). The data was therefore filtered to exclude reaction times that were more than two standard deviations above each individuals mean reaction time. Next, a log-transformation was performed. After these steps, the issue of skewness was solved (skewness = 1.019, SE = 0.033) and inspections of the histograms and Shapiro–Wilks tests showed that each experimental condition was normally distributed ($p > 0.064$). Data were analyzed in a repeated measures ANOVA implemented in IBM SPSS Statistics 20. Significant effects were followed up by Bonferroni-corrected pairwise comparisons.

Results

A 3 (Emotion: Angry/Fear/Neutral) × 2 (Source: Face/Body) repeated measures ANOVA showed a main effect of emotion

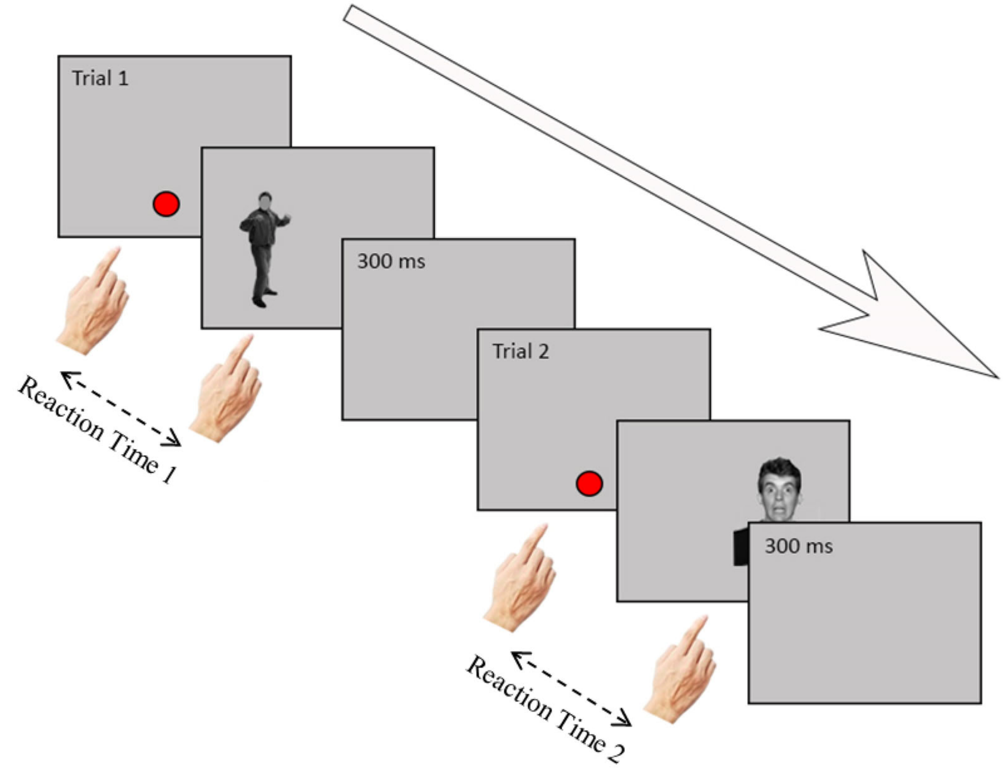

FIGURE 2 | Timeline of two trials in the touch screen task. At the start of a trial, participants touched the red dot to make it disappear. Then, an image (angry/fearful/neutral face or body) appeared at the left or right side of the screen. Participants had to touch the image as quickly as possible. A blank screen appeared for 300 ms, after which a new trial started.

$F(2,64) = 7.173$, $p = 0.002$, $\eta_p^2 = 0.183$[1], $1 - \beta = 0.922$, with faster (log-transformed) reaction times following angry (M = 2.624, SE = 0.005) as compared to neutral expressions (M = 2.633, SE = 0.006, $p = 0.004$), independent from the source [face or body: $F(2,64) = 0.225$, $p = 0.799$, $\eta_p^2 = 0.007$]. A Bonferroni-corrected pairwise comparison showed that the difference between fear (M = 2.628, SE = 0.005) and neutral (M = 2.633, SE = 0.006) was not significant (*Mean Difference* = 0.005, SE = 0.002, $p = 0.190$)[2]. A similar comparison between fear and anger yielded no significant difference either, $p = 0.148$[3] (see **Figure 3**).

Discussion

Emotions are intrinsically linked to actions (Frijda et al., 1989). The aim of the current study was to measure the speed of actions in response to emotional stimuli and to provide a new tool for measuring this, which can be implemented in future studies. In most previous studies investigating emotions and actions, participants were sitting in front of a computer screen and only indirectly responded to emotions. In the current study, participants were *standing* behind a touch screen on which pictures of fearful, angry and neutral faces and bodies appeared, which they had to tap on as fast as they could. Results showed that participants responded faster to angry as compared to neutral stimuli, regardless of whether the emotion was portrayed in the face or the body. No significant difference in response latencies was found between fearful and angry or fearful and neutral stimuli.

Many emotion studies have reported a threat bias in which threatening faces or scenes are prioritized over neutral (Hansen and Hansen, 1988; Öhman et al., 2001b; Williams et al., 2006; Pinkham et al., 2010). Our study adds to these findings by showing that angry bodies, like angry faces, trigger faster actions, supporting the idea of a general threat bias, independent of the source. Although a fearful expression is a threat cue as well, no reaction time difference was observed between fearful and neutral cues, possibly because this expression reflects a different source of threat, i.e., environmental and indirect rather than direct and personal (Whalen, 1998; Davis and Whalen, 2001; Adams et al., 2003). In other words, an angry person might be perceived as a direct threat to the participant but a fearful person might be more ambiguous as the source of the threat is unclear. This suggests

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[1] Conventionally, a test with a partial eta-squared (η_p^2) higher than 0.14 and a power ($1 - \beta$) greater than 0.8 is considered to have a high effect size and is statistically powerful (Field, 2013).

[2] A more liberal paired sample t-test without a correction for multiple comparisons yielded a statistical trend between fear and neutral, with somewhat faster response times following fear as compared to neutral $t(32) = 1.923$, $p = 0.063$.

[3] A more lenient paired sample t-test without a correction for multiple comparisons yielded a significant difference between the two emotions, with faster reaction times following anger as compared to fear $t(32) = 2.042$, $p = 0.049$.

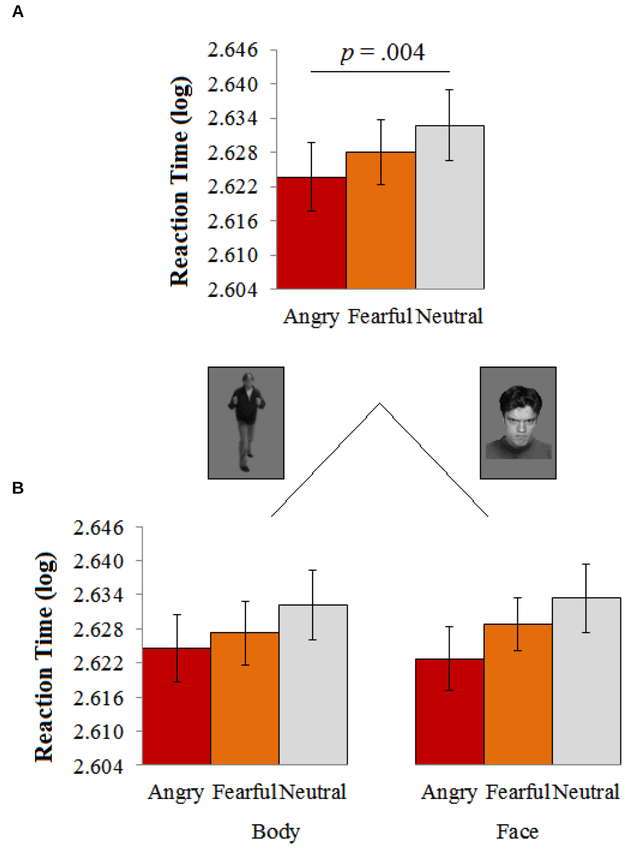

FIGURE 3 | (A) Participants were faster in responding to angry as compared to neutral expressions. **(B)** The faster response following anger was independent of the source (face or body). Error bars represent the standard error (SE) of the mean.

that a direct threat (anger), asks for immediate action and an ambiguous threat (fear) requires exploration and hence more processing time and a somewhat slower response. It is possible that different results may be obtained if the eye gaze of the fearful stimulus is averted rather than directed at the participant. This would also be interesting to test in a cueing paradigm. In sum, the threat bias reported in this study was probably related to the directness of the threat and not to the negativity of the stimuli.

Previous emotion studies mainly focused on faces. However, emotions are displayed in both the face and the body, the main difference being that bodies contain an action component and faces do not. We hypothesized that this action component would evoke faster actions in our participants, resulting in shorter response latencies when responding to bodies than to faces. Yet, no difference between bodies and faces was observed. Two explanations are possible. First, the results could indicate that it does not matter whether threat is displayed by the body or the face. A threat is a threat and it has evolutionary benefits to be able to quickly respond to that. Another explanation can be found in the nature of the stimulus material. Faces and bodies were not presented in true proportions: the size of the pictures was identical, which means that faces were displayed relatively larger than bodies. Bigger stimuli are seen as closer in distance and the relatively large faces may have therefore overshadowed a putative difference in reaction times between faces and bodies. To rule out this explanation, a future study should therefore present faces and bodies in true proportions.

In a previous study, Bannerman et al. (2009) aimed to pull apart effects of emotional faces and bodies on the speed of actions as measured through manual responses from effects on attention as measured through eye fixations. In their study, fearful/neutral body or face pairs were bilaterally presented for either 20 or 500 ms. Results showed faster saccadic orienting to fearful body and face emotions compared with neutral only at the shortest presentation time (20 ms). For manual responses, faster discrimination of fearful bodies and faces was observed only at the longest duration (500 ms). These results suggest faster localization of threat conveyed both by the face and the body within the oculomotor system. In addition, enhanced detection of fearful body postures suggests that we can readily recognize threat-related information conveyed by body postures in the absence of any face cues. One shortcoming of the study is that whereas fixations landed directly on the stimulus, movements did not and landed on a response box instead. Importantly, this and other studies all suggest that the core function of emotion may be to coordinate attention and action preparedness and other cognitive functions, in order to facilitate adaptation to environmental challenges (Öhman et al., 2001a,b; Lewis, 2005; Pichon et al., 2008, 2009; Schutter et al., 2008; Van Loon et al., 2010).

In the current study, the mechanism underlying the faster responses toward angry as compared to neutral stimuli remains speculative and might reflect enhanced attention (Wiers et al., 2010), increased readiness to act (e.g., Schutter et al., 2008; Van Loon et al., 2010; Borgomaneri et al., 2014) or both (for a recent discussion, see Frijda et al., 2014). Future studies could make use of our procedure and aim to disentangle effects of threat on attention and the speed of an approach action readiness. One approach would for example be to have participants stand in front of the screen and present pictures on the left, on the right or in the middle of the touch screen. The dot that needs to be tapped on at the start of a trial is then always presented in the middle of the screen. A picture presented at that exact location therefore does not require a shift in attention. If the threat bias disappears for centrally presented stimuli, the threat bias found in the current study would be completely driven by an attention bias. If the threat bias stays for centrally presented stimuli, the threat bias in this study does reflect action readiness.

The task employed in the current study required an approach-related movement. It is possible that different results can be obtained using an avoidance-related movement (Chen and Bargh, 1999). A future study could therefore investigate avoidance-related movements. For example, participants are requested to leave their hand rested on a dot presented on the middle, lower part of the computer screen and are asked to remove their hand as quickly as they can, once a stimulus is being presented. In addition, since angry stimuli are often related with approaching movements (see, for example Bossuyt et al., 2014), it is important to explore actions toward and away from different emotions in future studies.

In sum, the current study made use of a new device that makes it possible to directly test actions toward (or away from) emotions. Results showed a threat bias for angry faces and bodies, which is in line with previous studies showing that threat cues are prioritized over neutral cues. There was no threat bias for fearful stimuli, suggesting that the directness of the threat in case of anger sped up reaction times, rather than the negativity of a stimulus. Also, no difference was found between responding to faces and bodies, suggesting that the threat bias is general and not restricted to one source. The current study supports the notion that evolution prepared humans for fast actions when facing a threat.

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The perception of time while perceiving dynamic emotional faces

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Emotion plays an essential role in the perception of time such that time is perceived to "fly" when events are enjoyable, while unenjoyable moments are perceived to "drag." Previous studies have reported a *time-drag effect* when participants are presented with emotional facial expressions, regardless of the emotion presented. This effect can hardly be explained by induced emotion given the heterogeneous nature of emotional expressions. We conducted two experiments ($n = 44$ and $n = 39$) to examine the cognitive mechanism underlying this effect by presenting dynamic sequences of emotional expressions to participants. Each sequence started with a particular expression, then morphed to another. The presentation of dynamic facial expressions allows a comparison between the time-drag effect of homogeneous pairs of emotional expressions sharing similar valence and arousal to heterogeneous pairs. Sequences of seven durations (400, 600, 800, 1000, 1200, 1400, 1600 ms) were presented to participants, who were asked to judge whether the sequences were closer to 400 or 1600 ms in a two-alternative forced choice task. The data were then collated according to conditions and fit into cumulative Gaussian curves to estimate the point of subjective equivalence indicating the perceived duration of 1000 ms. Consistent with previous reports, a feeling of "time dragging" is induced regardless of the sequence presented, such that 1000 ms is perceived to be longer than 1000 ms. In addition, dynamic facial expressions exert a greater effect on perceived time drag than static expressions. The effect is most prominent when the dynamics involve an angry face or a change in valence. The significance of this sensitivity is discussed in terms of emotion perception and its evolutionary significance for our attention mechanism.

Keywords: emotion, face perception, time perception, approach avoidance, dynamic emotional faces

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Introduction

Factors affecting the perception of time are well-documented. Following the pioneering work of François (1927) and Hoagland (1933), the influence of various internal and external contexts on the perception of time became one of the major focuses of cognitive psychology. "Time flying" and "time dragging" have been demonstrated and investigated in various studies involving both adults and children (Droit-Volet and Wearden, 2002; Droit-Volet et al., 2004a,b; Droit-Volet and Rattat, 2007; Gil et al., 2007; Gil and Droit-Volet, 2011; Grommet et al., 2011). Emotion has been found to play an essential role in the aforementioned phenomena. In particular, it is commonly found that when one enjoys an event, one perceives the passage of time faster than the actual duration, or "time flying" (Agarwal and Karahanna, 2000). In contrast, when one experiences an event as distressing or boring, they perceive the passage of time as longer than the actual duration and a feeling of "time dragging" is experienced.

The number of events in a given period is found to be positively correlated with the perceived passing of time (Gibbon et al., 1984; Burle and Casini, 2001; Wearden, 2004; Ulrich et al., 2006). Events are registered mentally as "ticks" and perceived to occupy time. The time occupied is not absolute but relative to the number of "ticks." As such, a greater number of events happening in a given time duration will lead to an expansion of perceived time. The internal-clock model (Treisman, 1963) conceptualized this mechanism, and was later developed into scalar timing theory (Gibbon et al., 1984, 1997). The latter proposed that the internal clock is composed of three components: a pacemaker, a switch, and an accumulator. The pacemaker is a pulse generator; its function is to generate time-pulses and send them to the accumulator through the switch. The switch serves as a pulse guard that signals the start and the end of the timed event. The pulses are gathered by the accumulator and then converted into perceived duration. This mental model is widely successful in formulating testable hypotheses for time perception (Buhusi and Meck, 2005). For example, physical stimulation is proven to be sufficient in perturbing this mental process and to influence the perception of time (Treisman et al., 1994).

Recent studies have suggested that both arousal and attention can influence the internal clock (Gil and Droit-Volet, 2011). Increasing the level of arousal appears to increase the pulse-generating speed of the pacemaker. As a result, event duration is filled with more pulses and perceived as longer, resulting in "time dragging" (for a review, see Droit-Volet and Meck, 2007). Alternatively, attention influences one's perception of time by affecting the function of the switch. According to Zakay and Block (1996), the functioning of the switch requires attention resources. When attention is distracted from time perception, the switch cannot function properly. Time-pulses are then lost and ultimately time is perceived as shorter since less time-pulses are accumulated. To conclude, arousal influences time perception by changing the pulse-generating speed of the pacemaker, whereas attention affects time perception by moderating the function of the switch (Zakay and Block, 1997).

Induced emotion is also found to influence the perception of time. The individual's emotional state acts as a prime that prospectively affects time judgment on subsequent stimulus presentation. Since emotion can both provoke one's arousal and distract one's attention, the findings on the role of emotion in perception of time in humans were mixed (Lui et al., 2011). While some researchers have found a *time-drag effect* of emotion (Droit-Volet et al., 2004a), other found a completely opposite effect (Lui et al., 2011). The picture is even more complex as different emotions have been found to exert different effects on time perception. Gil and Droit-Volet (2011) found that anger, fear, joy, and sadness produce perceptions of "time dragging," whereas shame produces perceptions of "time flying," and disgust has no effect on time perception. They explained that different emotions with different levels of valence and arousal induce differential approach-avoidance motivations. For instance, emotions inducing salient avoidance enhance attentional resources allocated to detecting potential threats in the surrounding environment. The enhanced attention effect relays the switch and enables the registering of more mental events (Lejeune, 1998).

Notably, presenting emotional faces may induce a different subjective influence in viewers. Droit-Volet et al. (2004a) reported that presenting different emotional expressions influences the perception of time similarly. "Time dragging" resulted regardless of the emotional expression presented, though an angry expression induced the largest effect. A potential explanation is that the ecological significance of facial emotion among humans highly arouses the perceiver, speeding up the pulse generator, leading to an overestimation of the amount of time that has passed. Recent research has provided empirical evidence of this ecological significance (Doi and Shinohara, 2009; Kliegl et al., 2015), showing that the time-drag effect is maximal if an angry expression is presented directly to participants, whereas the effect diminishes when the gaze moves away. Such observations could be linked to the neuroanatomical pathway that enables preferential processing of affective stimuli in the amygdala (LeDoux, 2003). This thalamatic-amygdala "affective information highway," proposed by LeDoux et al. (1999), serves the function of passing coarse visual information into the amygdala for quick evaluation (Morris et al., 1998; de Gelder et al., 2005). This "affective information highway" enables an organism to quickly identify potential threats in the environment, divert attention to a threat, and come up with an appropriate action plan, ultimately enhancing the chances of survival. This effect is very compatible with the attentional account, according to which emotion influences time perception, but empirical evaluation is scarce.

One limitation of previous studies is that the stimuli used are mostly static: static photographs and pictures (Angrilli et al., 1997; Droit-Volet et al., 2004a,b; Gil and Droit-Volet, 2011). A static facial expression is rarely seen in daily life, however; our facial expression changes all the time. If the perceived time-drag effect is due to the ecological significance of emotional expressions for humans, more attention will be drawn to process dynamically changing emotional expressions. This will lead to a larger overestimation effect. However, a dynamically changing emotional expression may also induce confusion over time. For example, when a face changes from a happy expression to an angry one, there are moments in between when no salient emotion can be perceived, which may reduce the overestimation effect. The latter hypothesis also implies that the perception of time is moderated by a real-time processing mechanism. Empirical testing is required to test how these two seemingly counteracting effects interact.

Further, it is known that different duration judgment paradigms affect perceived duration significantly (see Block et al., 2000 for a review). Knowing and looking forward to a time duration is different from recalling and reproducing a time duration. Similar characteristics may affect how emotions influence the perception of time duration. Lee et al. (2011) explored this with a two-interval time reproduction paradigm. Participants were asked to reproduce the duration of an emotional expression with a neutral stimulus (i.e., a gray oval) and reproduced the duration of a neutral stimulus with an emotional expression. The prior condition showed a similar time-drag effect (cf. duration bisection tasks), while the later showed a *time-fly effect*. Lee and colleagues' findings show that when emotional expressions were used as a relative reference, a similar time-drag effect was observed. Therefore, recalling and experiencing a static emotion expression appear to have a similar influence on time perception.

In the present study, we asked how stimuli with dynamic emotional information affect time perception. While previous studies have shown that a static expression exerts a uniform effect on time perception, it is possible that dynamic change of facial expressions affects us more than the emotion *per se*. For instance, if a neutral stimulus morphs into an emotion-inducing stimuli, is its effect greater or smaller than a static counterpart showing the emotion alone? If dynamic change matters, it is possible that changes in valence and arousal may result in different time perception. This unexplored setting of dynamic stimuli could provide novel information about the mechanism of emotional information processing. Specifically, the results will help us to test whether emotion affects time perception in real-time, prospectively, or retrospectively. If emotional information prospectively influences time perception via arousal effects, the emotional expression with which the morphing sequence starts will determine the strength of the time-drag effect. A retrospective influence account predicts that the morphing sequence of two emotional expressions (e.g., happy>angry vs. angry>happy) will lead to an identical time-drag effect because the total amount of attention captured by the morphing sequences will be the same. If the influence of emotion on time perception is a real-time process, dynamic emotional expressions starting with a neutral expression will present a lesser effect than dynamic emotional expressions starting with a positive or negative expression, because a positive or negative expression will capture attention and influence the internal clock processes immediately.

To confirm the role of emotion in time perception, the present study has adopted the methodology of Droit-Volet et al.'s study (2004a). We first tested the hypothesis that presenting facial expressions causes systematic error in time judgment. We also intended to investigate whether emotions' valence and arousal are related to a specific type of time distortion—a time-drag effect, a time-fly effect, or no effect—and how the change of valence and arousal may influence our perception of time. To achieve this, the present study selected three emotions, happy, sad, and angry, and a neutral facial expression in Experiment 1, and four emotions, happy, angry, afraid, and disgusted in Experiment 2. The present study also adopted a morphing technique in both experiments, for two purposes. First, since dynamic facial expressions have been found to enhance one's experience of emotional arousal (Sato and Yoshikawa, 2007), a morphing technique was adopted in Experiment 1 to investigate the effect of change in a particular emotion's arousal level on the type and accuracy of time perception. Second, since morphing techniques allow us to switch from one emotion to another smoothly and naturally, which in turn allows us to change both the level of valence and arousal, a morphing technique is adopted in Experiment 2 to assist in investigating the impact of change of an emotion's valence and arousal on time perception.

Experiment 1 the Influence of Morphing Emotional Facial Expressions on the Perception of Time

In Experiment 1, we examined how a dynamic emotional facial expression affects time perception. Perceived durations of static emotional expressions were also measured as a reference. We hypothesized that if emotion affects time perception in real-time, then a dynamic expression conveying a salient emotion for a shorter duration should exert less influence on time perception. If the influence is retrospective, on the other hand, a morph from a neutral to an emotional expression will induce an effect similar to static photographs.

Stimuli

In this experiment, photographs of two models' emotional facial expressions, one male and one female, were chosen from a facial databank of nine models (five male and four female). The two chosen models were rated in the mid-range of the databank in terms of their emotional intensity (Female: 4.38; Male; 4.47; Mean: 4.45; $n = 20$) and attractiveness (Female: 3.36; Male: 3.86; Mean: 3.39; $n = 36$). We controlled the attractiveness ratings to minimize their potential influence on the perception of time due to induced pleasantness (Pruyn and Smidts, 1998). The intensity ratings indicated that the emotional expression of the chosen models were sufficiently intense to be identified. Four photographs of emotional facial expressions were chosen for each model: happy, angry, sad, and neutral. Thus, a total of eight photographs were used in Experiment 1.

The photographs were morphed from the neutral expression to one of the three emotional expressions using MagicMorph provided by Etinysoft (http://www.effectmatrix.com/morphing/). Grayscale versions of the photographs were chosen to minimize any observable image blur during the morphing process. There were 50 frames in the morphing sequence; 48 frames were produced in between the two original images. The number of frames depended on the duration of the stimulus: each frame presented for 40 ms with DirectRT. For example, a 1000 ms stimulus presented 25 frames evenly distributed in the morphing sequence (i.e., all the odd number frames starting from 1st to 41st, then 44th, 46th, 48th, and 50th frames), each presented for 40 ms. **Figure 1** shows two of the shortest sequences with 10 frames for a duration of 400 ms (1st, 6th, 12th, 18th, 23rd, 29th, 35th, 40th, 45th, and 50th frames). Sample stimuli are uploaded as Supplementary Materials.

Participants

Forty-four undergraduates (31 female and 13 male) from Hong Kong Shue Yan University participated in this experiment. They received participation credits to fulfill the requirements of an introductory level psychology course offered by the Department of Counselling and Psychology. They were randomly

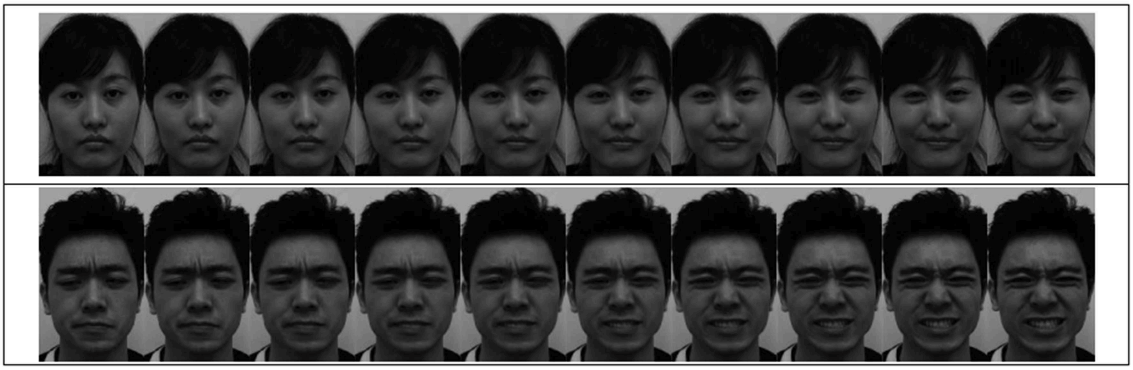

FIGURE 1 | Illustration of two sets of morphing sequence for a 400 ms stimulus. The upper panel is a morph from a neutral to a happy expression of our female model (a morphing sample from Experiment 1). The lower panel is a morph from disgust to anger of our male model (a morphing sample from Experiment 2).

TABLE 1 | A summary of participants' arrangement in the experiments of the present study.

	Left-Long	Right-Long
Experiment 1 (*n* = 44)		
Female	8/3	8/4
Male	8/4	7/2
Experiment 2 (*n* = 39)		
Female	8/2	6/4
Male	6/2	7/4

Numbers in cells indicate the number of female/male participants. Rows indicate the viewing conditions.

assigned to different viewing conditions, which are described in the following Procedures section. **Table 1** summarizes the participants' arrangement.

Procedures

The procedures of the present experiment were similar to the setup of Droit-Volet et al. (2004a). Participants practiced the task viewing either a long presentation lasting 1600 ms or a short presentation of 400 ms on a computer screen (17" Topcon LCD). The stimuli in the practice trials were gray ovals subtending 3.7" × 3.8" on the computer screen. Participants had to judge the length of the presentations; their responses were collected by keyboard keys "D" and "K," which were labeled "short" and "long." The labels representing "short" or "long" were randomized across participants so that around half of them pressed "D" for "short and "K" for long (21 out of 44), and the other half did the opposite (23 out of 44). The first practice block comprised 10 trials of alternate 400–1600 ms presentations. Each trial was separated by a random inter-trial interval ranging from 1 to 3 s. A feedback screen with the correct answer was presented for 2 s after each participant's response. The procedure for the second practice was the same except that it consisted of eight trials of 400–1600 ms presentations shown randomly.

In the main experiment, the gray oval was replaced by a static face or a morphing sequence of expressions. They were presented for 400, 600, 800, 1000, 1200, 1400, or 1600 ms. The morphing stimuli thus comprised 10, 15, 20, 25, 30, 35, and 40 frames, each presented for 40 ms. Participants indicated whether they perceived the stimuli as closer to the long duration (1600 ms) or the short duration (400 ms) by pressing one of the two keyboard keys. Besides counterbalancing the left and right response, the gender of the model was also counterbalanced by the fact that around half of the participants were presented with the male model's photographs (21 out of 44) and the other half with the female model's photographs (23 out of 44).

The participants repeated nine experimental blocks and were allowed to rest freely in between. The whole experimental session lasted around 45 min. All experimental procedures were approved by the Human Research Ethics committee of Hong Kong Shue Yan University.

Results and Discussion

There is no significant bias in female or male participants assigned to the two key press [$\chi^2_{(1,n=44)} = 0.38$, $p = 0.54$] and stimuli gender condition [$\chi^2_{(1,n=44)} = 0.02$, $p = 0.89$]. The potential key-press assignment and gender of the model were well-balanced, so they are collated and reported together in this section. Proportions of individuals' long-duration responses in every duration condition were computed. The data were then grouped according to emotional expression conditions. GraphPad Prism® 6 was used to analyse the data. Cumulative Gaussians were fit to the grouped proportion data using the maximum likelihood method. With this fitting of group data we estimated the Perceived Stimulus Equivalence (PSE), which indicate the stimulus durations participants were unable to identify as long or short. A graphical illustration of the PSE in the static neutral condition is shown in **Figure 2**. The estimated PSE (947.7 ms) is slightly shorter than 1000 ms. A PSE significantly shorter than 1000 ms implies overestimating perceived durations, equivalent to a time-drag effect. To test whether the differences are statistically significant, asymptotic standard errors and 95% confidence interval of the PSE estimates were approximated with the same statistical

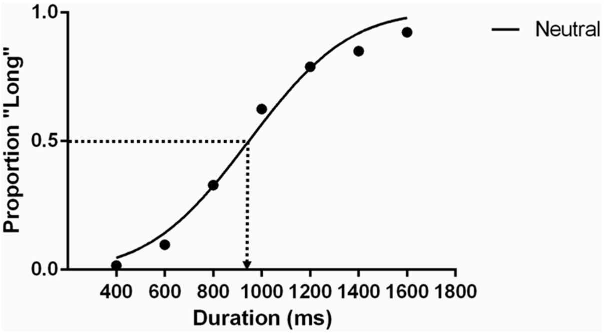

FIGURE 2 | The psychometric function of the static neutral expression condition in Experiment 1. Each data point is the average proportion across all participants. The dotted line indicates the estimated PSE that participants give 50% of "long" responses.

package. Although there is concern about the centrality of this approximation when the number of observations is small (number of intervals × trials in each<150) (McKee et al., 1985), the sample of observations for the group fits in the present study is sufficiently large to satisfy this criterion ($n = 2772$). In order to further show whether PSE estimates conform to the normality assumption, we performed a Monte Carlo simulation by randomly flipping the participants' responses to create a null distribution for PSE. We obtained a null distribution for PSE from 10,000 permutations and the D'Agostino and Pearson omnibus normality test suggests that the distribution is normal ($p = 0.79$).

Figure 3 shows the psychometric curves of the static (**Figure 3A**) and dynamic expressions (**Figure 3B**) in comparison to the neutral expression ($R^2 = 0.77$–0.80, indicating good fit). Similarly, the 0.5 point on the y-axis illustrates the point where participants perceived the stimuli as being presented for 1000 ms. The PSE of static emotional expression mostly falls around 1000 ms. A subsequent parametric test shows that there is no significant deviation of perceived duration from the actual stimulus duration for all static emotion expressions. In contrast, the curves in **Figure 3B** have significantly shifted to the left, indicating an overestimation of duration; that is, a duration shorter than 1000 ms was perceived as 1000 ms, suggesting a time-drag effect. To better illustrate the results, the PSE of all seven conditions are plotted in **Figures 2C,D** together with their estimated standard error.

Among the four static facial expression conditions, neutral, and happy expressions are perceived to be significantly shorter than 1000 ms (**Table 2**). The PSE for sad and angry expressions were not significantly different from 1000 ms. The PSE of all three static emotional expressions were not significantly different from the neutral expression. The dynamic expressions, on the other hand, had significantly shorter PSE compared to their static counterparts [Happy: $t_{(86)} = 4.23$, $p < 0.01$, $d = 0.91$; Sad: $t_{(86)} = 7.06$, $p < 0.01$, $d = 1.50$; Angry: $t_{(86)} = 8.06$, $p < 0.01$, $d = 1.72$] indicating time-drag effects (see **Table 2**). Among the three dynamic conditions, the angry expression is the most overestimated.

The dynamic facial expressions are found to induce time-drag consistently. The pattern of overestimation is similar to that reported by Droit-Volet et al. (2004a) and Tipples (2008), where the angry emotional expression was the most overestimated. Sad and happy were also overestimated but to a lesser extent. Their static counterparts, however, deviated less from 1000 ms and their deviations from the static neutral expression were not statistically significant.

There are three potential reasons why our static emotions do not induce substantial influence on participants' perception of time. An additional procedure in our setup differentiating it from the original study by Droit-Volet et al. (2004a) is the screening of attractiveness. The attractiveness of visual stimuli has been shown to affect the prompting of emotional states (Kenrick et al., 1993), which may in turn confound the effect of emotions on time perception. We chose two models from our photo bank who were not too distinctive but similar in attractiveness in order to minimize this potential confounder. Incidentally, the ratings of their emotional intensity also fall in the mid-range. The photographs chosen are perhaps not as salient as those in previous studies. Also, using black and white photographs may have further reduced the saliency of the emotions. The inclusion of a relatively large proportion of male participants in comparison to previous studies (Droit-Volet et al., 2004a; Tipples, 2008) may have further reduced the time-drag effect, which is more prominent in female subjects (Block et al., 2000).

Morphing facial expressions exaggerates the time-drag effect. This implies that the previously reported overestimation is not solely the result of a real-time mechanism. If the overestimation is an effect of real-time computation alone, morphing from a neutral expression to an emotional one should result in a diminished time-drag effect. In the current setup, given that all sequences started with a neutral expression, the participants had spent at least part of the stimulation time waiting for a readily perceivable emotional expression. Thus, the amount of time that participants were exposed to that emotion was reduced; the time in which it exerts an effect was in turn reduced. Our results imply that a pure real-time process of our internal clock cannot explain the results well. On the contrary, this process has to be retrospective: emotional expressions retrospectively expand the time-drag effect more than a static expression. A potential explanation is that a morphing expression resembles real life more than a static expression, thus magnifying the time-drag effect even though the emotion is only perceived about halfway into the stimulus' duration.

Another contributing factor could be the increased number of "events" experienced in a given time caused by the introduction of morphing. We argue that this cannot be the sole reason since the pattern of effects is highly reminiscent of those previously reported about static emotional expressions (Droit-Volet et al., 2004a; Tipples, 2008). If morphing is the sole reason for the magnification, the effect between emotions should be similar. Nevertheless, the dynamic conditions in this experiment provide references for comparison when morphing between two emotions is tested. Experiment 2 aimed to examine this in

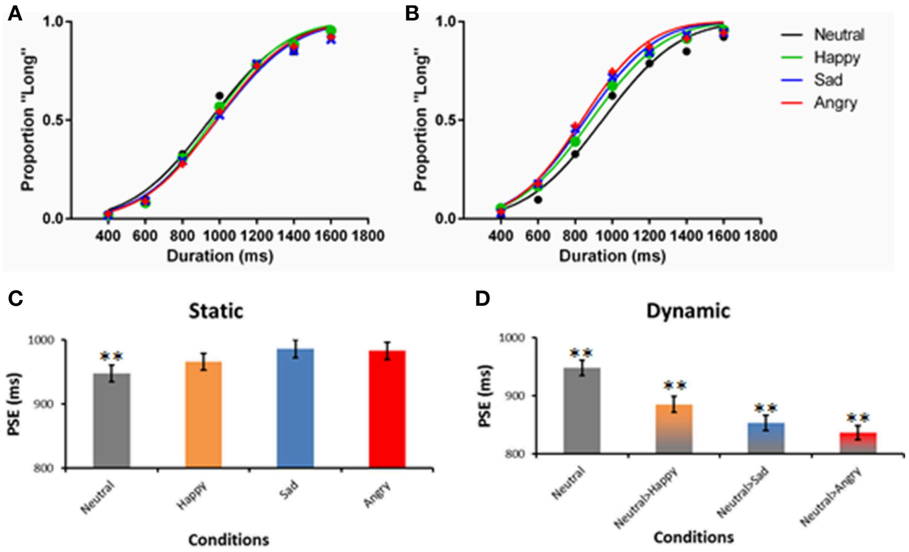

FIGURE 3 | Psychometric functions of Experiment 1. The left panel **(A)** illustrates the fit of the static facial expression, whereas the right panel **(B)** illustrates the fit of the morphing expression. The fit of the static neutral expression is plotted in both panels as a reference. The lower panels **(C,D)** plot the same data using bar graphs, with the SEM of PSE presented. **$p < 0.01$ in a one-sample t-test against 1000 ms.

TABLE 2 | Summary of one-sample *t*-test (test against 1000 ms) of the conditions tested in Experiment 1.

Expression	Estimated PSE (ms)	*SE*	*t*	*df*	*p*	*d*
Neutral	947.7	13.41	3.90	43	< 0.01	0.59
Happy	965.8	13.19	2.59	43	0.01	0.39
Sad	986.3	13.70	1.00	43	0.32	0.15
Angry	982.9	13.66	1.25	43	0.22	0.19
Neutral>Happy	885.1	13.56	8.47	43	< 0.01	1.28
Neutral>Sad	853.1	12.99	11.31	43	< 0.01	1.70
Neutral>Angry	836.2	12.02	13.63	43	< 0.01	2.05

depth by testing the effect of morphing from one emotion to another.

Experiment 2 the Influence of Morphing Direction on the Perception of Time

The morphing sequences in Experiment 1 involved only one salient emotion. In Experiment 2, we examined how the perception of time is affected by a morphing sequence involving two emotional expressions. It is interesting to examine whether the two emotional expressions jointly influence the perception of time or hinder each other's influence such that the perceived duration should lie between the perceived durations of the first and second expressions. An alternative possibility is that participants' perception of time depends only on either the primacy or recency effect, that is, the beginning or the end emotion will determine the perceived duration. Nevertheless, there is also a possibility that the effect depends on the emotion changes involved only without any observable direction effect.

Participants

Thirty-nine undergraduates participated in Experiment 2. Their arrangement in the experiment is shown in **Table 1**. All of them received participation credits for a psychology course.

Stimuli

Four sets of emotional expressions were extracted from the two models chosen in Experiment 1. The emotional expressions represented happiness, anger, fear, and disgust. While a happy expression differs from the other three in terms of valence, angry, fear, and disgusted expressions differ from each other in terms of the level of arousal (anger>fear>disgust, see **Figure 3**). They were morphed in four sequences. The happy-angry pair allowed direct comparisons with the static and neutral>emotional conditions in Experiment 1. Fear was chosen to explore how approach-avoidance motivation influenced the perception of time as reported in previous literature (Marsh et al., 2005). Two pairs of fear-related sequences were prepared: happy-fear and angry-fear. To better understand the prominent effect of an anger expression, it was paired up with a disgust expression as well. All pairs were presented in both directions. Thus, there were eight morphing sequences of seven set durations (400, 600, 800, 1000, 1200, 1400, and 1600 ms).

Procedures

The procedures were similar to Experiment 1. The first two blocks were a practice. Participants were randomly assigned to left-right and male-female viewing conditions (**Table 1**). They were allowed to rest in between blocks. The experimental sessions lasted less than an hour.

Results and Discussion

The Chi-square statistics were similar to those in Experiment 1. Male and female participants assigned to the key press [$\chi^2_{(1,n=39)} = 0.24$, $p = 0.62$] and gender of model conditions [$\chi^2_{(1,n=39)} = 0.01$, $p = 0.91$] were unbiased. An additional Chi-square test was conducted to ensure that the proportions of participants' gender did not differ between Experiments 1 and 2 [$\chi^2_{(1,n=83)} = 0.01$, $p = 0.90$]. Thus, the results of Experiment 1 provide a reasonable reference which is not influenced by gender difference. The key press and gender of model assignments were collated, and the proportions of "long" responses across time were fitted with cumulative Gaussian curves to estimate the PSE in each condition. **Figure 4** summarizes the PSE of the conditions in Experiment 2 and their SEM. The first notable finding is a general time-drag effect in all conditions (**Figure 4** and **Table 3**). In addition, all except the fear > angry and disgusted-angry pairs had significantly shorter PSE than the static neutral expression in Experiment 1 (**Figure 4**). This conforms to the findings in previous studies and our results in Experiment 1.

To further examine how dynamic changes between emotional facial expressions affect the perception of time, we regrouped the morphing pairs according to specific hypotheses concerning the induced approach-avoidance motivation, and valence and arousal changes. We first compared happy>angry morph with the neutral>happy and neutral>angry morphs in Experiment 1 (**Figure 5**). Dynamic expressions were found to have significantly stronger time-drag effects when compared to static expressions. In Experiment 1, the overestimation effect of the neutral>angry morph is significantly larger than the neutral>happy morph [$t_{(86)} = 2.70$, $p < 0.01$, $d = 0.58$]. Morphing between the happy>angry pair also induces a significant time drag, while the effect lies in between the two conditions. Both emotions appeared to exert an effect on the perception of time. This seems to indicate that a morph involving two distinct emotions has a time-drag effect that equals the average of the two neutral>emotional morphs. However, this interpretation remains a speculation and requires further testing because the happy>angry morphs are statistically not different from the neutral>happy or neutral>angry morph.

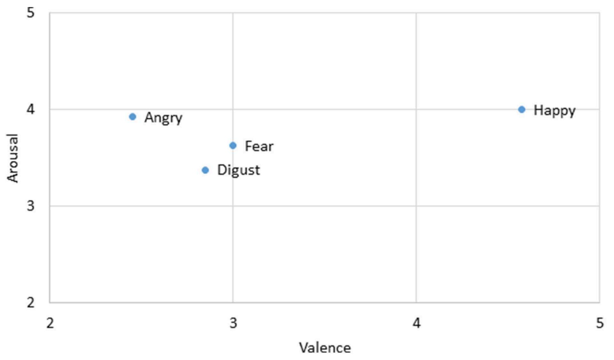

FIGURE 4 | Average valence and arousal ratings of the two models' photographs used in this condition on a seven-point scale rating task. Data were obtained from a pilot study to rate the stimuli ($n = 20$).

TABLE 3 | Summary of one-sample *t*-test (1000 ms) of the conditions tested in Experiment 2 (Static neutral expression condition is included for a comparison).

Expression	Estimated PSE (ms)	*SE*	*t*	*df*	*p*	*d*
Happy>Fear	836.3	14.66	11.17	38	< 0.01	1.79
Fear>Happy	820.3	12.11	14.84	38	< 0.01	2.38
Happy>Angry	874.9	13.42	9.32	38	< 0.01	1.49
Angry>Happy	863.7	13.14	10.37	38	< 0.01	1.66
Fear>Angry	922.9	14.59	5.28	38	< 0.01	0.85
Angry>Fear	884.7	16.57	6.96	38	< 0.01	1.11
Disgusted>Angry	941.5	15.85	3.69	38	< 0.01	0.59
Angry>Disgusted	892.4	14.59	7.38	38	< 0.01	1.18
Neutral (Experiment 1)	947.7	13.41	3.90	43	< 0.01	0.59

Among the eight pairs of dynamic emotional expressions, four pairs of morphing sequences with a happy face involve changes in valence whereas the rest involve mainly arousal changes (see **Figure 3**). To test whether the influence of valence change is greater or smaller than the influence of arousal change in the morphs, we regrouped the morph pairs accordingly. Additional *t*-tests comparing morph pairs involving happy and those without (the first four pairs against the last four pairs in **Table 4**) revealed a significant difference between these two groups [$t_{(6)} = 3.381$, $p = 0.01$, $d = 2.76$], suggesting that dynamic expressions involving major valence change are perceived as significantly longer than those involving arousal changes only. A change in valence in the morph sequence can potentially trigger the approach-avoidance motivation system, which in turn captures individual's attention, and as a result relays the switch of the internal clock for time perception.

Among the emotional facial expressions tested, an angry face was the most prominent trigger for the approach-avoidance motivation system. Therefore, examining the time-drag effect associated with the morphing sequences involving angry faces should give insight into this arousing, ecologically important stimulus. There is a significant difference between the two directions of the angry-disgusted pair [$t_{(76)} = 2.28$, $p = 0.03$, $d = 0.52$]. Similar trends of directional effects are observed in the other pairs involving an angry expression, though the differences are not statistically significant (see **Table 4**). Dynamic expressions starting with an angry expression were perceived as longer than dynamic expressions starting with other expressions and terminating with an angry expression. Such a pattern suggests that the arousing, avoidance-motivating angry expression has a primacy influence on the internal clock, which is consistent with the known neuroanatomical pathway between the thalamus and amygdala for quick processing of environmental cues of threats.

Overall Discussion

In the present study, we have examined whether dynamic facial expressions induce similar effects on humans' perception of time as static facial expressions. The effects are found to be similar

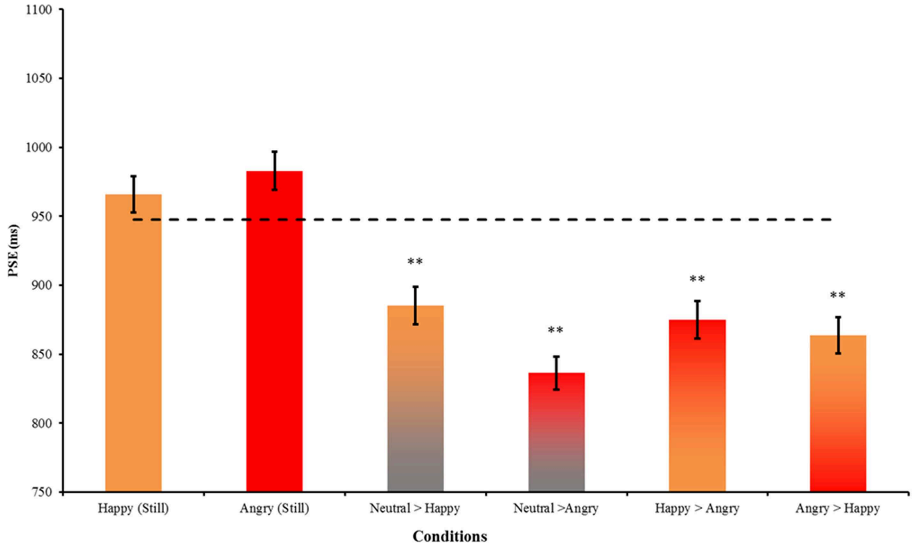

FIGURE 5 | A comparison of stimuli involving happy and angry expressions in Experiment 1 and Experiment 2. Error bars indicate ± SE. The dotted line indicates the PSE of static neutral expression as the reference. $^{**}p < 0.01$ in a t-test comparing the PSEs between this reference and the condition.

TABLE 4 | Comparison of PSE across pairs of dynamic expressions of opposite directions.

Expression pairs	Mean difference (ms)	*t*	*df*	*P*	*d*
Happy <> Fear	16.00	0.84	76	0.40	0.19
Happy <> Angry	11.20	0.60	76	0.55	0.14
Angry <> Fear	38.20	1.73	76	0.09	0.39
Angry <> Disgusted	49.10	2.28	76	0.03	0.52

and exaggerated for dynamic facial expressions. The time-drag effect persisted when morphing sequences involve two salient emotional expressions. A morphing sequence involving a valence change results in a larger time-drag effect than a morphing sequence involving arousal changes. Among all the pairs tested, those involving an angry expression demonstrated a primacy arousing effect in which angry-first sequences are perceived as longer than angry-last sequences. The implications of these findings are discussed below.

Experiment 1 explores the time-drag effect of dynamic expressions consisting of neutral>emotional pairs. The time-drag effects are much greater than when presenting a static emotional expression alone. This magnification could be explained by two factors. First, the morphing sequence introduced additional events to the time interval which perturbs the pacemaker and results in a perceived expansion of time by increasing the mental ticks. We argue that this is not the sole reason since the magnification is unequal between emotions and the pattern of difference across different emotional expressions conform to that reported in previous studies. We postulated that the ecological relevance of morphing stimuli may further exaggerate the overestimation: static faces are rarely seen in everyday life; real-life facial expressions involve dynamic changes in facial muscle configurations during talking, eating, and swallowing. A morphing sequence of facial expressions thus resembles a "real face" more than a static photograph, thus conveying richer emotional information and capturing more attention.

We further investigated the potential mechanistic influence of emotional facial expressions on the internal clock by using different morphing sequences in Experiment 2. Besides introducing dynamic changes as in Experiment 1, the morphing sequences in Experiment 2 involved two distinct emotional expressions. The results indicate that most pairs do not show any directional effect: there is little difference in the time-drag effect of the same pair of emotions regardless of their starting and ending emotions. The magnitude of the time-drag effect appears to fall between presenting the morphing sequence of the two expressions alone (i.e., neutral>emotional conditions in Experiment 1). If we assume that the time-drag effect is proportional to the exposure time for each emotional expression, a morphing sequence consisting of two emotional expressions should show a time-drag effect falling in between showing the two emotion expressions alone. Our finding seems to show such a trend. This interpretation, however, speculative since there is no statistical significant difference between the conditions and it also suffers from a confound: the frames in the middle of the morph sequence are ambiguous in nature. These frames do not convey salient emotional information; therefore their effects on time perception of a specific emotion are questionable. If emotional information influences time perception in a real-time manner, the reduction of salient information during these ambiguous frames would lead to a reduction of the time-drag effect, which is not support by the findings in the present study.

Among all the emotional expressions tested, the angry expression is the most prominent contributor to the time-drag effect. This conforms to studies in previous settings that revealed angry facial expressions as having the most significant effect on humans' perception of time (Droit-Volet et al., 2004a; Tipples, 2008). Another analysis indicated that an angry expression elicited a larger time-drag effect when presented first in a sequence than when presented at the end. It prospectively affects the subsequent experience of time perception. This could be due to the arousing effect of this prominent emotional expression on avoidance-related motivation (Marsh et al., 2005). This behavioral finding aligns with the neuroanatomical evidence for a preferential processing of potential threat information in the brain. Also, arousing the participants at the beginning of a sequence can trigger a larger time-drag effect, which provides evidence for a prospective effect of emotion on time perception.

Dynamic expressions involving a happy expression also appear to amplify the time-drag effect. A contributing factor could be changes of valence in the dynamic expressions. Among all the pairs in Experiment 2, dynamic expressions involving a happy expression involve a significant valence change (**Figure 6**). Other pairs of angry, disgusted, and fear expressions involve mainly changes in arousal. A valence change in emotional facial expressions potentially provides more information than arousal change for signaling approach or avoidance related motivation. In contrast, change in the arousal of an individual affects the immediacy of a reaction. For example, both sad and angry expressions hint at an avoidance reaction, though the latter signals an immediate escape while the former only hints at a reconsideration or a change of approach. A recent study shows that stimuli signaling a voluntary go/no-go action induce significant time distortion (Yabe and Goodale, 2015). An evaluation of valence change requires a clear recognition to the emotion at both ends, which is only achievable retrospectively. Future neuroimaging studies may explore whether this effect can be found in the affective information pathway.

There is abundant research reporting the effect of emotion on the perception of time. Most reports a time-drag effect (Droit-Volet et al., 2004a) but there are also contradictory reports showing that presenting emotions at different times induces a reverse effect (Lui et al., 2011). These studies, however, exclusively adopted unified static emotional stimuli and have not explored the potential influence of dynamic emotional changes on the perception of time. The present study reveals a set of novel findings regarding the influence of emotional information on the perception of time. Dynamic expressions amplify the time-drag effects of emotions. As discussed, intermediate frames between the two ends of a morphing sequence can be ambiguous and do not convey salient emotional meaning. This may speed up the internal clock by introducing ambiguous events that capture participants' attention, but has little to do with the actual emotional meaning. Thus, a real-time process is unlikely to explain how emotion influences the perception of time. Amplification of the time-drag effect of angry-start sequences suggests a prospective influence of emotion on the perception of time. According to the internal clock model, emotional expressions, especially those conveying cues of potential threats, capture the viewer's attention and speed up the pacemaker. Nevertheless, emotion also appears to modulate the perception of time retrospectively. The complex meaning of stimuli—for example, changes in valence—also amplifies the time-drag effect, which can only be achieved retrospectively.

A notable limitation of our study is the artificial nature of our stimuli. Though, the morphing sequences we used provide better ecological validity than static photographs and

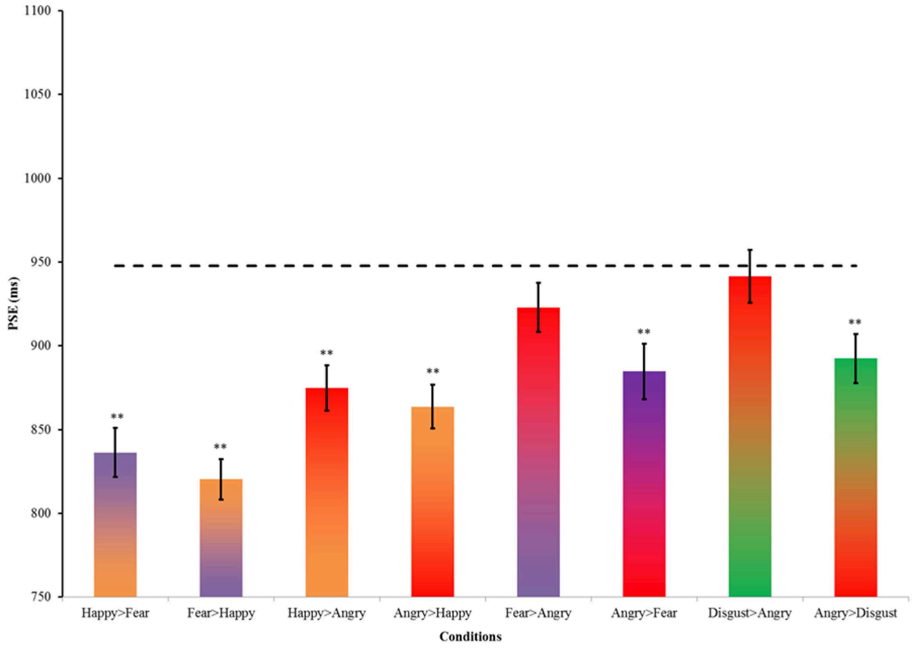

FIGURE 6 | Summary of PSEs in Experiment 2. Error bars indicate ± SE. The dotted line indicates the PSE of static neutral expression as the reference. $^{**}p < 0.01$ in a t-test comparing the PSEs between this reference and the condition.

pictures, they do not perfectly reproduce changes in real facial muscles. Nevertheless, given the similar pattern of our results to previous findings in various emotional conditions, the morphed frame should convey sufficient emotional information to participants. Besides, the morphing technique is limited in producing a dynamic expression without any emotion change. This condition will provide data in untangling the effects of emotion and pure facial movements in perceived duration. Morphing stimuli with perceivable facial changes requires two photographs differ significantly which usually entails changes in the perceived emotion expressions. In order to fully address these two limitations, real videos should be adopted (e.g., Botvinick et al., 2005) in future studies. This will help to understand the effect of real facial change on time perception. Also, models may perform action with their facial muscles without significant emotion expressions, for example chewing (Zhu et al., 2013; De Winter et al., 2015).

In summary, our results show that emotional information affects the perception of time at different time points. A retrospective process is evident across general emotional categories. A prospective process is also evident when motivations related to stimulus signaling approach or avoidance are involved. With the present setup, the evidence for a real-time effect on the internal clock appears to be weak. Despite the common belief that emotional processing is primitive and quick, its effect on time perception takes time. This delay diminishes its effect on time perception when emotional information changes in real time.

Supplementary Material

The Supplementary Material for this article can be found online at: http://journal.frontiersin.org/article/10.3389/fpsyg.2015.01248

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Encoding of goal-relevant stimuli is strengthened by emotional arousal in memory

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Emotional information receives preferential processing, which facilitates adaptive strategies for survival. However, the presence of emotional stimuli and the arousal they induce also influence how surrounding non-emotional information is processed in memory (Mather and Sutherland, 2011). For example, seeing a highly emotional scene often leads to forgetting of what was seen right beforehand, but sometimes instead enhances memory for the preceding information. In two studies, we examined how emotional arousal affects short-term memory retention for goal-relevant information that was just seen. In Study 1, participants were asked to remember neutral objects in spatially-cued locations (i.e., goal-relevant objects determined by specific location), while ignoring objects in uncued locations. After each set of objects were shown, arousal was manipulated by playing a previously fear-conditioned tone (i.e., CS+) or a neutral tone that had not been paired with shock (CS−). In Study 1, memory for the goal-relevant neutral objects from arousing trials was enhanced compared to those from the non-arousing trials. This result suggests that emotional arousal helps to increase the impact of top-down priority (i.e., goal-relevancy) on memory encoding. Study 2 supports this conclusion by demonstrating that when the goal was to remember all objects regardless of the spatial cue, emotional arousal induced memory enhancement in a more global manner for all objects. In sum, the two studies show that the ability of arousal to enhance memory for previously encoded items depends on the goal relevance initially assigned to those items.

Keywords: emotion, arousal, memory, top-down goal, fear-conditioning, arousal-biased competition, emotion-induced memory enhancement

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Introduction

Events or stimuli charged with emotional meaning stand out. For example, emotional faces, emotional words and emotional scenes are more likely to be detected (e.g., Amting et al., 2010) and remembered (e.g., Mather and Nesmith, 2008) than neutral ones. This preferential processing of emotional information is considered an adaptive strategy for survival and well-being (Öhman and Mineka, 2001), as attending to a threatening stimulus such as a snake or spider can help one avoid harm. In addition, the presence of such threatening stimuli, and the emotional arousal they induce, can also influence how surrounding non-emotional information is processed. For example, seeing a snake on a hiking trail could also lead you to better recall a distinctive feature of that trail so as to avoid it in the future.

Recent studies have shown that emotion's influence carries over to spatially or temporally adjacent non-emotional stimuli. For example, presenting an emotionally arousing cue (e.g., an emotional face or scene) influences visual perception of subsequent neutral items (Becker, 2009; Bocanegra and Zeelenberg, 2009; Ihssen and Keil, 2009; Wang et al., 2012; Lee et al., 2014a) and memory consolidation of preceding neutral items (Anderson et al., 2006; Dolcos and McCarthy, 2006; Knight and Mather, 2009). Yet these carryover effects of emotional arousal are not uniform. Some studies reveal emotion-induced enhancement of visual processing (e.g., Becker, 2009), whereas others reveal impairment due to emotion (e.g., Wang et al., 2012). The memory literature has also found both emotion-induced retrograde amnesia (e.g., Dolcos and McCarthy, 2006), and emotion-induced retrograde enhancement (e.g., Anderson et al., 2006).

The arousal-biased competition (ABC) model posits that emotional arousal can both enhance and impair processing of different representations simultaneously (for reviews, see Mather and Sutherland, 2011; Mather et al., 2015). ABC builds upon biased competition models (e.g., Desimone and Duncan, 1995), in which stimuli compete for neural representation in a mutually inhibitory fashion, with the competition being biased in favor of goal-relevant, or perceptually salient, stimuli (Itti et al., 1998; Beck and Kastner, 2009). The ABC model proposes that emotional arousal increases gain, there by enhancing mental representations of high-priority items even more than typical biased competition processes while inhibiting representations of low-priority items (i.e., "winner-take-more" and "loser-take-less"). Thus, the relative discrepancy between these types of stimuli is amplified. Priority in the competition is determined by both bottom-up perceptual saliency (e.g., stimuli that move suddenly or are brighter than their surroundings; Itti et al., 1998) and top-down goal-relevancy (e.g., finding a friend in a crowd; Beck and Kastner, 2009). Consistent with ABC, recent studies have demonstrated that emotional arousal facilitates subsequent perception of non-emotional, visually salient stimuli, while impairing perception of non-salient stimuli (Lee et al., 2012, 2014b; Sutherland and Mather, 2012, 2015).

Thus, the ABC model posits that a momentary increase in arousal will influence later memory for currently active representations and that whether arousal will lead to enhancement or impairment in memory for what was encoded right beforehand will depend on the priority of that information. In a study testing this hypothesis (Sakaki et al., 2014), participants saw a sequence of objects on each trial. In each sequence, there was one scene image that looked different than the objects. This scene served as a perceptual oddball. On half of the trials the oddball image was emotionally arousing. All participants were asked to report the identity of one of the items at the end of each list, but which item they had to report differed: One group of participants was asked to report the identity of the oddball. A second group was asked to report the object that immediately preceded the oddball. So in one condition, the oddball-1 item had high priority, whereas in the other condition it was just one item in a sequence. Memory for all the oddball-1 items was tested at the end of the session. Memory for the oddball-1 items was modulated by the subsequent emotional oddball in opposite directions in the two conditions. When the oddball-1 item had high priority, subsequent emotion enhanced long-term memory for it, whereas when it had low priority, subsequent emotion impaired long-term memory for it. Importantly, the direction of these effects varied as a function of goal-directed priority within the same task structure (Sakaki et al., 2014).

In the current study, we wanted to examine whether arousal after mental representations have been activated influences the degree of competition among different stimuli or whether it simply acts differentially depending on particular items' priority. Thus, we tested how arousal would modulate short-term memory consolidation when multiple target items were shown together. In particular, we were interested in whether multiple prioritized items could all benefit from subsequent arousal, and whether the amount of enhancement would depend on the degree of prioritization. To create top-down priority during the study, a spatial-attention cueing paradigm was adapted to a memory-encoding task in which participants tried to remember the neutral objects presented in the cued locations. We used a fear-conditioned tone (i.e., CS+) to manipulate participant's arousal levels on a trial-by-trial basis during the study. In Study 1, ABC predicted an arousal by task-relevance interaction such that post-encoding arousal would enhance memory for the objects in the cued locations (i.e., goal-relevant objects) more than for the objects in the uncued locations (i.e., non-relevant objects). In Study 2, we asked participants to prioritize all objects regardless of the cue location, but to give the cued objects highest priority. Thus, a key question in Study 2 was what would happen for the items that had some—but not the most—priority under arousal, and whether having matching items in this condition would matter.

Study 1

Materials and Methods

Participants

Based on previous studies examining the impact of fear-conditioning on behavior in which the number of participants varied between 25 and 40 participants (Lee et al., 2009a,b, 2014a), we included 33 participants (nine male; $M_{age} = 20.22$, range 18–27) with corrected-to-normal vision volunteered for this study and gave informed consent in accordance with University of Southern California Institutional Review Board guidelines.

Stimuli and Apparatus

We used 240 color photographs (5.5 × 5.5°) of real-world objects (e.g., fruit, car, animal, tools, etc.) from a previously published set of object stimuli (http://cvcl.mit.edu/mm/objectCategories.html). Electric shock administered with a human shock stimulator (Coulbourn Instruments, Allentown, PA, USA) served as an unconditioned stimulus (US) during the fear-conditioning session. The intensity of the shock was individually set by each participant at a level that was "*unpleasant but not painful*" (total

$M_{intensity} = 1.81$ mA, total range 1.0–4.0 mA). Two tones (500 and 1400 Hz) were adopted as conditioned stimuli (i.e., CSs).

Skin conductance response (SCR) was recorded at 1,000 Hz sampling rates with the MP-150 system (BIOPAC, Goleta, CA, USA). The SCR was calculated by subtracting a baseline (average signal between 0 and 1 s) from the maximum peak amplitude during the 1–7 s time window following the CS onset (Lee et al., 2014a,b). The trials that included shocks were excluded in subsequent analyses.

All procedures were performed in a dimly lit soundproof room at a viewing distance of 57 cm from a 19-in. CRT monitor (85 Hz refresh ratio; 1280 × 960 resolution).

Procedure

In an initial fear-conditioning phase, one tone was paired with electric shock (CS+) while the other tone was not paired with shock (CS−). To avoid ambiguity participants were told which tone signaled shock, and the tone-shock pairings were counterbalanced across participants (14 participants were conditioned with the high-pitch tone as the CS+). The US was delivered to the third and fourth fingers of the left hand. Each trial began with a fixation-cross jittered to appear for 7 to 10 s (i.e., inter-trial interval; ITI). Then one of the CS tones played for 1 s. On CS+ trials, a shock was delivered for 0.5 s after a 1.5 s-inter stimulus interval (ISI). We adopted a trace-conditioning paradigm to maintain participant's arousal level (or anticipation for the US) even after each CS tone terminated. In order to ensure that participants attended to the tones, they were asked to indicate the type of tone (i.e., low- or high-pitched) with a button press. To slow extinction learning for CSs, a partial reinforcement schedule (50%) was used; a total of 30 trials were presented in a random order: 10 CS+ with shock; 10 CS+ without shock; 10 CS− tones. Participants were not informed about the probability of the US delivery. To confirm the success of the conditioning, SCR was measured during the conditioning phase.

Following the conditioning phase, the encoding phase was administered in which participants were asked to remember objects in the cued location (i.e., prioritized objects) while ignoring the other objects (**Figure 1A**). Once every four trials, participants were given a 1-s cue to indicate the location (either vertical or horizontal; 6.0°eccentricity) to be attended for the next four trials. After the location cue, trials began with the object display for 1 s, followed by a 1-s blank screen. Then either the CS+ or CS− tone played for 1 s while a fixation cross was shown, followed by a 2-s blank screen. In order to ensure that participants attended to the task, they were also asked to indicate whether a pair of objects in the cued location was the same or different (i.e., matching task). A 5-s ITI was presented between trials. There were two runs for the encoding phase (16 CS+ and 16 CS− trials per run), and each run was repeated twice across the study. To minimize extinction of conditioned responses, three additional CS+ trials with shock were presented randomly in each run (i.e., booster trials).

Finally to test the primary hypothesis, an immediate recognition memory task with all object images used in the encoding phase (i.e., old items) and additional 48 objects as lures (i.e., new items) was administered after the matching task (**Figure 1B**). On each trial, participants were presented with one object item, and asked to indicate whether the item was "old" or "new" by pressing a key in a self-paced manner.

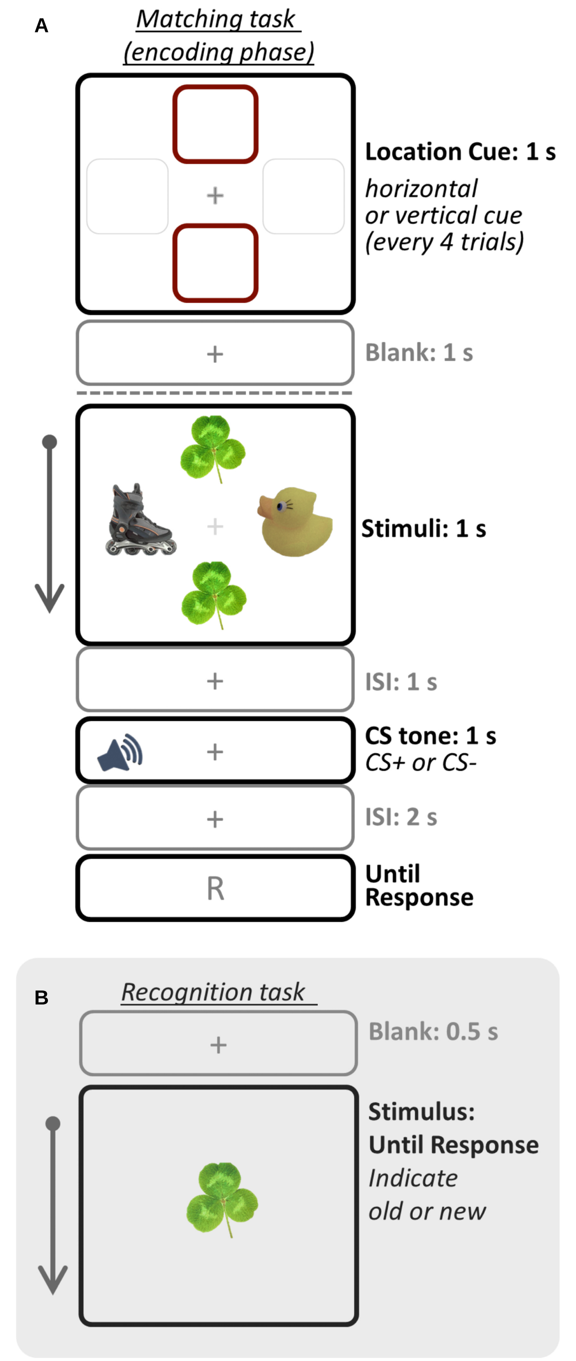

FIGURE 1 | Schematic illustration of one trial for the (A) matching task (encoding phase) and (B) recognition task (test phase). In Study 1, participants were asked to remember only objects in the cued location whereas in Study 2 they were asked to remember all objects. Therefore, only objects in the cued location were top-down prioritized in Study 1, but all objects were prioritized in Study 2. The recognition task was administered right after the matching task session. Images were drawn not to scale.

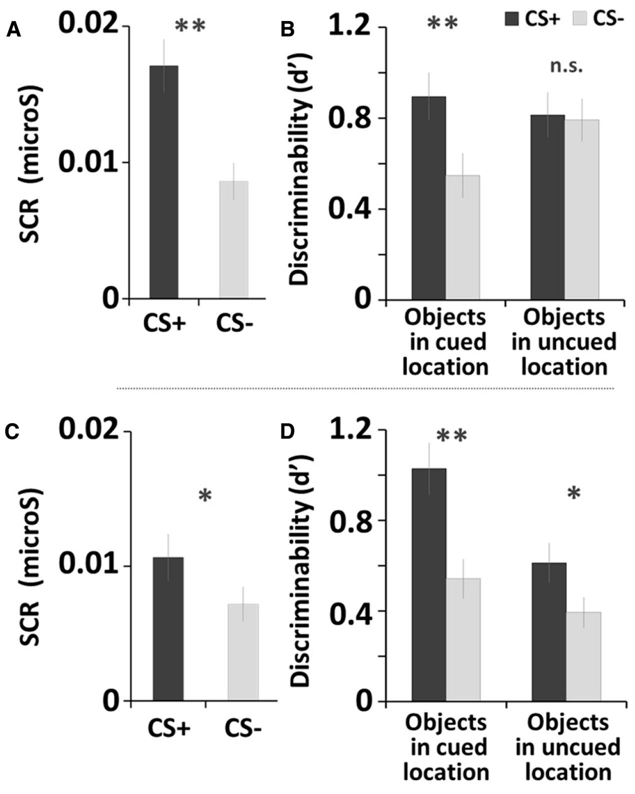

FIGURE 2 | Fear conditioning and memory recognition task results of Study 1 (A,B) and Study 2 (C,D). Error bars represents standard errors. $^{**}p < 0.001$; $^{*}p < 0.05$.

Results and Discussion

For the fear-conditioning session, the SCR results confirmed that fear conditioning successfully manipulated arousal in the current study, as the CS+ yielded greater SCR than did the CS− tone, $t(32) = 6.41$, $p < 0.001$, Cohen's $d = 2.70$ (**Figure 2A**).

For the memory task, we used individual d-prime (d') scores to obtain a quantitative measure of memory accuracy, as d' indicates how accurately participants discriminates between signal (old items) and noise (new items) (Macmillan and Creelman, 2004). The d' score was calculated by taking the difference between z-scored proportions of hits [p(H): correct responses to old items] and false alarms [p(FA): incorrect responses to new items]; p(H) and p(FA) were adjusted as follows: $p(\text{H}) = 1$ was recalculated as 1–1/(2N), $p(\text{FA}) = 0$ was recalculated as 1/(2N), where N is the maximum number of hits or false alarms possible. Higher d' scores indicate greater memory accuracy. A 2 (*Arousal Condition*: CS+, CS−) × 2 (*Stimulus Type*: objects in cued locations, objects in uncued locations) repeated-measures ANOVA was conducted on the d-prime score[1]. There were main effects of *Arousal Condition*, $F(1, 32) = 22.46$, $p < 0.001$, $\eta_p^2 = 0.41$, showing that overall memory accuracy was higher for objects with the CS+ tone ($M_{CS+} = 0.86$) than with the CS− tone ($M_{CS-} = 0.67$). There was also a main effect of *Stimulus Type*, $F(1, 32) = 4.72$, $p < 0.05$, $\eta_p^2 = 0.13$, showing that participants remembered objects in the uncued locations better ($M_{cued} = 0.72$) than objects in the cued locations ($M_{uncued} = 0.80$) regardless of arousal condition. Finally, a significant *Arousal Condition* × *Stimulus Type* interaction was observed, $F(1, 32) = 30.55$, $p < 0.001$, $\eta_p^2 = 0.49$, as the differences between CS+ and CS− tones was only seen for items shown in the cued locations. Subsequent pairwise comparisons (least significant difference; *LSD*) showed that the post-encoding CS+ tone enhanced later recognition of objects shown in the cued locations, compared with the CS− tone ($p < 0.001$; **Figure 2B**; see also **Table 1**). In contrast, there was no significant difference between CS+ and CS− tones for objects in the uncued locations (i.e., non-prioritized stimuli). We also compared memory accuracy within the same arousal condition, and found that there was a marginally significant difference in d-prime for objects in the cued location compared to the uncued location in the CS+ trials ($p = 0.076$).

In sum, as expected, the effects of arousal were most apparent for cued items that had top-down high priority. However, arousal had no significant impairment effect on uncued items, suggesting that post-perception arousal does not amplify competition between multiple items. Study 2 was designed to test whether arousal only enhances retrograde memory when there was one high priority item (the cued matching condition) or whether multiple prioritized items can benefit from arousal, and also to see if the finding that effects of arousal were strongest in the matching condition would replicate.

Study 2

Study 1 suggests that arousal amplifies existing effects of top-down priority, but we did not see impairment of competing, lower priority stimuli under arousal, as would be predicted from a competition model. An alternative model is that arousal can enhance multiple high priority items simultaneously. To test this, we needed to increase the priority of the non-cued items. Thus, in Study 2, participants were told that they should remember all objects on the screen, but only two of them were also cued. Thus, Study 2 tested whether arousal only enhances short-term memory consolidation of the highest priority item or whether it can enhance it for multiple high-priority items. Objects in the cued location were still the focus of the matching task as in Study 1. All experimental method and materials for Study 2 were the same as for Study 1, except for the following: (1) There were 27 participants (11 male; $M_{age} = 20.30$; range 18–29; 18 were conditioned with the high-pitched tone); (2) The mean shock intensity was = 1.41 mA, range 0.6–4.0 mA; (3) The task goal (i.e., priority) during the encoding phase was changed such that participants were asked to remember all objects regardless of the cued location for matching.

Thus, in Study 2, all items were prioritized for the memory task, but cueing two items gave them higher priority than uncued

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[1] Repeating this analysis on the hit rate for old items revealed the same patterns. There was a significant *Arousal Condition* × *Stimulus Type* interaction, $F(1, 32) = 25.17$, $p < 0.001$, $\eta_p^2 = 0.44$, indicating that the CS+ led to higher recognition for objects in the cued-location than did the CS− tone. There was also a main effect of *Arousal Condition*, $F(1, 32) = 21.47$, $p < 0.001$, $\eta_p^2 = 0.40$, as memory was higher for objects with the CS+ tone than for objects with the CS− tone ($M_{CS+} = 0.26$ vs. $M_{CS-} = 0.21$). Note that the hit rate data was not z-scored for this analysis.

TABLE 1 | Averaged recognition accuracy (standard error) in both Study 1 and Study 2.

	Stimulus condition	Arousal condition	Study 1 ($N = 33$)		Study 2 ($N = 27$)	
			Hit	***d′***	***Hit***	***d′***
Old	Object in cued location	CS+	0.276 (0.022)	0.895 (0.105)	0.421 (0.031)	1.028 (0.115)
		CS−	0.183 (0.020)	0.547 (0.098)	0.284 (0.027)	0.612 (0.087)
	Object in uncued location	CS+	0.246 (0.016)	0.814 (0.099)	0.268 (0.031)	0.542 (0.088)
		CS−	0.242 (0.019)	0.792 (0.093)	0.218 (0.023)	0.393 (0.067)
New	New object		*False alarm*		*False alarm*	
			.092 (.018)		0.139 (0.022)	

items. If experiencing arousal after perceiving multiple visual objects amplifies competition among the representations of these objects, arousal should enhance memory for the highest priority objects but impair memory for lower priority competing objects. In contrast, if arousal generally enhances anything that has high priority (i.e., is highly activated) at the moment arousal is experienced, then if all the objects have high enough priority, none should be inhibited.

Results and Discussion

The SCR analysis confirmed the success of the fear conditioning, as the CS+ yielded significantly greater SCR than the CS−, $t(26) = 2.58, p < 0.05, d = 1.13$ (**Figure 2C**).

For memory accuracy, a repeated-measures ANOVA[2] revealed a significant main effect of *Arousal Condition*, $F(1, 26) = 27.29$, $p < 0.001$, $\eta_p^2 = 0.51$, as memory was better with the CS+ tone ($M_{CS+} = 0.79$) than with the CS− tone ($M_{CS-} = 0.50$). There also was a main effect of *Stimulus Type*, $F(1, 26) = 12.24$, $p < 0.005$, $\eta_p^2 = 0.32$; as shown in **Table 1**, memory was better for items in the cued location ($M_{cued+} = 0.82$) than in the uncued lovation ($M_{uncued} = 0.47$). Subsequent pairwise comparisons (*LSD*) showed that the CS+ increased recognition for objects in both the cued location ($p < 0.001$) and the uncued location ($p < 0.05$; **Figure 2D**), but that the arousal-induced memory advantage was greater in the cued location, leading to a significant *Arousal Condition* × *Stimulus Type* interaction, $F(1,26) = 7.29$, $p < 0.05$, $\eta_p^2 = 0.22$. In sum, overall the CS+ enhanced later recognition of prioritized objects compared to the CS−, but for the objects in the cued location most.

General Discussion

In the current study, we examined whether arousal enhances information processing only for the highest priority information at a particular moment, or whether it can enhance priority for other prioritized items. The ABC model predicts that emotional arousal selectively enhances information processing for stimuli that are perceptually conspicuous or relevant to task goals (Mather and Sutherland, 2011) while impairing lower priority stimuli, but previous studies have not tested the role of competition in this process.

In the current two studies, participants were shown a set of objects and cued to two of them, and then they were exposed to an emotionally arousing stimulus (i.e., CS+) after encoding (**Figure 1A**). In Study 1, whereas memory for goal-relevant matching objects was enhanced on the CS+ compared to the CS- trials, no enhancement was observed for uncued, non-priority, objects. This suggests that the strength of top-down goal priority was amplified by emotional arousal, but competing items were not suppressed. In Study 2, emotional arousal produced memory enhancement for objects in both cued and uncued locations of the matching task when the task goal was to remember all objects irrespective of the cued location. Furthermore, arousal enhanced memory for objects in the cued location to a greater extent than it did for objects in the uncued locations. Taken together, these findings are consistent with the notion that arousal modulates representations based on their priority, amplifying the effect of top-down goals on memory consolidation, but that these modulation effects do not depend on competitive interactions among representations.

This is the first study to show that arousal induced after seeing a simultaneous display of multiple items enhances memory for the highest priority items. Previous findings of enhanced retrograde memory only had one preceding item shown and tested (Knight and Mather, 2009; Sakaki et al., 2014). The results from the current study also indicate that representations of other prioritized items (that are not necessarily the highest priority in the current set of items) can also be enhanced by subsequent arousal. Models of biased competition often suggest a "winner-take-all" mechanism (Itti et al., 1998; Beck and Kastner, 2009). Yet top-down goals sometimes require the prioritization of more than one item at a time, which would be impossible to do with a winner-take-all process.

In Study 1 we also found differential levels of enhancement based on item priority, but no strong indication of suppression of low priority items. This is contrary to the effects observed for low-priority oddball-1 items in Sakaki et al. (2014). This lack of suppression suggests that merely being encoded in the presence of higher priority items is not a sufficient basis for something to be the target of suppression under arousal. Instead, it may be that a stronger initial competition between stimuli or even an initial suppression process may be necessary. For instance,

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[2] For hit rates, the same patterns were observed: a significant *Arousal Condition* × *Stimulus Type* interaction, $F(1, 26) = 8.33$, $p < 0.01$, $\eta_p^2 = 0.24$, significant a main effect of *Stimulus Type*, $F(1, 26) = 13.97$, $p < 0.001$, $\eta_p^2 = 0.35$ ($M_{cued} = 0.35$ vs. $M_{uncued} = 0.24$) and *Arousal Condition*, $F(1, 26) = 32.55$, $p < 0.001$, $\eta_p^2 0= 0.56$ ($M_{CS+} = 0.35$ vs. $M_{CS-} = 0.25$). Note that the hit rate data was not z-scored for this analysis.

having one stimulus overlaid on top of another would induce stronger competition, which arousal should amplify (e.g., Ponzio and Mather, 2014). Another possibility is that a process akin to inhibition of return (IOR) produced greater encoding of items in the uncued location (e.g., Posner et al., 1985). Future studies are needed to determine if the degree of initial competition in visual processing or attentional focus in relation to the IOR effects can explain the current study's lack of memory suppression of low priority objects during emotional arousal (e.g., Lee et al., 2012).

One limitation of this study is that we only used negative stimuli to increase the participants' arousal levels as negative stimuli generally induce stronger arousal responses than positive stimuli (Lang et al., 1998; Baumeister et al., 2001). This means that we cannot be sure whether our results are due to the effects of negatively valenced emotional arousal *per se* or emotional arousal more generally. There are two additional possibilities to consider, both of which might influence the breadth of attention. First, that a safety feeling was produced upon hearing a CS− tone. Second, during the CS+ condition participants might have engaged in regulatory processes to avoid processing the CS+ tone. By influencing the breadth of attention, either of these two processes could change the initial encoding of the viewed images. Indeed previous research has shown that positive and negative stimuli have differential effects on the breadth of attention selectivity (e.g., Schmitz et al., 2009) and encoding processes (e.g., Kensinger and Corkin, 2004). However, a more recent study revealed that emotional arousal induced by either positive or negative stimuli enhances memory consolidation for previously viewed objects (Sakaki et al., 2014). Specifically, arousing stimuli enhanced later memory of preceding goal-relevant objects while impairing later memory of preceding goal-irrelevant ones. Thus, although in certain contexts positive and negative valences may have differential effects on memory, more recent evidence suggests that arousal amplifies the gain on strong vs. weak mental representations, regardless of whether that arousal was induced via positive or negative stimuli.

An important direction for future research is to better understand the neural bases of these retrograde effects of arousal that vary depending on the priority of each specific stimulus representation. A recent proposal is that, during moments of phasic arousal such as those induced by a CS+ tone, interactions between the brain's primary excitatory neurotransmitter, glutamate, and the concurrent release of a neuromodulator during arousal (i.e., norepinephrine) lead to local hotspots at the sites of highly active neurons, amplifying high priority representations (Mather et al., 2015). This model provides one potential explanation for the current findings. Namely, that arousal has differential effects on representations depending on their level of priority.

Taken together our studies demonstrate the ability of fear-induced arousal to enhance memory for previously encoded items and to do so differentially depending on the level of initial priority. This process operates on a moment-by-moment basis, with brief fluctuations in arousal (such as those induced by a conditioned tone) modulating currently activated representations such that higher priority representations are later remembered even better than they would have been otherwise. This targeted retrograde enhancement is likely one way that our arousal system helps us remember the things that really matter.

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Tryptophan supplementation and the response to unfairness in healthy volunteers

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Experimental manipulation of serotonin (5-HT) availability has been shown to modulate social behavior. For instance, serotonin depletion increased the rejection rates of unfair offers in the ultimatum game (UG), whereas a single dose of the serotonin reuptake inhibitor (citalopram) decreased rejection rates. These effects were observed immediately after the manipulation. The aim of this study was to investigate the effect of prolonged tryptophan (TRP) supplementation on UG performance in healthy individuals. A randomized double-blind placebo (PLC)-controlled design was used. Healthy volunteers ($N = 47$) completed the UG before and after a 6-day intervention of TRP (2.8 g/day) or PLC. Impulsivity was measured with a Go-Stop task. The overall analyses showed that TRP supplementation had no significant effect on UG scores, but the direction of the effect was opposite from expectations. Because repeated performance of the UG may lead to unwanted learning effects or strategical changes, additional analyses were conducted in which participants ($N = 7$) who accepted all offers on the second measurement were excluded. These analyses revealed that the TRP-group rejected very unfair offers more often than the PLC group. The groups did not differ on impulsivity. Increasing serotonin through TRP supplements increased the rejection of very unfair offers. The direction of our findings is inconsistent with earlier studies that showed that increasing 5-HT availability results in less rejection of unfair offers. The current findings thus importantly suggest that effects of acute vs. prolonged enhancement of 5-HT availability may differ. Also, the outcomes show that the UG is a complex task and participants' decisions may depend on context, e.g., prior experience with the task.

Keywords: serotonin, tryptophan supplementation, ultimatum game, unfairness, impulsivity

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Introduction

Substantial evidence from preclinical and clinical studies emphasize the importance of the serotonergic system in the regulation of social behavior (Sandi and Haller, 2015). Changes in the serotonergic system (e.g., receptor expression and serotonin levels) have repeatedly been reported to affect social behavior in animals and humans (Sandi and Haller, 2015). Specifically, low serotonin (5-HT) levels have not only been associated with aversive social behavior such as aggression (Brown et al., 1979), but also with psychopathological conditions such as depression (Owens and Nemeroff, 1994). Since 5-HT appears to play a key role in the regulation of social behavior and in maintaining mental health, studies have been conducted in order to gain a more thorough understanding of the role of serotonin in various aspects of social cognition (Young and Leyton, 2002). Accordingly, studies have experimentally manipulated 5-HT levels and examined the effect of increasing (or decreasing) central 5-HT levels on social cognition.

For instance, experimental depletion of tryptophan (TRP; precursor of 5-HT) in healthy volunteers made them judge couples as being less intimate and romantic (Bilderbeck et al., 2011). On the other hand, increasing 5-HT levels by means of TRP supplementation for 15 days decreased quarrelsome behavior in 'quarrelsome' men and women (Aan het Rot et al., 2006). Studies investigating the effects of experimental manipulation of 5-HT levels in humans suggest that lowering central 5-HT availability is associated with disruptive social behavior, whereas increasing 5-HT is associated with pro-social perception and behavior (Merens et al., 2007).

Manipulation of 5-HT levels also affects our response to unfairness as was shown in the ultimatum game (UG; Crockett et al., 2008, 2010). In the UG, the participant (responder) is exposed to offers to split a sum of money from other individuals. The responder can either accept the offer (in which the money is divided accordingly) or reject the offer (in which case both players receive nothing). The strategy maximizing gain is to accept every offer regardless of its fairness. However, very unfair offers (offering 20% of the total amount) have a 50% chance of being rejected (Güth et al., 1982; Bolton and Zwick, 1995), which indicates that emotion plays an important role in those decisions. Acute tryptophan depletion (ATD) was associated with a higher rejection rate (approximately 81%) of very unfair offers than sham ATD (~65%) in healthy individuals (Crockett et al., 2008). This effect was independent of the size of the offer and ATD had no effect on self-reported mood or on response inhibition. In healthy participants, a single dose of the selective serotonin reuptake inhibitor (SSRI) citalopram (30 mg) was associated with a lower rejection rate of unfair offers (~34%) than PLC and the norepinephrine reuptake inhibitor atomoxetine (60 mg; ~48 and 50%, respectively; Crockett et al., 2010). This time the effect did not appear for very unfair offers but was restricted to moderately unfair offers (27–33% of the stake). Citalopram did not alter self-reported mood. In another study, healthy students who tended to reject unfair offers had lower platelet serotonin content than participants who tended to accept the offers (Emanuele et al., 2008). Finally, a PET study in 20 healthy males showed that individuals with low levels of 5-HT transporter binding in the dorsal raphe nucleus were more likely to reject unfair offers (Takahashi et al., 2012). In summary, UG behavior seems to be under serotonergic influence and the direction of the effect on the UG is consistent with the direction of the 5-HT manipulation (Crockett et al., 2008, 2010; Emanuele et al., 2008; Takahashi et al., 2012).

In contrast to acute serotonergic interventions, only a limited number of studies have investigated the effects of prolonged serotonergic interventions on social behavior in humans (Young and Leyton, 2002). Given (a) the finding that prolonged TRP intake in humans leads to prosocial behaviors (Aan het Rot et al., 2006) and (b) the relevance of prolonged serotonergic interventions in clinical settings (e.g., treatment of depression), the aim of the present study was to investigate the effects of a prolonged increase of 5-HT availability on social decision-making. We hypothesized that healthy volunteers who had taken TRP supplements for 6 days would accept more unfair offers than volunteers who had taken PLC capsules. We measured impulse control as a secondary outcome. We expected a selective effect on the UG.

Materials and Methods

Participants

The participants of this study are the same as reported in Cerit et al. (2013). Individuals were included who were healthy (self-report), non-smoker and whose grandparents were all West-European. The age range was 18–35 years and Body Mass Index was between 19 and 29 kg/m^2. Exclusion criteria were a current diagnosis of depression or post-traumatic stress disorder, a lifetime history of psychosis, and use of medication, including oral contraceptives. Female participants were tested in their luteal phase of their menstrual cycle, defined as day 14–28 of their menstrual cycle. Written informed consent was obtained before data collection. The research was approved by the Medical Ethics Committee of Leiden University Medical Centre in The Netherlands. Participants received €40 upon completing the study.

Instruments

Diagnosis

The Mini International Neuropsychiatric Interview (M.I.N.I.) was administered (Sheehan et al., 1997; Van Vliet et al., 2000) to assess psychiatric diagnoses.

Ultimatum Game

The UG consists of three conditions in which participants are exposed to fair (45% of stake), unfair (32% of stake), and most (i.e., very) unfair (21% of stake) offers from a "proposer," who had split a sum of money provided by the experimenter. If the participant accepts the offer, both the proposer and participant will receive the money as proposed in the offer. In case of a rejection nobody receives money. Both fairness levels and offer size were manipulated. The value of the stake was either low (between 1 and 7 euro) or high (between 8 and 33 euro).

After 10 practice trials, participants were asked to respond to 48 offers (16 per fairness level). With each offer a photograph of a new proposer, the amount of the stake, and the amount of the offer was shown. The 48 photographs were counterbalanced for gender (24 male and 24 female proposers). All 48 offers were presented in a random order at each session. The participants were told that they would receive a percentage of the total amount that they had gained after having completed both sessions. In reality, there were no actual proposers and all participants received the same propositions. To increase credibility, the participants were first asked to split 24 sums of money (on paper) and had their photograph taken to be used in future experiments.

Impulsivity

The Go-Stop test is a stop-signal task and measures a dimension (impulse control) of impulsivity (Dougherty et al., 2005, 2010). In this task a series of 5-digit numbers are displayed for 500 ms with a 1,500 ms inter-stimulus interval. The 5-digit numbers appear in series, and some of these numbers are identical to the immediately preceding 5-digit number. Participants are instructed to respond to these matching numbers (Go Signal). Some of these matching numbers are first presented in black and then suddenly turn red. This is a Stop Signal cue, and the participants are instructed to withhold responding to any matching numbers that turn red. The timing of these stop signals varied across the testing session (e.g., 50, 150, 250, and 350 ms). The two dependent measures of interest were: (1) correct responses and (2) response inhibition failures. The primary dependent measure is the Go-Stop Ratio, which is the ratio of these two measures. The Go-Stop Ratio has been validated as a measure of the ability to inhibit an already initiated response, and data from the 150 ms stop delay typically provides the best group discrimination (Dougherty et al., 2010).

Design and Procedure

This study had a randomized double-blind PLC-controlled design. Participants were randomly allocated to receive seven capsules containing either 400 mg TRP (total dose of 2.8 g/day) or PLC (cellulose microcrystalline) for a period of 6 days.

The dosage and duration were based on previous studies that had shown social-behavioral effects of TRP administration (3 g/day) after a period of 15 days (Aan het Rot et al., 2006) and cognitive effects after a single dose of 0.8 g TRP (Markus and Firk, 2009). The experimental procedure included two visits to the laboratory. The first visit to the laboratory included baseline measurements before the participants were provided with the capsules. The second visit included measurements after 6 days of intervention.

First Visit to Laboratory (Pre-Intervention)

Upon arrival at the laboratory, participants provided written informed consent. Following the M.I.N.I. interview, participants completed the UG and Go-Stop test, respectively (as part of a larger test battery). At the end of the first visit, participants were provided with 42 capsules that contained 400 mg TRP or placebo (PLC). Oral and written instructions were provided regarding the timing of administration of capsules and lifestyle restrictions during the next 6 days and on the day of the second lab visit.

Tryptophan Supplementation

Participants started to take the capsules the day after their first lab visit. They were instructed to take two capsules in the morning, two in the afternoon (before meals) and three in the evening (before 23.00 h). Participants received a diary in which they were asked to write down the exact time of intake and number of capsules. Compliance was not measured through blood sample analyses, however, participants were led to believe that compliance would be assessed at post-intervention through a saliva sample. Lifestyle instructions included: no smoking, no use of dietary supplements and vitamins, and consumption of alcohol limited to three units/day. Participants were also instructed to refrain from alcohol and caffeine-containing consumptions and avoid high carbohydrate meals on the day of their second visit. Further instructions for the day of the second visit included: no eating and drinking 1 h before arriving at the laboratory (except water), and no physical exercise at least 2 h before arrival. All test sessions started in the afternoon between noon and 5pm.

Second Visit to Laboratory (Post-Intervention)

Upon arrival at the lab, participants handed in their diary regarding the intake of capsules. In addition, they were asked to fill out a debriefing questionnaire regarding compliance to the instructions during the previous 6 days. They were also interviewed about their compliance to the instructions for the second lab visit. Next, participants were asked to complete the UG and Go-Stop test in fixed order.

Results

Participant Characteristics

We contacted 184 individuals from a participant pool ($N = 581$) by email. Of these, 130 individuals expressed interest in the study (**Figure 1**). After screening for in- and exclusion criteria we included 48 participants. One participant dropped out of the study. The first two participants received TRP single-blind.

The demographic details of both groups are shown in **Table 1**. Groups did not differ significantly on demographic characteristics. One participant in the PLC group had a current diagnosis of panic disorder, and one participant in the TRP group had a specific phobia (for needles). No participant was on medication.

The groups did not differ on UG behavior at baseline. A repeated measures ANOVA (RM-ANOVA) on UG rejection

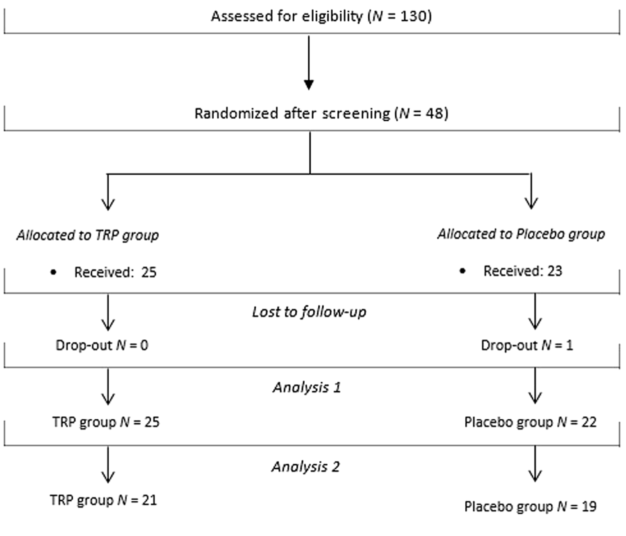

FIGURE 1 | Consort diagram.

TABLE 1 | Demographic characteristics of the tryptophan (TRP) and Placebo (PLC) groups*.

	TRP (*N* = 25)	PLC (*N* = 22)
Age (M ± SD)	20.7 ± 3.6	19.9 ± 2.2
Female/male	14/11	9/13
Compliance (%)	97.6 ± 6.6	99.4 ± 1.8

*(M, Mean; SD, Standard Deviation); *In the PLC group one participant had a current diagnosis of panic disorder, and in the TRP group one participant had a specific phobia (for needles). Compliance % refers to the intake of the capsules over 6 days of intervention.*

rates pre-intervention (baseline) with offer size (low, high) and fairness level (fair, unfair, and very unfair) as within subjects factors and intervention (TRP/PLC) as between subjects factors revealed that neither the main effect of Intervention nor any of the interactions with the factor Intervention were significant (all Fs < 3.35, all ps > 0.074), Supplementary Figure S1.

Compliance

According to self-report, 98% of the capsules were taken according to instructions. The minimum percentage of capsules taken by a participant was 69%. Three participants had taken two capsules in the morning of the second lab visit. All these participants were retained.

Ultimatum Game

A RM-ANOVA on UG rejection rates post- intervention with offer size (low, high) and fairness level (fair, unfair, and very unfair) as within subjects factors and intervention (TRP/PLC) as between subjects factors revealed the expected main effect of fairness level [$F(1.63,73.14) = 95.50$, $p < 0.001$, $\eta_p^2 = 0.680$]; fair ($M = 8.0$), unfair ($M = 40.7$), very unfair ($M = 68.2$) and a main effect of offer size [$F(1.00,45.00) = 5.87$, $p = 0.020$, $\eta_p^2 = 0.115$]; low ($M = 41.6$) and high ($M = 36.4$). There was no main effect of Intervention [$F(1.00,45.00) = 0.355$, $p = 0.554$, $\eta_p^2 = 0.008$], nor a significant interaction (all Fs < 1.87, all ps > 0.168).

This study was part of a larger study in which baseline measures pre-intervention were included. Repeated administration of behavioral measures, such as the UG, has the disadvantage of habituation and/or unwanted learning effects or changes in strategy. Therefore, an additional analysis was conducted in which participants who accepted all offers in the UG task (regardless of offer size or fairness level) on the second lab visit were excluded from the analyses. After exclusion of these seven participants (TRP, $N = 4$; PLC, $N = 3$) a RM-ANOVA on UG rejection rates post-intervention with Offer size (low, high) and Fairness level (fair, unfair, and very unfair) as within subjects factors and Intervention (TRP/PLC) as between subjects factors revealed main effect of Fairness level [$F(1.93,73.34) = 157.76$, $p < 0.001$, $\eta_p^2 = 0.806$] and Offer size [$F(1.00,38.00) = 5.91$, $p = 0.020$, $\eta_p^2 = 0.135$]. There was no main effect of Intervention [$F(1.00,38.00) = 1.020$, $p = 0.319$, $\eta_p^2 = 0.026$], nor a significant interaction between Offer size and Intervention [$F(1.00,38.00) = 0.48$, $p = 0.508$, $\eta_p^2 = 0.012$]. Importantly, however, the interaction between Fairness and Intervention was significant [$F(1.93,73.34) = 3.715$, $p = 0.030$, $\eta_p^2 = 0.089$] and remained significant ($p = 0.015$, $\eta_p^2 = 0.127$) when we corrected for possible pre-existing differences (i.e., entering UG rejection rates at the pre-intervention measurement as a covariates in the analyses)[1].

Separate RM-ANOVAs with Offer size (low, high) as within subject factor and Intervention (TRP/PLC) as between subject factor were conducted on the rejection rate of the three levels of fairness post-intervention. The PLC and TRP groups did not differ on rejection rates of Fair and Unfair offers (both Fs < 0.45, both ps > 0.50), however, there was a significant main effect of Intervention on rejection rates of Very Unfair offers [$F(1,38) = 4.682$, $p = 0.037$, $\eta_p^2 = 0.110$]. The TRP group rejected more very unfair offers compared to the PLC group (**Figure 2**; **Table 2**). There was no main or interaction effect involving offer size.

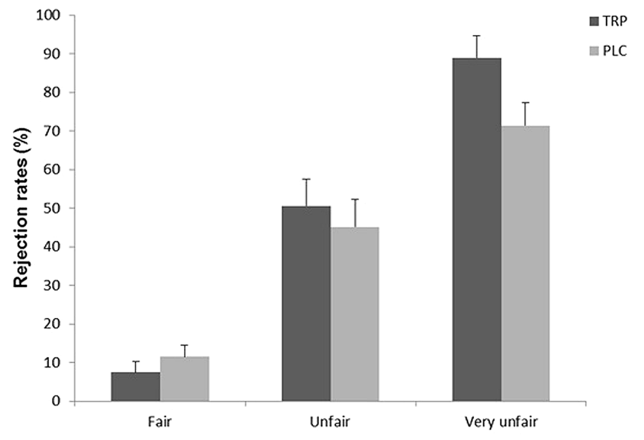

FIGURE 2 | Rejection rates (%) in the ultimatum game (UG) following TRP supplementation. (TRP, Tryptophan; PLC, Placebo). Error bars represent SE.

TABLE 2 | Ultimatum Game (UG), rejection rates following 6 days of TRP/PLC (M ± SE).

Fairness	Offer size	Analysis 1		Analysis 2	
		TRP (*N*=25)	PLC (*N*=22)	TRP (*N*=21)	PLC (*N*=19)
Fair	Low	7 ± 3.05	12 ± 3.25	8 ± 3.50	14 ± 3.68
	High	6 ± 2.45	8 ± 2.61	7 ± 2.83	9 ± 2.98
Unfair	Low	47 ± 7.09	42 ± 7.56	55 ± 7.09	49 ± 7.46
	High	39 ± 7.23	36 ± 7.71	46 ± 7.70	41 ± 8.09
Very unfair	Low	76 ± 7.43	66 ± 7.92	90 ± 4.96*	77 ± 5.22
	High	74 ± 8.33	57 ± 8.88	88 ± 7.14*	66 ± 7.51

TRP, Tryptophan; PLC, Placebo. Main effect of Intervention on rejection rates of very unfair offers [F287 (1,38) = 4.682, p = 0.037, $\eta_p^2 = 0.110$].

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[1] Please note that excluding the two participants with a psychiatric condition did not affect our outcomes. The interaction between Fairness and Intervention remained significant ($p = 0.039$). Follow-up analyses demonstrated increased rejection rates of the TRP group in response to very unfair offers ($p = 0.043$).

Impulsivity

A repeated measures ANOVA conducted on the primary dependent measure (i.e., Go-Stop ratio) of the impulsivity task post-intervention, with the four stop signal intervals (i.e., 50, 150, 250, and 350 ms) as within subject factors and Intervention (TRP/PLC) between subjects factors, revealed a main effect of stop signal intervals [$F(2.68,120.39) = 269.90$, $p < 0.001$, $\eta_p^2 = 0.857$]; 50 ms ($M = 0.135$), 150 ms ($M = 0.382$), 250 ms ($M = 0.671$), and 350 ms (0.844; **Figure 3**). There was no main effect of Intervention [$F(1.00,45.00) = 0.738$, $p = 0.40$, $\eta_p^2 = 0.016$], nor a significant interaction [$F = 0.818$, $p = 0.48$]. Moreover, the groups did not differ on impulsivity when seven participants were excluded, i.e., no interaction or main effect of intervention was found [$F(1,38) = 0.873$, $p = 0.36$].

Discussion

The current study aimed at investigating effects of prolonged TRP supplementation on social decision-making as measured with the UG. The overall analysis showed that TRP supplementation had no significant effect on decision behavior, but the direction of effect was opposite from expectations. An additional analysis, in which seven participants who accepted all offers post-intervention were excluded, showed that the TRP-group rejected very unfair offers more often than the PLC group. TRP supplementation did not affect impulsivity, indicating that the effect was specific for social decision-making.

Our findings are not consistent with other studies in which healthy participants performed the UG following a serotonergic manipulation. A single dose of citalopram reduced the rejection rate of unfair offers compared to PLC condition in healthy volunteers (Crockett et al., 2010), whereas TRP depletion had an opposite effect (Crockett et al., 2008). Crucially, while previous studies mainly investigated acute effects of serotonin manipulations, we looked at prolonged TRP supplementation. Participants took high dosages of TRP for six consecutive days before the UG was administered again. The current results thus suggest that the effects of serotonin manipulation on social decision-making may importantly depend on the duration and intensity of the manipulation.

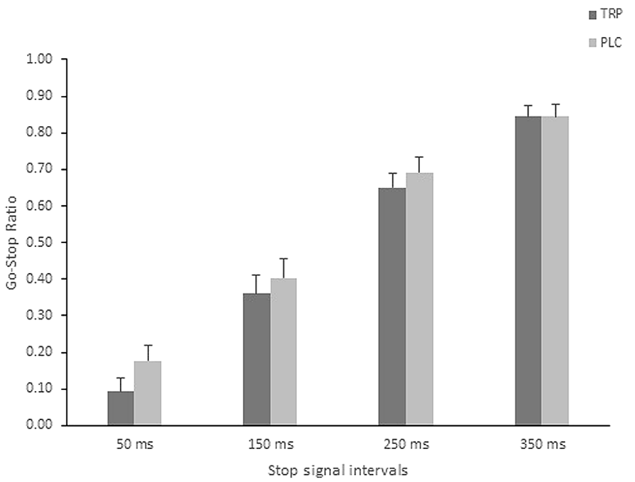

FIGURE 3 | Go-stop Ratio (stop signal task) following TRP Supplementation. (TRP, Tryptophan; PLC, Placebo). Error bars represent SE.

A possible explanation for our findings is that increasing serotonin availability during 6 days may make participants more sensitive to the socio-emotional aspect of the UG rather than to the monetary rewards. Elevated levels of serotonin may facilitate constructive social interactions by reducing aggression and increasing dominance (Young and Leyton, 2002). Dominance includes sociable behavior (i.e., prosocial actions; Kalma et al., 1993). Since fair treatment may be considered a premise for constructive social interactions, the TRP group may have become more sensitive to the social aspect of the task (i.e., being treated fairly by others).

Alternatively, since our participants did not take TRP on the day of testing, our findings might be due to the withdrawal of TRP that caused a relative depletion compared to the previous days. As we did not collect blood samples, we cannot be sure about the TRP concentrations at the time of testing. This relative depletion hypothesis, however, seems quite unlikely, considering that we found a lower cortisol response to social stress in the same participants, which is theoretically consistent with supplementation (Cerit et al., 2013).

Furthermore, previous studies have demonstrated that the effects of serotonin on cognitive functioning follow an inverted *U*-shape (see e.g., Chamberlain et al., 2006; Cano-Colino et al., 2014), explaining how baseline differences in neurochemical activity lead to divergent effects of drugs on cognitive performance. Acute and prolonged manipulation of serotonin may result in different baseline activities and thus be associated with different locations on the inverted *U*-shape. The aim of the current study was not to investigate whether the effect of TRP on social decision-making follows an inverted *U*-shape, however, this may be a possible explanation of contradictory findings from previous studies and the current, and may also be an important matter to consider for future investigations on the effect of increasing serotonin availability.

Our study shows that repeated administration of the UG may cause difficulties in interpreting the outcomes. Seven participants accepted all offers on the second test session (i.e., post-intervention). Examination of the health status, the demographical and compliance data of these seven participants did not indicate a difference that may explain their deviating behavior on the UG.

Accepting all offers is a gain maximizing strategy, which may simply reflect individual behavioral differences. Importantly, however, this strategy may obscure fairness considerations during social decision-making and thus lower the chance of finding effects of the intervention on this process of interest. Future studies should therefore try to avoid repeated administration of this paradigm.

One of the limitations of the current study is that our study sample included two participants with psychiatric conditions (i.e., specific phobia and panic disorder). Since the additional analysis conducted after excluding these two participants yielded similar results, it is highly unlikely that these two participants affected our main results.

Also, we have no information on the diet of the participants during the 6-day lasting TRP intervention, neither do we have information on the type of meal that participants have consumed on day 7. We did not take blood samples to measure peripheral parameters (e.g., TRP/LNAA ratios) which could have provided us with a manipulation check.

Future studies may benefit from measuring plasma amino acid levels, however, the usefulness is limited to a manipulation check as peripheral TRP concentrations are an indirect index of central serotonin.

Our study shows that increasing serotonin through prolonged TRP supplements increases the rejection of very unfair offers in healthy volunteers. If replicated, this implies that a prolonged increase of serotonin availability affects social decision-making differently than acute enhancement of serotonin availability. Given the interpretational difficulties of the UG, future studies may use other measures of social cognition and behavior, particularly with repeated test administration.

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Supplementary Material

The Supplementary Material for this article can be found online at: http://journal.frontiersin.org/article/10.3389/fpsyg.2015.01012

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Executive and semantic processes in reappraisal of negative stimuli: insights from a meta-analysis of neuroimaging studies

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Neuroimaging investigations have identified the neural correlates of reappraisal in executive areas. These findings have been interpreted as evidence for recruitment of controlled processes, at the expense of automatic processes when responding to emotional stimuli. However, activation of semantic areas has also been reported. The aim of the present work was to address the issue of the importance of semantic areas in emotion regulation by comparing recruitment of executive and semantic neural substrates in studies investigating different reappraisal strategies. With this aim, we reviewed neuroimaging studies on reappraisal and we classified them in two main categories: reappraisal of stimuli (RS) and reappraisal via perspective taking (RPT). We applied a coordinate-based meta-analysis to summarize the results of fMRI studies on different reappraisal strategies. Our results showed that reappraisal, when considered regardless of the specific instruction used in the studies, involved both executive and semantic areas of the brain. When considering different reappraisal strategies separately, in contrast, we found areas associated with executive function to be prominently recruited by RS, even if also semantic areas were activated. Instead, in RPT the most important clusters of brain activity were found in parietal and temporal semantic areas, without significant clusters in executive areas. These results indicate that modulation of activity in semantic areas may constitute an important aspect of emotion regulation in reappraisal, suggesting that semantic processes may be more important to understand the mechanism of emotion regulation than previously thought.

Keywords: emotion regulation, reappraisal, reappraisal via perspective-taking, reappraisal of stimuli, ALE, meta-analysis

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Introduction

Emotion regulation plays a key role for the capacity, unique to humans, to react in a flexible way to emotional events (Thayer and Lane, 2000, pp. 201–216; Rozanski and Kubzansky, 2005, pp. S47–S53). Indeed, the capacity to adaptively regulate negative emotion seems to be a protective factor against the development and maintenance of psychopathology (Aldao and Nolen-Hoeksema, 2010, pp. 974–983; Aldao et al., 2010, pp. 217–237; Berking and Wupperman, 2012, pp. 128–134). Moreover, the improvement of adaptive emotion regulation skills is one of the most important aims in several psychotherapeutic treatment approaches (Greenberg and Pascual-Leone, 2006, pp. 611–630; Berking et al., 2008, pp. 1230–1237) and interventions in health psychology (Cameron and Jago, 2008, pp. 215–221; Smyth and Arigo, 2009, pp. 205–210). Especially in neuroscience, the concept of emotion regulation is key to explaining brain functioning alterations associated to psychopathology (Taylor and Liberzon, 2007, pp. 413–418) and their normalization due to psychotherapy (DeRubeis et al., 2008, pp. 788–796; Messina et al., 2013, p. e74657).

Individuals may use different emotion regulation skills to change the spontaneous flow of emotional reactions. For example, following stressful events individuals may attempt to positively reappraise the event (Weber et al., 2014, pp. 345–360), use humor (Harm et al., 2014, pp. 1895–1909), avoid thoughts associated to such events by suppressing them (Wenzlaff and Wegner, 2000, pp. 59–91), or may ruminate on the stressful event (Watkins, 2008, p. 163). Differences between emotion regulation strategies are therefore of great interest in the context of models of mental health and psychological intervention.

Among emotion regulation strategies, reappraisal has been defined as "*construing a potentially emotion-eliciting situation in non-emotional terms*" (Gross, 2002, pp. 281–291). The importance of reappraisal is due to its adaptive value in decreasing emotional experiences in response to negative events. For example, the habitual use of reappraisal has been found to be associated with the increased expression of positive emotion, more effective interpersonal functioning and increased well-being (Gross, 2002, pp. 281–291; Gross and John, 2003, pp. 348–362). In developmental psychology, evidence from longitudinal studies suggests that the habitual use of reappraisal predicts the development of interpersonal flexibility, interpersonal openness and stronger social connections in children and adolescents (English et al., 2012, pp. 780–784; Xia et al., 2014, pp. 779–786). In clinical psychology, it has been shown that reappraisal is positively correlated with mental health and negatively with emotional disorders (Aldao and Nolen-Hoeksema, 2010, pp. 974–983; Hu et al., 2014, pp. 341–362).

Several recent studies have used neuroimaging to clarify the neural mechanisms mediating reappraisal. In most of these studies, participants were exposed to negative emotional stimuli and were instructed to use emotion regulation strategies to regulate their emotional response to them (Ochsner et al., 2002, pp. 1215–1229). Using this methodology, neural correlates of emotion regulation have been identified as increases of activation in several prefrontal areas, such as the dorsolateral prefrontal cortex (dlPFC), the dorsal anterior cingulate (dACC) and the ventromedial prefrontal cortex (vmPFC) (Ochsner and Gross, 2008, pp. 153–158; Buhle et al., 2014, pp. 2981–2990). Accompanying these increases, the decrease of amygdala activation has been reported as a correlate of successful regulation of negative emotions (Diekhof et al., 2011, pp. 275–285). The involvement of prefrontal areas has been consistently reported in tasks that recruit executive attention and working memory, the control mechanisms that supervise the activation of various cognitive sub-processes through voluntary attention (Kane and Engle, 2002, pp. 637–671; Wager and Smith, 2003, pp. 255–274; Owen et al., 2005, pp. 46–59). Building on these well-established models of executive function, neurobiological models of reappraisal have focused on the concept of cognitive control to characterize the key process involved in reappraisal when responding to emotional stimuli (Ochsner and Gross, 2005, pp. 242–249; Ochsner et al., 2005, pp. 797–814). In this form of reappraisal, voluntary attention is directed to modulate responses to perceived emotional stimuli, instead of letting automatic reactions alone determine behavioral, physiological and experiential responses.

One outstanding question concerns the involvement of semantic areas in emotion regulation. Semantic processes include attributes of cognitive representations that are based on the generalization of experiences in the interaction with the environment and are subsequently used to give meaning to the new experience (Tulving, 1972, p. 4). In emotion regulation studies, temporal, inferior parietal and ventromedial prefrontal areas have been reported as activated during reappraisal tasks (Buhle et al., 2014, pp. 2981–2990). These areas are considered part of the semantic system (Patterson et al., 2007, pp. 976–987; Binder et al., 2009, pp. 2767–2796), which is the neural substrate of mental functions that allow the formation and recovery of conceptual knowledge, including representations of elements that are relevant in the context of emotion regulation such as generalization of emotional experiences (Neumann and Lozo, 2012, p. 223) and relationships that govern social interactions (Gobbini et al., 2004, pp. 1628–1635; Zahn et al., 2007, pp. 6430–6435).

The present study extends previous meta-analyses of reappraisal studies (Diekhof et al., 2011, pp. 275–285; Buhle et al., 2014, pp. 2981–2990; Kohn et al., 2014, pp. 345–355) by addressing the issue of the involvement of executive and semantic systems in emotion regulation of negative stimuli and by comparing recruitment of executive and semantic neural substrates in studies investigating different reappraisal strategies. We separately considered two different strategies of reappraisal [reappraisal of stimuli (RS) and reappraisal via perspective-taking] and performed a contrast analysis to examine the existence of significant statistical differences between the two sets of studies. The importance of this analysis stems from the consequent refinement of current neurobiological models of reappraisal, which focus on the concept of cognitive control. In contrast, the present study suggests that brain systems associated with cognitive control are not central in all forms of reappraisal, and at least another neural network – the semantic system – should be considered in emotion regulation. With this aim, we analyzed separately studies of different reappraisal strategies and we performed a contrast analysis to statistically compare these different strategies.

Our attempt to compare different emotion regulation strategies required addressing a taxonomic issue that had remained unresolved despite the increasing number of neuroimaging studies on emotion regulation. Neuroimaging studies on reappraisal provide similar instructions to investigate different strategies and different instructions to investigate similar reappraisal strategies. For example, two studies that both aimed to evaluate the effect of reappraisal of emotional stimuli provided participants with quite different instructions. Eippert et al. (2007, pp. 409–423) asked participants to "*decrease their* *emotional reactions by distancing themselves from the picture, by becoming a detached observer through thinking that the depicted situation is not real, only a picture*" (p. 412), but specified that "*subjects were told not to substitute negative emotions with positive emotion*" (p. 412). In contrast, Phan et al. (2005, pp. 210–219) asked participants to "*transform the scenario depicted into positive terms (e.g., women crying outside of a church could be alternatively interpreted as expressing tears of joy from wedding ceremony rather than of sorrow from a funeral)*" (p. 211). However, similar instructions have been used to evaluate different strategies of emotion regulation. For example, to investigate the strategy used in suppression, Lévesque et al. (2003, pp. 502–510) have used a typical instruction used in reappraisal studies: "*to suppress any emotional reaction to the sad stimuli. That is, they had to voluntarily decrease the intensity of the sad feelings felt in response to the sad film excerpts. To accomplish that goal, subjects were encouraged to distance themselves from those stimuli (i.e., to become a detached observer)*" (p. 503).

The need for taxonomy of reappraisal strategies was addressed in a meta-analysis of behavioral studies on emotion regulation conducted by Webb et al. (2012, p. 775). In this work three different kind of reappraisal were described: (1) RS, in which, participants are instructed to reappraise the situation or the cause of the stimulus; (2) reappraisal via perspective taking (RPT), in which participants are instructed to take another perspective (usually the perspective of a detached observer); (3) reappraisal of emotion, in which participants are instructed to interpret the emotion associated to experimental stimuli by accepting their emotional experience. Using this classification, Webb et al. (2012) were able to detect differences between specific reappraisal strategies. For example, reappraising using perspective taking proved to be more effective than reappraising the emotional stimulus or the emotional response in influencing emotional experience and expression. However, with the exception of this study, the comparison between different reappraisal strategies has been neglected in both behavioral and neuroimaging investigations.

In the present work we used the classification proposed by Webb et al. (2012, p. 775) to systematically review neuroimaging studies on reappraisal and shed light on the specific aspects of different strategies of reappraisal by investigating possible differences in the associated neural substrates. We adopted a coordinate-based meta-analytic technique specifically developed for neuroimaging studies, the Activation Likelihood Estimation (ALE) method (Laird et al., 2005, pp. 155-164), to quantify the results of fMRI studies on different reappraisal strategies.

Materials and Methods

Studies Selection and Classification

Neuroimaging studies on reappraisal were collected through searches in PUBMED[1] and Google Scholar[2] using the keywords "emotion regulation neuroimaging" or "affective regulation neuroimaging." Additional studies were obtained reviewing the references of papers founded on PUBMED database.

We included all the papers in accordance with the following criteria: (a) use of fMRI to investigate neural correlates of reappraisal; (b) use of general linear models to analyze contrasts between reappraisal conditions versus control condition and viceversa; (d) involvement of adult healthy participants; (e) activation foci reported in 3D coordinates (x, y, z) in stereotactic space. Despite the presence of studies that have focused their analyses on specific Regions of Interest (ROIs) and may therefore bias the detection of cerebral areas (Ragland et al., 2009), we included both whole brain and ROIs analyses because of the exiguous number of studies that have investigated the whole brain activity in reappraisal (see **Table 1**). Exclusion criteria were: (a) studies investigating emotion regulation strategies different than reappraisal; (b) studies investigating reappraisal of positive emotional stimuli; (c) studies investigating reappraisal with the purpose of increasing emotional responses. Following these criteria a total of 21 studies and 437 participants were found (the main features of selected studies are shown in **Table 1**).

A careful coding of emotion regulation instructions that participants received in the neuroimaging studies was followed (see **Table 1** for original instructions of experimental and control tasks reported in single studies). Thus, according to the taxonomy proposed by Webb et al. (2012, pp. 775), we classified reappraisal strategies as: (1) Reappraisal of stimulus in which participants are instructed to reappraise the situation or the cause of the stimulus, for example thinking that it is not real (RS; $N = 8$); (2) RPT in which participants are instructed to take the perspective of a detached observer; (RPT; $N = 7$); (3) Reappraisal of emotional response ($N = 1$), in which participants are instructed to interpret the emotion associated to experimental stimuli in a mindfulness manner (Kross et al., 2009, pp. 361–366); (4) Reappraisal not-specified ($N = 5$), when instructions were generic or included more strategies. Instructions for control tasks were quite similar for all studies and they consisted in natural responses to experimental stimuli.

Meta-Analytic Procedure

Several meta-analyses were carried out based on the classification described in the previous section. Firstly, a preliminary meta-analysis aimed at evaluating the neural correlates of reappraisal regardless of the specific instructions. Secondly, on the basis of the classification of the instructions, we conducted two separate analyses to verify the existence of specific neural correlates of RPT and reappraisal of the stimulus. Because we found only one study investigating reappraisal of emotion (Kross et al., 2009, pp. 361–366), we were not able to explore neural correlates of this strategy in a separate meta-analysis.

To conduct the meta-analyses, the ALE method for coordinate-based meta-analysis of neuroimaging data was used (Eickhoff et al., 2009, pp. 2907–2926). This methods is based on the evaluation of the overlap between foci of activation found in different studies and treats the reported foci not as single points, but as centers for 3D Gaussian probability distributions capturing the spatial uncertainty (Turkeltaub et al., 2002, pp. 765–780; Turkeltaub et al., 2012, pp. 1–13). To this aim, an

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[1] http://www.ncbi.nlm.nih.gov/pubmed/

[2] http://scholar.google.com/databases

TABLE 1 | Main features of studies included in the meta-analysis.

Studies	*N*	Emotion	Stimuli	Experimental Task Instruction	Control Task Instruction	Strategy	Whole brain/ROIs*	N Foci
Banks et al. (2007)	14	Negative	Pictures	"To reinterpret the content of the picture so that it no longer elicited a negative response" (p. 305)	"During the Maintain ask, participants were instructed to attend to, be aware of and experience naturally (without trying to change or alter) the emotional state elicited by the pictures; they were told to maintain the evoked affect for the entire task block" (pp. 304–305)	*nc*	WB	9
Domes et al. (2010)	33	Negative	Pictures	"To image that the situation was not real or that they were a detached observer" (p. 760)	"Maintain trials required attentive viewing of the pictures without trying to alter the affective reaction" (p. 760)	*nc*	WB	17
Eippert et al. (2007)	24	Fear	Pictures	"Becoming a detached observer through thinking that the depicted situation is not real, only a picture" (p. 412)	"Subjects should view the picture attentively without trying to alter their emotional reactions" (p.412)	*nc*	ROIs	11
Erk et al. (2010)	17	Negative	Pictures	"To look at the following picture directly but try to take the position of a detached observer, thinking about the present picture in a neutral way" (p. 15727)	"Look at the following picture directly and permit feeling your emotions" (p. 15727)	RPT	WB/ ROIs	11
Goldin et al. (2008)	17	Disgust	Videos	"Thinking objectively to decrease emotional reactivity to films, for example, by assuming the perspective of a medical professional watching an instructional video or focusing on technical aspects of the film" (p. 578)	No instruction	RPT	WB	35
Hayes et al. (2010)	25	Negative	Pictures	"Place yourself as an observer in the scene, but change the way you think about it by making it not relevant to you or your loved ones" (p. 3)	"Simply look at the picture and let any emotions you're feeling unfold naturally" (p. 3)	RS	ROIs	23
Kanske et al. (2011)	25	Negative	Pictures	"Decrease any emotional response by reinterpreting the displayed situation, for example, as produced by actors and therefore not real, as meaning something else, or having a different outcome than initially suggested by the picture" (Kanske et al., 2011, p. 1380)	"Participants attended the content of the picture but did not manipulate the emotional response to it" (Kanske et al., 2011, p. 1380)	RS	ROIs	24
Kim and Hamann (2007)	10	Negative	Pictures	"Imagining the scenes as less personally relevant (e.g., dissociating themselves from the main figures), imagining the scenes as unreal, and imagining the scenes as physically farther away from themselves" (pp. 777-778)	"participants were instructed to view the picture in a natural way and not to try to change the emotion elicited by the picture" (p. 777)	RS	WB/ ROIs	40
Koenigsberg et al. (2010)	16	Negative	Pictures	"Relate to the image as though they were not personally connected in any way to the pictured individuals or the context in which they were situated, i.e., as though they were an anthropologist viewing the scene objectively or an emergency room doctor maintaining a detached clinical perspective so that he can function coolly in the situation" (p. 1815)	"(Subject) were to simply allow themselves to experience whatever emotion the picture spontaneously evoked in them" (p. 1815)	RPT	WB	11
Kross et al. (2009)	16	Negative	Sentences	"to recognize that the feelings they experienced during recollection were passing mental events that were psychologically distant from the self and did not control them" (p. 361)	"The first "feel" strategy directed individuals to focus on the specific feelings that naturally flowed through their mind as they thought about their recalled experiences" (p. 361)	*nc*	WB	6

(Continued)

TABLE 1 | Continued

Studies	*N*	Emotion	Stimuli	Experimental Task Instruction	Control Task Instruction	Strategy	Whole brain/ROIs*	N Foci
Lévesque et al. (2003)	20	Sadness	Videos	"Voluntarily decrease the intensity of the sad feelings felt in response to the sad film excerpts. To accomplish that goal, subjects were encouraged to distance themselves from those stimuli (i.e., to become a detached observer)" (p. 503)	"Subjects were instructed to react normally to the sad film excerpts, that is, to allow themselves to become sad in response to these stimuli" (p. 503).	RPT	WB/ ROIs	11
McRae et al. (2008)	25	Negative	Pictures	"Reinterpretations were limited to three categories: (1) It's not real (e.g., it's just a scene from a movie, they're just pretending), (2) Things will improve with time (e.g., whatever is going wrong will resolve over time), (3) Things aren't as bad as they appear to me (e.g., the situation looks worse than it is, it could be a lot worse, at least it's not me in that situation)" (p. 148)	No instruction	RS	WB/ROIs	16
McRae et al. (2010)	18	Negative	Pictures	"To reinterpret the situation depicted in the picture in a way that made them feel less negative about it. When reappraising, participants used the instructed strategy of reinterpreting the affects/dispositions, outcomes, and contexts depicted in images" (p. 249)	"Participants were instructed to pay attention and respond naturally to the subsequent stimulus, allowing themselves to have whatever reaction the picture would normally evoke in them" (p. 249)	*nc*	WB/ROIs	19
Modinos et al. (2010)	18	Negative	Pictures	"To reinterpret its content so that it no longer elicited a negative response" (p. 371)	"Subjects were instructed to attend and naturally experience any feelings elicited by the photo" (p. 371)	*nc*	WB/ROIs	10
Ochsner et al. (2002)	15	Negative	Pictures	"Participants were instructed to reinterpret the photo so that it no longer elicited a negative response. Reappraisal was commonly accomplished by generating an interpretation of, or a story about, each photo that would explain apparently negative events in a less negative way (e.g., women depicted crying outside of a church could be described as attending a wedding instead of a funeral)" (p. 1225)	"Participants were instructed to attend to and be aware of, but not to try to alter, any feelings elicited by it" (p. 1225)	RS	WB/ROIs	19
Ochsner et al. (2004)	24	Negative	Pictures	"Participants in the self-focus group were instructed to increase their sense of objective distance, viewing pictured events from a detached, third-person perspective. To decrease negative emotion participants could view the sick person from the detached; clinical perspective of one not personally connected in any way to the pictured individual and the context in which she is situated. Participants assigned to the situation-focused group were instructed to reinterpret the emotions, actions, and outcomes of individuals as depicted in their situational context. To decrease negative emotion, participants in the situation-focused group were asked to imagine pictured events getting better" (pp. 484–485)	"Participants were instructed simply to look at the image and let they respond naturally" (p. 485)	RPT	ROIs	40

(Continued)

TABLE 1 | Continued

Studies	*N*	Emotion	Stimuli	Experimental Task Instruction	Control Task Instruction	Strategy	Whole brain/ROIs*	N Foci
Phan et al. (2005)	14	Negative	Pictures	"To decrease voluntarily the intensity of their negative affect by using the cognitive strategy of reappraisal which is to reinterpret the content of the picture so that it no longer elicited a negative response [. . .] Two main examples of cognitive reappraisal were provided to facilitate understanding of the strategy: (1) transforming the scenario depicted into positive terms (e.g., women crying outside of a church could be alternatively interpreted as expressing tears of joy from wedding ceremony rather than of sorrow from a funeral) and (2) rationalizing or objectifying the content of the pictures (e.g., a woman with facial bruises could be translated as an actor wearing makeup rather than a victim of domestic abuse)" (p. 211)	"Subjects were instructed to attend to, be aware of, and experience naturally (without trying to change or alter) the emotional state elicited by the pictures; they were told to maintain the evoked affect for the entire block" (p. 211)	RS	ROIs	18
Schardt et al. (2010)	37	Fear Disgust	Pictures	"To look at the picture while detaching yourself from any emotional response which may arise by adopting the position of a detached observer, who is not affected by the scene presented in the picture" (p. 945)	"Participants were instructed to look at the picture and permit you to feel whichever emotional response arises naturally, without trying to alter it" (p. 945)	RPT	WB, ROIs	22
Urry et al. (2006)	19	Negative	Pictures	"To reduce the intensity of their negative affect, for which they were trained to either (1) view the situation as fake or unreal, or (2) imagine that the situation being depicted had a different outcome than the one suggested (e.g., victims of a car accident survived and healed well)" (p. 4416)	"Participants were instructed to maintain their attention to the picture without changing their negative affective experience" (p. 4416)	RS	WB/ROIs	2
Wager et al. (2008)	30	Negative	Pictures	"Participants viewed aversive images, and were asked to reappraise the emotional value of those images so that the emotional impact was less negative. More specifically, they were instructed to generate a positive interpretation of the scene depicted in each picture that reduced the emotional impact" (p. 1048)	"Participants were asked to view the image, understand its content, and allow they to experience/feel any emotional response it might elicit" (p. 1048)	RS	WB/ROIs	10
Walter et al. (2009)	20	Negative	Pictures	"Subjects were instructed to intentionally regulate their emotions by taking the position of a neutral observer. More specifically they were instructed to: "Look at the following picture directly but try to take the position of a Non-involved observer, thinking about the present picture in a neutral way" (p. 2)	"Subjects were instructed to simply watch the pictures and permit all upcoming emotions. More specifically they were instructed to: "Look at the following picture directly and permit feeling your emotions" (p. 2)	RPT	WB/ROIs	14

*nc, not classified; RST, reappraisal via perspective-taking; RS, reappraisal of stimuli; WB, whole brain analyses; ROIs, regions of interest analysis. *In case of Whole brain/ROIs studies, all foci of brain activation have been considered in the meta-analysis.*

algorithm is used to identify clusters of brain activity that show a convergence of activation across experiments and determine if the clusters thus obtained occur more frequently than in the null distribution arising from random spatial association between the results of different experiments. ALE meta-analysis was carried out using GingerALE 2.3 software distributed by the BrainMap project[3] (Laird et al., 2005, pp. 155–164). We employed the "non-additive" method, which models each focus with a Gaussian function defined by a full-width at half-maximum (FWHM) kernel size empirically determined by finding the maximum across each focus's Gaussian (Turkeltaub et al., 2012, pp. 1–13). The non-additive method allows the modeling of the spatial uncertainty of each focus arising from inter-subject and inter-study variability. The meta-analyses were performed in Talairach space. Coordinates reported in studies in Montreal Neurological Institute (MNI) space were transformed into Talairach coordinates using the Lancaster transform, icbm2tal algorithm (Laird et al., 2010, pp. 677–683) included in the Convert Foci tool of GingerALE.

We conducted several meta-analyses. In the first meta-analysis we included all reappraisal studies irrespective of the strategy. Foci of activation were collected from all the contrasts between reappraisal conditions versus control conditions and vice versa, as reported in the original studies. In the second meta-analysis we considered the contrasts between RS *versus* the control condition and vice versa. In the third meta-analysis we considered the contrasts between reappraisal via perspective-taking *versus* the control condition and vice versa. Finally, to test the interaction between condition (experimental condition *versus* control condition) and strategy (RS *versus* reappraisal via perspective-taking), a subtractive analysis was conducted comparing ALE values of specific reappraisal strategies (RS versus RPT; Eickhoff et al., 2011, pp. 938–949). In all cases statistical significance was determined through a permutation tests.

Results

Neural Correlates of Reappraisal

The first meta-analysis evaluated the main effect of reappraisal regardless of the specific reappraisal instruction used in the studies (see **Table 2**, **Figure 1**). This analysis was based on 21 studies and 437 participants, yielding a total of 245 foci for the contrast reappraisal condition versus control condition and 13 studies, 272 participants, yielding a total of 73 foci for the contrast control condition versus reappraisal condition. The probability maps were thresholded at $p < 0.001$ and corrected using false discovery rates (FDRs), the minimum clusters extent was of 200 mm × 200 mm × 200 mm.

Significant clusters of increased activation were found in the dorsal attentional system (dlPFC and the posterior medial prefrontal cortex, with extension to the anterior cingulated cortex). Several clusters of increased activation were located also in the semantic system, i.e., in the inferior prefrontal gyrus, superior/middle temporal gyrus and in the angular gyrus on the left side. Finally, clusters of decreased activation were found in limbic areas such as the amygdala and the parahippocampal gyrus.

Neural Correlates of Specific Reappraisal Strategies

Meta-analyses on the effect of specific strategies were conducted considering RS and RPT separately. For both meta-analyses, probability maps were thresholded at $p < 0.01$ and corrected using FDRs.

The meta-analysis of studies on RS included eight studies and 163 participants, yielding a total of 105 foci for the contrast RS condition versus control condition and four studies, 73 subjects yielding a total of 18 foci for the contrast control condition versus RS. The results of this meta-analysis were quite similar to the results of the main meta-analysis, with significant clusters of increased brain activation in dorsal attentional system (in dorsolateral and medial prefrontal cortex) and in the sematic system (temporal gyrus and angular gyrus on the left, inferior

TABLE 2 | Significant clusters of brain activity in reappraisal studies.

Cluster	Areas	Talairach Coordinates			Brodmann's areas	Cluster size (mm^3)	ALE score
		x	*y*	*z*			
(A) Reappraisal versus Control Task ($p < 0.001$, FDR correction)							
(1)	Medial prefrontal cortex/dorsal anterior cingulate	4	22	42	32/8/6	1008	0.031
(2)	Middle temporal gyrus/superior temporal gyrus	−58	−34	−2	21/22/42	864	0.029
(3)	Inferior frontal gyrus/middle frontal gyrus	46	26	0	47/45/13	840	0.037
(4)	Dorsolateral prefrontal cortex	−38	12	44	6/8/9	400	0.023
(5)	Inferior frontal gyrus	−46	26	−6	47/45	320	0.026
(6)	Angular gyrus/middle temporal gyrus/inferior parietal lobe	−46	−66	32	39	296	0.022
(B) Control Task versus Reappraisal ($p < 0.001$, FDR correction)							
(1)	Amygdala/putamen	−26	−2	−14	34	1288	0.033
(2)	Parahippocampal gyrus/amygdala	12	−12	−16	34	704	0.024

ALE, activation likelihood estimation; FDR, false discovery rate.

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[3] http://brainmap.org/ale/

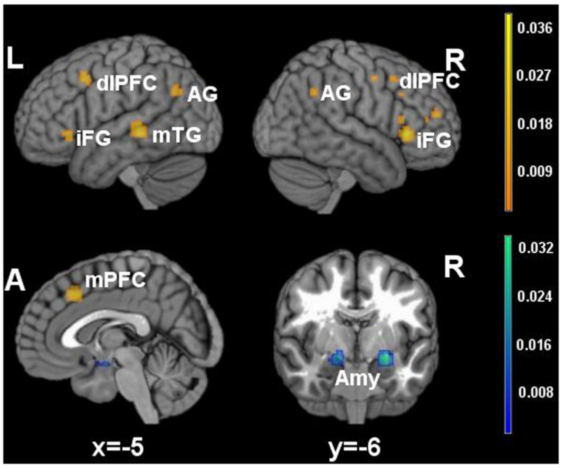

FIGURE 1 | Brain activity in reappraisal tasks. In warm colors significant cluster of increased brain activity, in cold colors significant clusters of decrease brain activity. mPFC, medial prefrontal cortex; dlPFC, dorsolateral prefrontal cortex; iFG, inferior frontal gyrus; mTG, middle temporal gyrus; AG, angular gyrus; Amy, amygdala.

prefrontal cortex; see **Table 3A**, **Figure 2** in violet), and significant clusters of decreased activation in areas involved in emotional reactivity (amygdala and parahippocampal gyrus bilaterally; see **Table 3B**, **Figure 2** in violet).

The meta-analysis of RPT studies included seven studies and 151 participants, yielding a total of 77 foci for the contrast RPT condition versus control condition and 51 foci for the contrast control condition versus RPT. Here, the biggest clusters of increased activation were located in the right inferior parietal lobe/angular gyrus on the right and in the superior temporal gyrus on the left (see **Table 3C**, **Figure 2** in green). No significant cluster of activation was found in the prefrontal cortex. Significant clusters of decreased activation were found in the amygdala bilaterally and thalamus (see **Table 3D**).

Finally, a comparative analysis was conducted to quantify the differences between the RS and RPT reappraisal strategies. Also in this case, probability maps were threshold at $p < 0.01$ and corrected using FDRs. Due to the small number of studies, only a cluster survived to the direct comparison between strategies. This cluster was specific for RS strategies but not for RPT. It was located in the medial prefrontal cortex (localization of the cluster in 3D Talairach coordinates: $x = -14$, $y = 11$, $z = 54$; Broadmann's area = 6; z-score obtained in the subtractive analysis: $z = 3.01$, $p < 0.01$ corrected for FDR).

Discussion

Neurobiological models of reappraisal emphasize the role of executive function in emotional control (Ochsner and Gross, 2005, pp. 242–249; Ochsner et al., 2012, pp. E1–E24), whereas the contribution of semantic processes has been less addressed in the literature. In the present study we systematically reviewed, classified and meta-analyzed neuroimaging studies on different reappraisal strategies of negative stimuli. Our attempt was to investigate the role of executive and semantic functions in emotion regulation. Namely, we verified the involvement of these functions in reappraisal regardless of the specific form of reappraisal investigated in single studies, and considering two specific reappraisal tasks on the basis of the instruction provided by authors to participants in each single study.

The classification of neuroimaging studies on reappraisal was carried out through careful coding of emotion regulation instructions that participants received in each neuroimaging study that corresponded to our selection criteria. We focused on two main categories of studies on reappraisal that resulted to be well-represented in the literature: RS and RPT. In studies on RS participants were instructed to reappraise the situation or the cause of experimental stimulus. In this case typical experimental paradigms were based on the exposure of participants to emotional negative pictures during the fMRI scanning, and they were asking to think that the picture was not real (for example, to think that the pictures showed was a movie or that the persons in the pictures were actors). In studies of reappraisal via perspective-taking participants were instructed to take the perspective of a detached observer during the exposure to negative emotional pictures.

In the main meta-analysis of reappraisal, which considered all studies regardless of the specific instruction adopted in the study, the neural substrates associated with recruitment of executive processes resulted activated by reappraisal. Significant clusters of increased activation were detected in dorsolateral and dorsomedial prefrontal/anterior cingulated areas, which are part of the voluntary attentional system (Duncan and Owen, 2000, pp. 475–483; Hopfinger et al., 2000, pp. 284–291). Accompanying such activations, clusters of decreased activity were detected in subcortical areas associated to emotional reactivity such as the amygdala (Phan et al., 2002, pp. 331–348; Sergerie et al., 2008, pp. 811–830). As in previous meta-analyses (Diekhof et al., 2011, pp. 275–285; Buhle et al., 2014, pp. 2981–2990; Kohn et al., 2014, pp. 345–355), the observed increased activation in areas of the voluntary attentional system is consistent with the neurobiological model of reappraisal, which views it as a controlled process involving executive functions and working memory (Ochsner and Gross, 2005, pp. 242–249). Furthermore, the decreased activation of limbic areas may be interpreted as diminished arousal following regulation (Banks et al., 2007, pp. 303–312; Wager et al., 2008, pp. 1037–1050). Together with these results regarding the voluntary attentional system, the meta-analyses also detected activations of areas that are considered part of the semantic system, such as the temporal lobe, inferior frontal gyrus and angular gyrus (Patterson et al., 2007, pp. 976–987; Binder et al., 2009, pp. 2767–2796). Despite also these results have been observed in previous meta-analyses (Diekhof et al., 2011, pp. 275–285; Buhle et al., 2014, pp. 2981–2990; Kohn et al., 2014, pp. 345–355), the importance of their contribution to emotion regulation has been neglected in neurobiological models of reappraisal.

In the present study, the separate consideration of RS and RPT strategies allowed us to observe the different prominence

TABLE 3 | Significant clusters of brain activity in RS and (A,B) and reappraisal via perspective-taking (RPT; C,D).

Cluster	Areas	Talairach coordinates			Brodmann's areas	Cluster size (mm^3)	ALE score
		x	*y*	*z*			
(A) Reappraisal of stimuli versus control task ($p < 0.01$, FDR correction)							
(1)	Inferior frontal gyrus/middle frontal gyrus	44	26	0	13/47/45	1232	0.034
(2)	Medial prefrontal cortex/dorsal anterior cingulate	6	20	44	6/8	744	0.016
(3)	Dorsolateral prefrontal cortex	−40	12	44	6/8/9	704	0.018
(4)	Inferior frontal gyrus	−46	26	−6	47/45	544	0.021
(5)	Medial prefrontal cortex/dorsal anterior cingulate	−8	14	46	32/6/8	400	0.016
(6)	Middle temporal gyrus	−56	−38	−4	20/22	304	0.014
(7)	Angular gyrus/middle temporal gyrus	−46	−66	32	39	264	0.015
(B) Control task versus reappraisal of stimuli ($p < 0.01$, FDR correction)							
(1)	Parahippocampal gyrus/amygdala	−22	−8	−12	34	472	0.016
(2)	Parahippocampal gyrus/amygdala	16	−8	−12	34/28	360	0.011
(C) Reappraisal via perspective-taking versus control task ($p < 0.01$, FDR correction)							
(1)	Inferior parietal lobule/angular gyrus	50	−56	36	39/40	696	0.018
(2)	Superior temporal gyrus/ middle temporal gyrus	−58	−34	6	22/42	320	0.016
(D) Control task versus reappraisal via perspective-taking ($p < 0.01$, FDR correction)							
(1)	Parahippocampal gyrus/amygdala/putamen	−26	−2	−14	34	848	0.021
(2)	Parahippocampal gyrus/amygdala	16	−6	−12	34/28	456	0.021
(3)	Parahippocampal gyrus/thalamus/hippocampus	−22	−28	−4	27/28	352	0.016

ALE, activation likelihood estimation; FDR, false discovery rate.

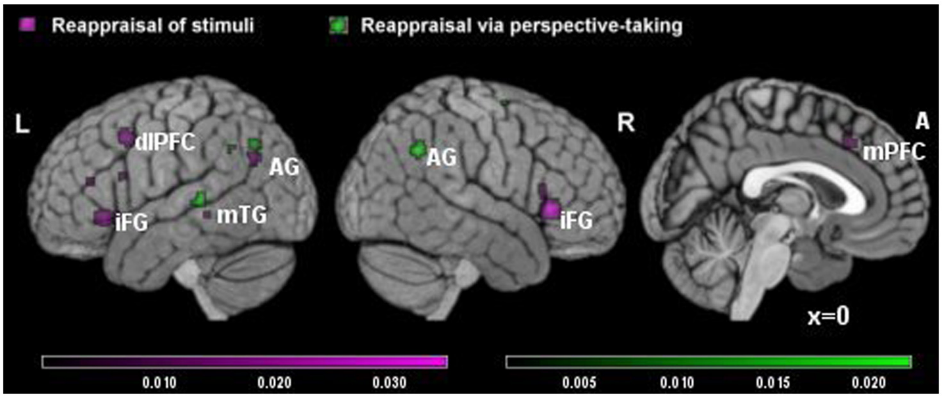

FIGURE 2 | Brain activity in reappraisal of stimuli and reappraisal via perspective-taking. In violet increased brain activity during RS; in green increased brain activity during reappraisal via perspective-taking. mPFC, medial prefrontal cortex; dlPFC, dorsolateral prefrontal cortex; iFG, inferior frontal gyrus; mTG, middle temporal gyrus; AG, angular gyrus.

of executive and semantic areas in the reappraisal strategies. We observed that areas of the voluntary attentional system were activated in RS strategy but not in RPT. Specifically, in the analysis in which these two strategies were directly compared a significant cluster of increased activation located in the dorsomedial/anterior cingulated cortex differentiated activations in RS from RPT reappraisal. These results suggest that the RPT strategy may rely less on executive control than RS, suggesting that executive functions might be not as essential for emotion regulation as previously thought (Ochsner and Gross, 2008, pp. 153–158; Ochsner et al., 2012, pp. E1–E24).

Several considerations support this conclusion. According to the models of reappraisal as a form of cognitive control (Ochsner and Gross, 2005, pp. 242–249; DeRubeis et al., 2008, pp. 788–796), the involvement of voluntary attention in RS should be associated with increased effectiveness in emotion regulation. However, this association was not observed in the meta-analysis, where the different involvement of prefrontal areas in RS and RPT did not correspond to different outcomes in terms of limbic activation (both strategies were associated to similar decrease in amygdala activity). These results are not surprising in the light of behavioral data to the effect that both RS and RPT are similar in reducing emotional response to unpleasant stimuli (Deveney and Pizzagalli, 2008, pp. 435–444; Webb et al., 2012, p. 775). In one study RPT was even more effective in this regard, whereas RS was more likely to maintain subjective experience and facial expression associated to the emotion elicited by the experimental stimuli (Shiota and Levenson, 2012, p. 416). Due to the absence of evidence on differences in effectiveness of the reappraisal strategies considered in the present study, the variable involvement of executive functions in RS compared to RPT may simply reflect a difference in the amount of cognitive effort required by each strategy. Neuroimaging studies of working memory have reported progressive activation of areas of the voluntary attentional system in association with the cognitive demands required by the task (Rypma et al., 2002, pp. 721–731). Reappraisal may involve working memory when a cognitive effort is required, but this effort may be reduced when the strategies adopted to regulate are less demanding (Jansma et al., 2001, pp. 730–743). Furthermore, other studies report the existence of implicit forms of emotion regulation, in which emotion are regulated without voluntary attempts to control them (Mauss et al., 2007, pp. 1–18; Koole and Rothermund, 2011, pp. 389–399). The few existing neuroimaging studies on implicit forms of emotion regulation have shown that the areas of the voluntary attentional system are not recruited (Viviani et al., 2010, p. e15454) and do not correlate with individual differences in spontaneous avoidance (Benelli et al., 2012, p. 239).

In contrast to the inconstant recruitment of the voluntary attentional network, the activation of semantic areas emerged as a common aspect of emotion regulation despite of the specific strategy adopted by participants. How do semantic processes contribute to emotion regulation? The presence of specific semantic content may have a role in the effectiveness of reappraisal. It is conceivable that the existence of a wealth of semantic representations that one can activate in order to reappraise emotional stimuli facilitates the generation of alternative representations of what happened. Instead, a person with poor semantic representations of contingencies related to emotionally arousing situations may have more difficulties in using semantic information to reappraise emotional stimuli. For example, black/white thinking in borderline patients may be related to their difficulties in generating mentalizing appraisals of other people's possible motives, a form of knowledge that is based on semantic memory for social interactions (Irish et al., 2014, pp. 1241–1253). Due to the evidence that semantic activation may play a role in emotion regulation regardless to the involvement of executive functions, our hypothesis is that semantic processes may involve different kind of attentional processes. In studies on spatial attention (Corbetta and Shulman, 2002, pp. 201–215; Chica et al., 2013, pp. 107–123), a ventral attentional network has been described that is activated when attention is directed spontaneously to stimuli that are behaviourally relevant, regardless the voluntary attempt of participants to direct their attention to this stimuli and regardless to the salience of this stimuli, but is also recruited in studies in which top–down control of emotional stimuli is required (Corbetta et al., 2008, pp. 306–324). Such network includes the temporo-parietal junction observed in RS and RPT studies meta-analyzed in the present study.

In the context of emotion regulation, the ventral network may influence emotion regulation by conveying the influence of semantic networks due to the intervention of a proactive mechanism of control on the emotional representations (Viviani, 2013). Because emotion regulation strategies such as spontaneous avoidance (Viviani et al., 2010, p. e15454; Benelli et al., 2012, p. 239) or acceptance (Kross et al., 2009, p. 361–366) also appear to recruit these areas, there is room in future studies for investigating forms of emotion regulation not based on cognitive control to enrich emotion regulation models and to clarify the adaptive value of emotion regulation strategies.

Limitations

Several limitations of the present study should be noted. First, the majority of the studies which have investigated emotion regulation have used ROIs approach. The *a priori* definitions of ROIs may bias the detection of cerebral areas in emotion regulation literature, as the effects in ROIs that were defined *a priori* are likely to be overrated (Diekhof et al., 2011, pp. 275–285). Secondly, many of the studies investigating reappraisal used quite generic instructions that did not allow us to classify the specific strategies under investigation. This limitation had the consequence to reduce the number of studies included in meta-analyses of specific strategies. Third, we cannot exclude that participants were using the strategy of distracting themselves from the experimental stimuli (despite the instruction provided by experimenters). For example, if self-distraction involved the generation of alternative verbal material, then it would be expected to be associated with the activation of semantic areas, which has been detected in words generation tasks (Petersen et al., 1989, p. 153–170). However, as we noted in Section "Discussion," the ready availability of appropriate alternative semantic content may be an important factor in the effectiveness of reappraisal also when following the strategy of "thinking of something else." Hence, an important message of the present paper is that semantic activation may play a role in emotion regulation regardless of the involvement of executive functions. Future studies may define more carefully the specific reappraisal strategy under investigation. Because of the small number of studies included in meta-analyses of specific strategies, their results should be considered as explorative, but not conclusive.

Conclusion

Both executive and semantic aspects of emotion regulation were found to be involved in functional imaging studies of emotional reappraisal, but with a different pattern according to the reappraisal strategy. In reappraisal of emotional stimuli, executive functions were found to be recruited in the meta-analysis, even if also semantic areas were activated. Instead, in RPT the most important clusters of brain activity were found on parietal and temporal semantic areas, similarly to less adaptive strategies such as suppression or avoidance. This heterogeneity suggests that executive functions are just one aspect of emotion regulation, and that their relevance may depend on the specific reappraisal strategy adopted by participants, including the depth of semantic encoding and the use of semantic networks.

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Emotional expressions beyond facial muscle actions. A call for studying autonomic signals and their impact on social perception

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Humans are well adapted to quickly recognize and adequately respond to another's emotions. Different theories propose that mimicry of emotional expressions (facial or otherwise) mechanistically underlies, or at least facilitates, these swift adaptive reactions. When people unconsciously mimic their interaction partner's expressions of emotion, they come to feel reflections of those companions' emotions, which in turn influence the observer's own emotional and empathic behavior. The majority of research has focused on facial actions as expressions of emotion. However, the fact that emotions are not just expressed by facial muscles alone is often still ignored in emotion perception research. In this article, I therefore argue for a broader exploration of emotion signals from sources beyond the face muscles that are more automatic and difficult to control. Specifically, I will focus on the perception of implicit sources such as gaze and tears and autonomic responses such as pupil-dilation, eyeblinks and blushing that are subtle yet visible to observers and because they can hardly be controlled or regulated by the sender, provide important "veridical" information. Recently, more research is emerging about the mimicry of these subtle affective signals including pupil-mimicry. I will here review this literature and suggest avenues for future research that will eventually lead to a better comprehension of how these signals help in making social judgments and understand each other's emotions.

Keywords: affect, pupil size, facial reddening, tears, contagion, synchronization, impression formation

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Introduction

Imagine how different life would be if we were unable to recognize another's expressions and from that, infer or even *feel* how the other must be feeling? During interactions with others, we automatically make use of another's facial expressions and bodily signals and use that information to contextualize what is being said. Often, we are not aware of being influenced by these signals, except when they are absent from a "conversation," for example during email or phone (mis)communication. Modern communication media aim for making conversations as natural as possible. However, even a Skype-conversation which from all communication media best simulates a natural interaction, does not even approach the richness and quality of real face-to-face interactions. One key limitation of Skype is that it is impossible to make eye-contact. Making eye-contact over Skype would require both interaction partners to look into the camera (and miss out upon each other's eyes). **Table 1** gives an overview of the various cues available in different communication mediums. In this review I will focus on the visual domain and on the face alone (columns E and F in **Table 1**) and explain how humans use a variety of sources from others' facial signals during natural interactions.

Emotion processing is a broad and general term that refers to a complex of affective, behavioral and cognitive mechanisms that underlie our emotions. Given the impact of our emotions on a wide range of mental processes (e.g., perception, impression formation, decision making, memory) and manifest behaviors (e.g., helping or aggressive and abusive behavior), being able to recognize and regulate our emotions is of crucial importance and an essential feature of mental health (Kret and Ploeger, 2015).

During social interaction, interaction partners continuously express and regulate emotional states and simultaneously process affective cues expressed by the other. They orient to their partner's tractable characteristics, such as facial or bodily features and emotion expressions. By attending to the stream of subtle dynamic facial reactions during an interaction, they "feel themselves into" the emotional landscapes inhabited by their partners; they rely on, and are influenced by implicit signals from their partner's face that are autonomic and not under someone's control, yet reflective of his or her emotions and intentions (Hatfield et al., 1994). This interchange of emotion processing influences impressions that are formed during a social interaction.

Figure 1 shows how *emotions* that are expressed during a social interaction by Person A, through emotional *contagion*, influence the emotions and expressions of Person B. Person A and B not only mimic each other's facial expression, they also link on the physiological level and without being aware of it, synchronize on the level of arousal. Whereas they from time to time may "force" social smiles when considered appropriate (this is where '*cognition*' comes into play), they have no or very little control over their autonomic responses such as blushing, sweating and pupil dilation which may nonetheless spread to the other person. Emotions and feelings, the extent to which they are expressed and converged with, together with cognitive processes influence how the other person is perceived. I call this '*social perception,*' which includes impressions, beliefs about how the other person is feeling, trust, liking etc.

The fact that emotions are not just expressed by the face and its muscle actions alone is often ignored in emotion perception research. In this article, I therefore argue for a broader exploration of emotion signals from sources beyond the face muscles that are more difficult to control. More specifically, I will focus on the perception of implicit sources that may be equally salient and familiar in daily life such as eye-gaze, pupil-dilation, eyeblinks, blushing and sweating. Although these cues may be subtle, they are visible to observers and may add to the perceived intensity of an emotional expression, or to its perceived genuineness. But prior to discussing these autonomic responses, I will review the literature on facial emotion perception.

Emotions Shown by the Whole Face

Expressions of emotion have evolved not only to move blood and tears in the service of emotions, but also to provide us with a rich set of tools that help us communicate and signal the nature of our internal emotional experiences so that we can call on others empathy and receive help.

Emotions Expressed by Face Muscles

Humans are experts at processing faces. They can recognize the identity of 1000s of individual faces and in addition quickly decode a variety of emotional expressions. Like the face itself, facial expressions of emotion may be processed configurally, a processing style that presumably enables speed and efficiency (Tanaka and Farah, 1993). The hallmark of this processing routine is the inversion effect, i.e., the impaired recognition performance when a face is shown upside down (Yin, 1969; for a review, see Maurer et al., 2002). Inversion appears to weaken or remove emotion category boundaries along continua of morphed stimuli and it has therefore been argued that the categorization of facial expressions draws upon configural information (de Gelder et al., 1997). It has also been proposed that categorical processing can be based on features, for example for happy expressions with the salient mouth curvature feature or for fearful faces with the display of eye-white, and, thus, precede affective attribution at the stage of configural processing (Calvo et al., 2012). This might explain why inversion has no effect when facial expressions are

TABLE 1 | Cues available in different communication mediums.

Medium	(A) Literal Message	(B) Shared environment	(C) Auditory	(D) Other sensory cues	(E) Facial expression	(F) Eye contact	(G) Body language
Real life	✓	✓	✓	✓	✓	✓	✓
Skype	✓	–	✓	✓	✓	–	✓/–
Phone	✓	–	✓	–	–	–	–
Email	✓	–	–	–	–	–	–

Depending on the type of communication medium, more is transmitted than just the literal, "cold" message (A). Apart from interfering visual or auditory delays, one large difference between real life interactions and interactions via other mediums is the being versus not being in the same environment, both in terms of time and place (B). In addition, during email contact, one misses out upon important auditory cues such as the tone of voice of the interaction partner, and his intonation or use of sarcasm which might change the meaning of the literal message (C). Apart from auditory cues, other sensory information such as smell and touch might impact on how the literal message is transferred and interpreted (D). The face, its expression and autonomic signals that are visible in it provide important cues about the emotional state of the interaction partner such as intensity or genuineness (E). Eye-contact is very important during interactions and is impossible via modern communication mediums (F). Body language and autonomic signals visible from the body reveal important emotional information (G).

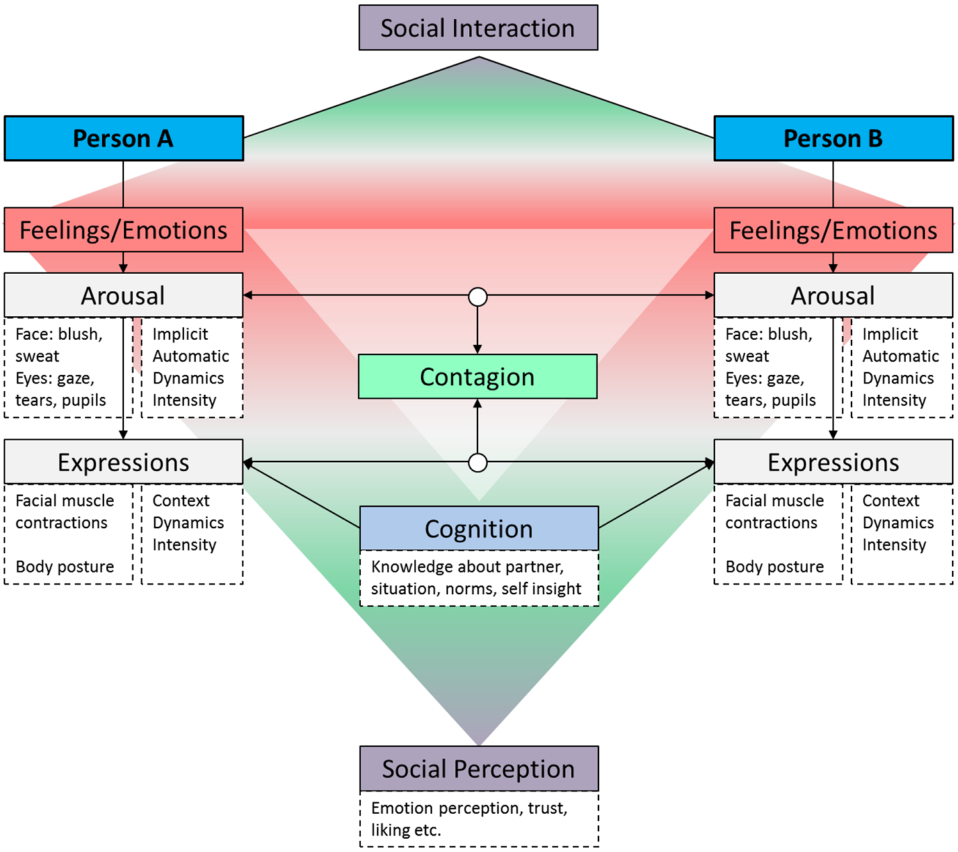

FIGURE 1 | Schematic representation of emotion processing during a social interaction.

employed in a visual search task (Lipp et al., 2009; Savage and Lipp, 2014).

The many distinct facial expressions of emotions can be accurately encoded with aid of the facial action coding system (FACS; Ekman and Friesen, 1978). This anatomically based system segments the visible effects of facial muscle activation into “action units” (AUs). Each AU relates to one or more facial muscles. FACS describes facial activity on the basis of 33 unique AUs. This system not only helped in developing standardized stimuli sets of facial expressions of emotion [for example JACFEE (Biehl et al., 1997) and Ekmans pictures (Ekman and Friesen, 1978)], but also resulted in the development of automated facial expression recognition software.

Emotional expressions, facial expressions included, are highly contagious. It has been suggested that facial mimicry, i.e., the imitation of others’ facial displays by an observer, plays an important role in the communication of affective states. Evidence exists that mimicry accompanies the perception of a facial expression (Dimberg, 1982; Bush et al., 1989). The mere observation of a facial expression can also evoke the corresponding emotion in perceivers (Berger, 1962; Bandura and Rosenthal, 1966; Hygge, 1976). Other research shows that mimicry can be involved in the detection of change in facial expressions of emotion. Specifically, evidence suggests that individuals detect changes in the facial expression of another person through the feedback, and perhaps change in subjective state, caused by facial mimicry (Zajonc et al., 1987; Wallbott, 1991; Niedenthal, 1992; see also Niedenthal and Showers, 1991). Facial mimicry can occur unconsciously and has for example been observed in response to subliminally presented pictures and in cortically blind patients (Dimberg et al., 2000; Tamietto et al., 2009).

The majority of emotion studies make use of prototypical static facial expressions in their experimental paradigms which in fact are fairly impoverished representations of facial expressions in real life. In reality, facial expressions are sometimes partly occluded and not fully visible and almost always paired with other expressive signals including prosody and body language that provide a context (for example, see Regenbogen et al., 2012). The perception of facial expressions of emotion is influenced by such context cues. Context, even when it needs to be ignored within an experimental task, can completely shift the emotional category recognized in a facial expression (Meeren et al., 2005; Righart and de Gelder, 2006; Van den Stock et al., 2007; Aviezer et al., 2008; Kret and de Gelder, 2013; Kret et al., 2013a,b). In addition, facial expressions are dynamic by nature, with varying intensity and ambiguous. For brevity I will not further discuss these aspects, although I think it is important to mention that dynamics in facial stimuli are especially important not only to enhance recognition or increase naturalness, but also to create the *impression of an interaction* in observers [a face that slowly starts to smile (video) might be perceived more as a reaction to the participant than an already smiling face (picture)].

In addition to facial actions, there are other ways for the face to reveal emotions than via its muscle movements. When highly emotional, our forehead may show sweat drops, our cheeks may blush, our eyes may tear and our pupils may dilate. All these automatic and autonomic reactions are not specific for one particular emotion and may also occur when in pain or during sport. Importantly, they may also happen during an emotional experience, and because they are much *harder to control* than our facial muscles, and *are visible to others*, they might add to the perceived intensity of a facial expression or even overrule the emotion signal the facial muscles try to reveal. Not much is known about how these autonomic reactions or signals impact on emotion perception and whether they can modulate or even change the perception of facial expressions, and provide a context. For example, it is possible that a person with an angry, reddened face and sweat pearls on his forehead is perceived as more intensely angry than a person without these signs of arousal. See **Figure 2**.

Facial Reddening

Facial redness is associated with the perfusion of the skin with oxygenated blood. Research shows that facial redness is sexually dimorphic (men are slightly redder than women; Edwards and Duntley, 1939; Frost, 1994), and is strongly androgen-dependent in men (Jeghers, 1944). Moreover, increased skin blood perfusion is related to health and is enhanced by physical training (Johnson, 1998) and reduced in different patient groups (Richardson, 1987; Panza et al., 1990; Charkoudian, 2003). Skin redness enhances the healthy appearance of faces, also in dark-skinned people (Stephen et al., 2009). A recent study examined whether one's own positive and negative emotions affect how healthy we perceive our own face to appear as compared to how others faces appear. Participants reported on their own affective state and then judged their own face, either healthy (red-tinged) or unhealthy looking (green-tinged) against stranger's faces. Results show that participants high in negative affectivity judged themselves as equivalent to less healthy looking versions of their own face and a stranger's face (Mirams et al., 2014).

FIGURE 2 | Expressing anger. The face on the right is reddened (except for the eyes and teeth) and shows drops of sweat. How these expressions of autonomic arousal impact on the perception of the emotional facial expression is not known.

In addition to a healthy appearance, facial redness may also signal emotionality. Anger, for example, also increases the blood flow to the face (Drummond and Quah, 2001; Montoya et al., 2005). Stephen et al. (2012) asked a group of women to manipulate pictures of men's faces to make them as attractive as possible. Women in this study made the skin tone redder and even added more red when asked to make the men look more dominant. However, it was also observed that the women associated very red faces with aggression. Clearly, these studies suggest that redness is associated with health, physical dominance and anger or aggression, and someone with reddened cheeks will likely be perceived as dominant, angry or aggressive. However, facial redness might also reflect shyness in the form of blushing.

Many socially anxious individuals are anxious about blushing and regard it as the cause of their social difficulties rather than as a symptom of them. Although there is a lot of research on why, when and who blushes (Leary et al., 1992), there is no research on how blushing is actually perceived by others. Dijk et al. (2011) examined whether blushing after a sociomoral transgression remediates trustworthiness in an interdependent context. In their study, participants played a computerized prisoner's dilemma game with a virtual partner who defected in the second round of the game. After the defection, a picture of the opponent was shown, displaying a blushing (reddened) or a non-blushing face. In a subsequent trust-game, participants invested more money in the blushing opponent than in the non-blushing opponent. In addition, participants indicated that they trusted the blushing opponent more, that they expected a lower probability of future defeat, and judged the blushing opponent in general more positively.

Above research indicates that the redness of a face impacts on observers' social judgments. However, exactly *how* a red face is interpreted ("shy blushing," "angry," more ambiguously "aroused" or simply "hot") is unsure and deserves further investigation and experimental control. Another avenue for future research is to use dynamic morphs from normally colored to slightly reddened faces and to manipulate the redness of the face so that the observers get the impression that the reddening of the face is a reaction to them, as in social interaction. In addition, it would be interesting to test whether humans would mimic or synchronize with such changes in color in their own face, which could be predicted based on previous research showing that people synchronize their level of arousal (Levenson and Gottman, 1983; Feldman et al., 2011; Cooper et al., 2014).

Emotions Shown by the Eyes

Among the many implicit cues that may inform assessments of someone's internal state, the human eye region stands out as salient and powerful. Especially during short distance intimate interactions, both infants and adults focus on their interaction partner's eyes, grasp emotion signals and follow gaze (Baron-Cohen, 1997; Driver et al., 1999; Farroni et al., 2002; Macrae et al., 2002).

Eyes and Gaze-Direction

The eyes are richly informative and important for understanding emotion and communicative intention of other individuals (Emery, 2000). Emotion-driven complex musculature contractions such as the raising of the eyebrows in fear enables observers to decode emotions from just the eye region (Baron-Cohen, 1997). The eye region captures more attention than other areas of the face in adults (Janik et al., 1978; Adolphs et al., 2005) as well as in infants (Haith et al., 1977) and this bias may reflect an innate predisposition (Argyle and Dean, 1965). In view of the importance of the eye region, one may predict that information from the eyes is robust such as to resist influence from the surrounding context. We often only see the eyes because items such as caps, hats, helmets, medical masks, beards or headdresses hide the rest of the face. Whether the perception of the expression of the eyes is sensitive to such visual context cues is a question that has hardly ever been asked.

There is some evidence that emotion categorization from the eye region is a process that is triggered automatically and unconsciously in a bottom–up fashion on the basis of the information available from the position of the eyebrows (Sadrô et al., 2003; Leppänen et al., 2008) and the visibility or display of eye white (Whalen et al., 2004). However, other research suggests that it is too early to rule out that context does play a role in the perception of expressions from the eyes. For example, Kret and de Gelder (2012) investigated how briefly presented angry, fearful, happy, and sad expressions were recognized when presented in different contexts including Islamic headdresses, a cap or a scarf. Results show that participants (all with a non-Islamic background) were better at recognizing fear from women wearing a niqāb as compared to from women wearing a cap and a shawl. An opposite effect was found for expressions of sadness and happiness. Furthermore, response patterns showed that 'anger' and 'fear' were more often chosen when the observed woman wore a niqāb as compared to a cap and a shawl. An opposite pattern was again found for the label 'happy.' Islamic cues triggered negative associations with the Islam, which influenced how emotions from the eyes were perceived. In line with the face literature this study shows that the recognition of emotional expressions from the eyes is also influenced by context.

Direct eye gaze captures and holds visual attention more efficiently than averted gaze and signals an expressor's approach-avoidance behavioral tendency (Stern, 1977; von Grünau and Anston, 1995; Conty et al., 2010; Palanica and Itier, 2012; Böckler et al., 2014). Baron-Cohen (1995) states that this innate capacity to process gaze direction plays an important role in the development of a 'Theory Of Mind.'

Gaze direction of an expressor also impacts on how observers perceive an expressed emotion. Adams and Kleck (2003) showed that expressions of anger and happiness were easier identified when presented with direct versus averted gaze, whereas fear and sadness expressions were more quickly labeled when presented with averted than with direct gaze. In a fear-conditioning experiment, Wieser et al. (2014) did not find an interaction between gaze direction and emotional expression either in terms of visually evoked steady-state potentials amplitude or affective ratings. This research underscores the importance of incorporating gaze direction in future work on facial expression perception.

Recent research has shown that social cognition including emotion perception is fundamentally different when we are engaged with others in real-time social interaction with eye-contact ('online' social cognition), rather than merely observing them ('offline' social cognition; e.g., Pfeiffer et al., 2013; Schilbach et al., 2013). The time has come to study emotion perception during real interactions between two participants as the mechanisms underlying actual social interactions in real life are insufficiently understood.

Eyeblinks

Apart from social interest or attention that may be inferred from gaze cues, research suggests that humans are also sensitive to another's eyeblinks. Humans spontaneously blink every few seconds. Eyeblinks are necessary to moisturize the eye, but occur more frequently than necessary. The spontaneous eye blink is considered to be a suitable ocular indicator for fatigue diagnostics (Stern et al., 1984) and reflects the influence of central nervous activation without voluntary manipulation (Blount, 1928; Ponder and Kennedy, 1928). Nakano et al. (2009) showed that spontaneous blinks synchronized between and within subjects when they viewed short video stories. Synchronized blinks occurred during scenes that required less attention such as at the conclusion of an action, during the absence of the main character, during a long shot and during repeated presentations of the same scene. In contrast, blink synchronization was not observed when subjects viewed a background video or when they listened to a story that was read aloud. The results suggest that humans share a mechanism for controlling the timing of blinks that optimizes the processing of critical information, in order to not miss out on important information while viewing a stream of visual events. In a next study, Nakano et al. (2013) show that eyeblinks are involved in attentional disengagement. Authors demonstrated that during cognitive load, eyeblinks momentarily activate the brain's default-mode network, while deactivating the dorsal attention network. It is thus far unknown whether the observation of eyeblinks in another person influences how that person is perceived.

Tears

Crying is a typically and, as far as known, uniquely human form of emotional expression. This phenomenon is controlled by the sympathetic and the parasympathetic nervous system, the latter being responsible for the tears (Botelho, 1964). Recent research has offered several accounts of how tears may have become adaptive over the course of evolution. Two main functions of crying have been distinguished, namely (i) tension relief and promoting the recovery of psychological and physiological homeostasis, and (ii) communication. Thus, on the one hand crying may impact on psychobiological processes in the individual and facilitate the physiological and psychological recovery after distress but on the other hand it may elicit positive or negative reactions from the social environment (Hendriks and Vingerhoets, 2002). For example, Hill and Martin (1997) observed that crying female confederates were more sympathized with than non-crying confederates. The results of this study suggest that crying may communicate the need for emotional support and help and calls on empathy. Crying is very contagious. Even newborn children may spontaneously start crying when they hear other children cry (Simner, 1971). It has been argued that empathy is related to the capacity to react to and mimic emotional others. In line with this argument, Wiesenfeld et al. (1984) observed that highly empathic women were more likely to react with a corresponding facial reaction when observing crying infants.

Research has shown that tears are an important visual cue that add meaning to facial expressions. Provine et al. (2009) and Zeifman and Brown (2011) have demonstrated that tears are helpful to identify sadness and to perceive a need for help and comfort. Similarly, Balsters et al. (2013) show that tears increase the accurate recognition of sadness and also the extent to which the displayed crying persons were in need of social support. Interestingly, in this last study, images were shown for just 50 ms, demonstrating the strength of tears even at an early pre-attentive level.

One consequence of crying is that the eyes redden. Although research on the perception of sclera color exists, this is mostly focusing on perceived health, age and attractiveness. For example, faces with artificially reddened sclera are rated less attractive (Provine et al., 2011). Whether red eyes also impact on the perception of a facial expression is an open question.

The Perception of Another's' Pupil-Dilation

Pupil size is an interesting social signal because it cannot be controlled or faked, in contrast to features such as eye gaze and facial expression and reflects much more than changes in light, namely, our inner cognitive and affective state (Bradshaw, 1967). Precisely because pupil changes are unconscious, they provide a veridical reflection of the person's inner state.

Hess (1975) was the first to recognize the social potential of pupil dilation. In one study, he presented a group of men a series of pictures of which two showed an attractive young woman. One of them had been retouched to make the woman's pupils larger and the other smaller than the original version. Interestingly, participant's pupil response to the picture with the large pupils was larger than to the one with small pupils. Despite being unaware of the manipulation, participants liked the woman with the large pupils better, describing her as "more feminine," "prettier," and "softer" than the woman with small pupils (Hess, 1975; **Figure 3A**). In order to control for possible effects of luminance, in a later study, Hess created schematic eyes that consisted of a circle with a small, medium or large black dot in the middle. The circles were presented in isolation, in pairs with equally sized black dots, or with three of those in a row. Participants observed these stimuli whilst their pupil size was measured. Hess observed that both male and female participants showed the greatest pupil response to the 'eye-like' pair with the large black dot in the middle, an effect that could not be explained by luminance (Hess, 1975).

Later research replicated this early work and showed that pupillary changes are indeed picked up by observers and influence assessments: partners with large pupils are judged positive and attractive, and those with small pupils cold and distant (Demos et al., 2008; Amemiya and Ohtomo, 2012).

Kret et al. (2014) suggest that this positive association with large pupils is formed *through* pupil-mimicry. Within a close social interaction, mutual pupil dilation might indicate and reinforce social interest and liking. In their study, human and chimpanzee subjects viewed the eye region of both species. In this eye region, the stimulus pupils were manipulated to dilate or constrict dynamically, suggesting a response in view of the participant, as in an interaction. Results show that pupil-mimicry is not uniquely human, but has also been observed in chimpanzees. Even more interestingly, the phenomenon was restricted to within-species interactions (i.e. humans with humans, and chimpanzees with chimpanzees). It should be noted that the human participants in this study were mostly Japanese with pupils hardly distinguishable from their dark irises. Even in them, pupil-mimicry occurred, which is in line with the great importance of pupil size in the Japanese culture. As in Disney figures, good and bad cartoon characters in Japanese Manga are characterized by large and small pupils respectively.

The study by Kret et al. (2014) suggests that apart from passively reflecting inner states, pupils have a social signaling function and provide a basic form of communication between members of one's own species. A more recent study further supports that idea. Kret et al. (2015; **Figure 3B**) observed that participants not only synchronized their pupil size with the pupil size of their virtual partner, but that this also helped them to trust that partner. More precisely, in their study, they used eye-images of Dutch and Japanese students and presented these to Dutch students. The pupils within these images dilated, constricted, or remained static. Whereas pupil dilation mimicry was amplified in interactions with the Dutch partners (who were considered closer to the in-group than the Japanese partners), pupil-constriction mimicry was stronger with the Japanese partners. Interestingly, a link was observed between pupil dilation mimicry and trust in Dutch, but not Japanese partners. Whether pupil-mimicry impacts on real interactions is unsure; pupils are prone to changes in ambient light and as mentioned earlier, are not equally visible in all individuals or circumstances. However, the fact that pupils have such profound effects in lab studies with virtual partners demonstrates their large potential in future live interaction studies with two participants.

Conclusion

During social interactions, humans willingly and unwillingly express their emotional state through facial muscle movements

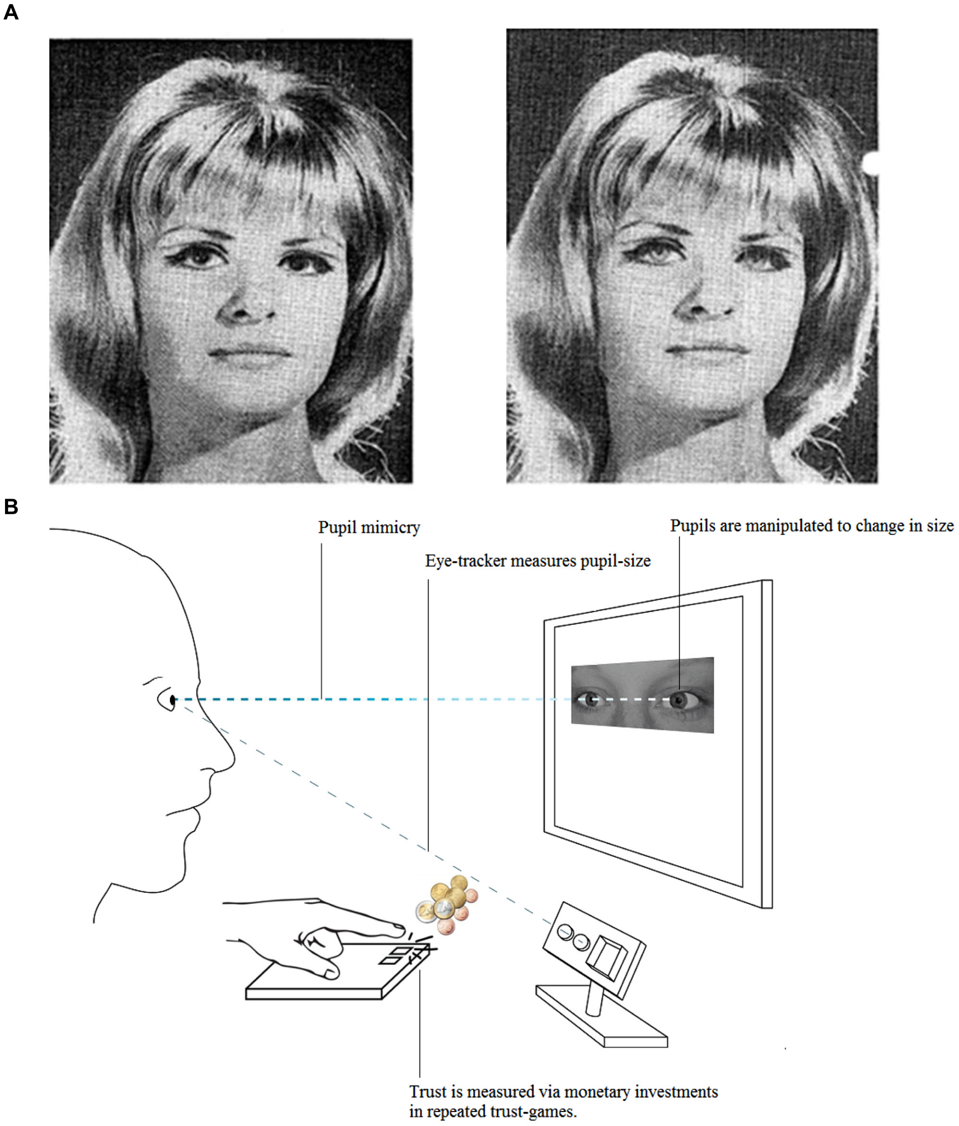

FIGURE 3 | Observed pupil size impacts on social evaluations. **(A)** The woman on the left is judged positive and attractive, and the one on the right with small pupils, as cold and distant. Picture is taken from Hess (1975). **(B)** A partner with dilating pupils is better trusted than a partner with static or constricting pupils, especially when the participant (on the left) synchronizes his own pupil size with the observed partner. Visual representation of the experimental setup of the study by Kret et al. (2015).

but also via other channels including pupil-dilation, eyeblinks and blushing. Over the course of human evolution, it became adaptive to not only perceive and be aware of emotions in one self, but also to process emotions including these implicit cues of others. Such perceptual abilities insure smooth interpersonal cooperation, for example by permitting the monitoring of expressions of fear and facilitating quick actions in response to environmental threat. In the past century, research on this topic has accumulated steadily and shown that humans, from early age on, respond to the emotions of others, empathize with them, and are very good at distinguishing between different expressions of emotion (i.e., Izard, 1971; Ekman and Friesen, 1982). The majority of this research has focused on the perception of pictures of faces showing prototypical, intense and unambiguous emotional expressions. Research has for example shown that humans mimic facial expressions (Dimberg, 1982) and according to the theory of emotional contagion, this might even improve emotion recognition (Hatfield et al., 1994).

At the beginning of this article, I noted the importance of context in the perception of emotions from the face. Emotions as displayed in the face are perceived in the context of the person's body posture and the social emotional scene context (Kret and de Gelder, 2010). Clearly, the studies that did take these factors into account show that the percept of a face can change as a function of these contextual factors (Meeren et al., 2005; Righart and de Gelder, 2006; Van den Stock et al., 2007; Aviezer et al., 2008;

Kret et al., 2013a,b). Also, emotions seen from just the eye region appear different, depending on what is visible around the eyes such as various types of clothing including caps, scarves and Islamic headdresses (Kret and de Gelder, 2012). My argument that autonomic expressions of arousal such as pupil dilation are less prone to cognitive control than facial expressions does not imply that they are not sensitive to contextual factors. On the contrary, pupil-mimicry for example, a phenomenon individuals are absolutely unaware of when doing it, is enhanced in interactions with members of an in-group (other humans and own culture) as compared to members of an out-group (chimpanzees and other cultural and ethnical background; Kret et al., 2014, 2015). I would like to argue that facial expressions of emotion beyond facial muscle actions can provide an additional context for the interpretation of emotional expressions.

When experiencing an emotion, it is not just the facial muscles that communicate that to other individuals. The current article is not the first call for studying 'emotion-signaling sources' beyond the well-known facial muscle movements. Other research has for example stressed the importance of studying the perception of bodily expressions (Dittrich et al., 1996; Pollick et al., 2001; Kret et al., 2011a,b,c, 2013a,b; Sokolov et al., 2011; Krüger et al., 2013). Although facial muscle actions can be unconscious, it is possible to control or regulate them via 'top–down' cognitive processes, yet our verical emotion often speaks through our body (for a review, see de Gelder et al., 2010). While fully acknowledging the importance of that work, I here would like to stress that also within a face there are more verical emotion signals than the signals sent by the facial muscles. Instead, autonomic expressions of arousal are much harder to control and more driven in a bottom-up fashion. For that reason, autonomic expressions might provide implicit insight into another's experienced emotions, and might impact on the perceived intensity or genuineness of the expressed emotion.

To conclude, psychophysiological research has shown that the perception of emotional expressions in another individual triggers autonomic reactions that are for example measurable via electrodes measuring skin conductance (sweat), eye-tracking equipment (fixated attention and pupil dilation), (i.e. Bradley et al., 2008) or thermal imaging (to measure facial heating; for a review, see Ioannou et al., 2014). All these measures, these dependent variables, are in principle *visible* to others, and could serve as independent variables, possibly impacting on the total percept of a person and his emotional expression, its intensity and/or genuineness. The shedding of tears in sadness or joy, the reddening of the face and the pearls of sweat on ones forehead in anger or love, the blushing of the face and averting of gaze in embarrassment or shame, the dilating pupils indicating social interest and trust, happiness or stress are just examples of emotion signals that have received very little attention in the literature. Studying emotion perception beyond the face muscles including the perception of autonomic signals and the synchronization therewith is a promising avenue for future research.

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REVIEW
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Follow the heart or the head? The interactive influence model of emotion and cognition

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The experience of emotion has a powerful influence on daily-life decision making. Following Plato's description of emotion and reason as two horses pulling us in opposite directions, modern dual-system models of decision making endorse the antagonism between reason and emotion. Decision making is perceived as the competition between an emotion system that is automatic but prone to error and a reason system that is slow but rational. The reason system (in "the head") reins in our impulses (from "the heart") and overrides our snap judgments. However, from Darwin's evolutionary perspective, emotion is adaptive, guiding us to make sound decisions in uncertainty. Here, drawing findings from behavioral economics and neuroeconomics, we provide a new model, labeled "The interactive influence model of emotion and cognition," to elaborate the relationship of emotion and reason in decision making. Specifically, in our model, we identify factors that determine when emotions override reason and delineate the type of contexts in which emotions help or hurt decision making. We then illustrate how cognition modulates emotion and how they cooperate to affect decision making.

Keywords: emotion, reason, dual-process, decision making, emotion regulation

> The heart has its reasons which reason does not know.
> —Blaise Pascal

Introduction

What is the distinction between emotion and reason? This question is as old as psychological science itself. Barrett (2012) suggested that emotions were both biologically evident and socially constructed. According to her conceptual act theory (Barrett, 2006, 2013; Barrett and Kensinger, 2010), physical states and actions can be transformed into different emotion expressions under different social contexts. Based on Barrett's concept, we define emotion as a subjective, conscious experience characterized by biological reaction and mental states. When referring to reason, words like logic, analytic or reflective may come to mind. Reason plays a central role in our daily life, especially when we are confronted with different choices, decisions and judgments. According to classic rational decision theories (Kahneman and Tversky, 1979; Hey and Orme, 1994), we define reason as a process in which individuals analyze the pros and cons of the presented alternatives, calculate the utility of different options, and then choose one option that leads to a maximal profit.

The relation between reason and passion has fascinated philosophers for centuries. After Plato and Aristotle, western literature often treated reason as being opposed to emotion. This is the so called dilemma between "the head" (rationality) and "the heart" (emotion). Though, the exact relationship between reason and emotion remains a mystery, our daily experience leaves little doubt that both emotion and reason impact our decision making to a great extent. Decision making is often referred to as a process in which a choice is made after reflection about consequences of that choice. That is, making a decision requires knowledge about facts and values as well as involves the deliberation about consequence of the selected choice (Bechara and Van Der Linden, 2005). One example might help to illustrate the relationship of emotion and reason in decision making. Imagine that you are going to have a summer vacation and you have to choose between destinations A and B. During the decision making process, you firstly analyze the pros and cons of the two locations, and find that destination A is better than destination B. But at the same time, you remember a piece of recent news that there was an airliner crash in destination A. This news makes you anxious and you can anticipate the unpleasantness of the vacation assuming history repeats itself. You may also know that the chances of dying in a plane crash are extremely low and that flying is still incredibly more safe than driving. Eventually, you give up destination A and choose destination B instead. The contribution of both emotion and cognition is undeniable in this situation. However, the exact dynamic interplay between emotion and cognition remains to be fully explored. In this review, drawing on findings from behavioral economics and neuroeconomics, we firstly identify decision contexts in which emotion overrides reason to influence human behaviors and then discuss how cognition regulates emotion as well as how emotion and cognition cooperate to influence decisions. We then propose a novel model, labeled "The interactive influence model of emotion and cognition" (IIEC), to illustrate the relationship between emotion and reason. To note, because both the term "passion" and "emotion" represent humans' subjective feeling and have been used interchangeably (Lazarus, 1996; Kappas, 2011a), then throughout the review we will employ the terms "emotion" and "passion" as well as the terms "reason" and "cognition" in an approximately interchangeable manner.

When Does Emotion Dominate Cognition in Decision Making?

From an evolutionary point of view, emotion has evolved to guide behavioral responses in certain contexts. For example, immediate danger elicits fear, encouraging avoidance of close or looming threat (Mobbs et al., 2010); unfair treatment provokes anger, leading to more rejection even at great cost (Sanfey et al., 2003; Dawes et al., 2012). In this review, we propose that two typical contexts, labeled as "cognition reduction" and "emotion exaggeration," may lead us to make a decision based more on emotion. In cognition reduction, cognitive capability is reduced so that it is less able to exert control over related tasks. Cognition reduction can be observed when information is incomplete (ambiguity), decision time is limited (time constraint), or self-control is impaired (ego depletion). In emotion exaggeration, emotional reaction is greatly enhanced, interfering with cognition and making a passionate response salient. This context can be seen when threat is proximal (proximity), stimuli are self-relevant (social distance), and equal resources are distributed unfairly (social instinct). From an evolutionary perspective, the context of emotion exaggeration creates a pressing need to react to environmental cues (Mobbs et al., 2010). In this section, we will identify the two contexts in which emotion overrides reason to influence decision making and try to explain the underlying mechanism within the reigning framework of dual-process models (Evans, 2008; Keren and Schul, 2009; Kahneman, 2011). Notably, the dual-process models suggest that mental processes are divided into two systems—one "hot" system that is emotional and intuitive, and another "cold" system that is rational and deliberative. The "cold" deliberative system battles against the "hot" intuitive (emotional) system (Seymour and Dolan, 2008). As intuitions are often in the form of emotional responses (Bechara et al., 1997; Monin et al., 2007; Helion and Pizarro, 2015), we then use intuitive process (in contrast to deliberative process) to represent emotional process in the following sections.

Cognition Reduction: When Cognitive Capacity is Weak

Making a decision always requires cognitive resources and self-control. However, when cognitive capacity is weak, which we have labeled "cognition reduction," emotion may overwhelm reason and become more salient in our decision making. In this section, we summarize evidence about how individuals rely more on emotion when cognitive capacity is insufficient in decision settings such as ambiguity, time constraint, and ego depletion.

Ambiguity

Decisions are often required to be made when information is incomplete. Ambiguity refers to the situation where decision makers have no information about the mathematical probabilities of possible outcomes (Huettel et al., 2006). Recent neuroimaging evidence (Hsu et al., 2005; Huettel et al., 2006) suggests that ambiguity engages brain regions such as the orbital frontal cortex (OFC), the amygdala, and the dorsomedial prefrontal cortex (PFC). These regions have been implicated in reacting to emotional information (Critchley et al., 2000; Bechara et al., 2003) and integrating emotion and cognitive input (Critchley et al., 2001).

It seems that ambiguity elicits both a deliberation system (e.g., dorsomedial PFC) as well as an intuition system (e.g., amygdala), showing that reason and passion interplay to influence ongoing behaviors. However, we cannot conclude that emotion and reason are interactive in ambiguous situations because neural system responses depend on the degree of uncertainty. Relative to ambiguous conditions, situations involving clear risk (where the likelihood of different outcomes is expressed with certainty and mathematical precision) engage greater activation of the dorsal striatum (Hsu et al., 2005). The dorsal striatum is implicated in reward prediction (Knutson et al., 2001; O'Doherty et al., 2004), indicating that ambiguity decreases the anticipated reward associated with a decision. Moreover, on the behavioral level, consistent evidence shows that mean response time is faster in ambiguous gambles than in risky gambles (Huettel et al., 2006; Kuo et al., 2009). Taken together, the evidence from research in

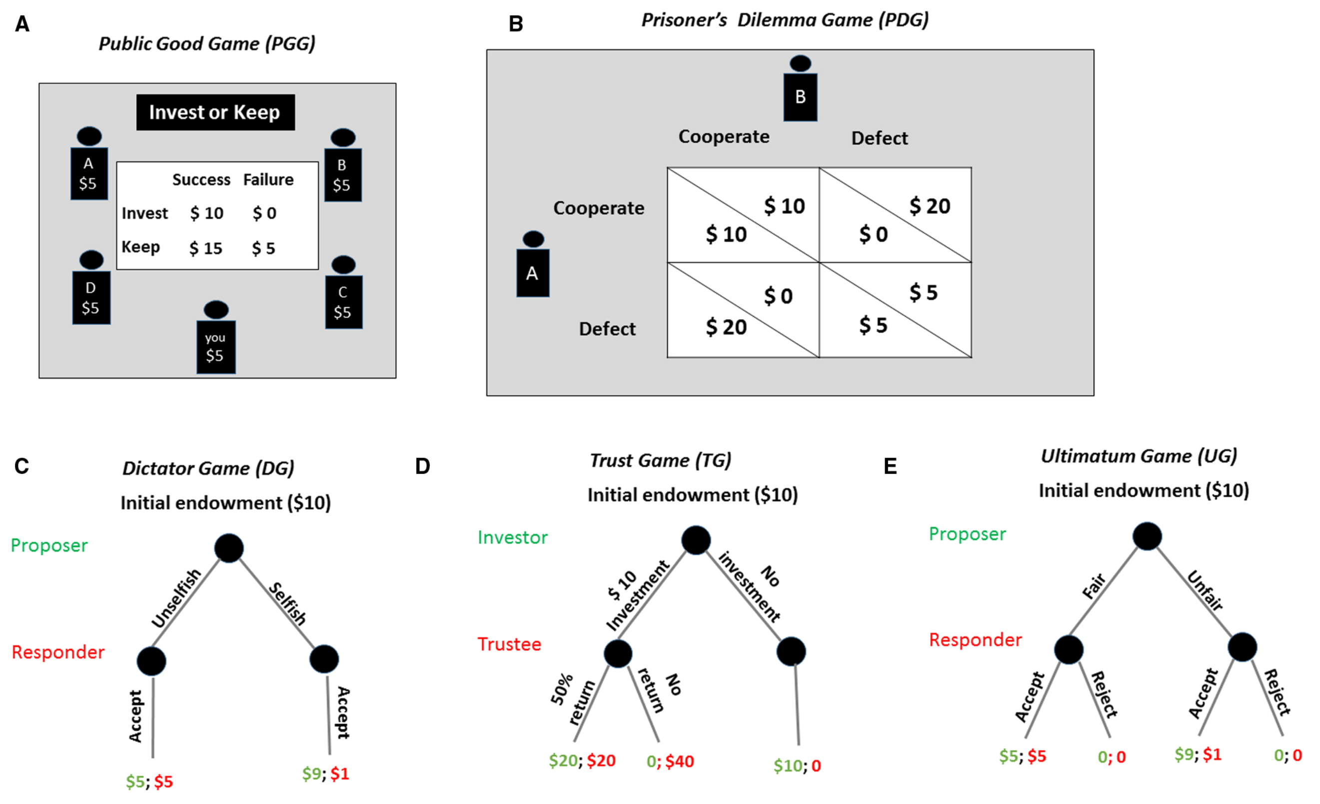

FIGURE 1 | Strategic decision making tasks. (A) The public good game. In this task, subjects are given an amount of money, and they can decide how much to contribute to a common pool. The money contributed would be doubled and split evenly among the group members. **(B)** The prisoner's dilemma game. The players each choose to either cooperate or defect with their opponent. Each player's payoff depends on the interaction of the two choices. For example, the player A can get the largest payoff if he chooses to defect and player B chooses to cooperate, while the worst outcome occurs when he decides to cooperate but his partner defects. **(C)** The dictator game. The proposer determines a split of a certain endowment. The responder simply accepts the proposal. **(D)** The trust game. The investor decides whether or not to invest and how much of the endowment to invest with the trustee. The investment will be multiplied. The trustee is free to return any amount of the increased investment back to the investor; or he can keep all of the increased investment. **(E)** The ultimatum game. The proposer provides a proposal how to divide the money between the two while the responder has the option of accepting or rejecting the offer. If the responder accepts the offer, they both get the money as proposed; however, if the responder rejects the offer, neither player receives anything.

neuroeconomics suggests that ambiguous conditions engage the intuition system, allowing individuals to respond more rapidly and automatically. In contrast to the idea that ambiguity involves the emotional system, a meta-analytic study (Krain et al., 2006) showed that ambiguous decision-making elicited greater activation in the dorsolateral PFC relative to risky decision-making. These results indicate that ambiguous decision-making is associated with cognitive processes. The reasons for these different findings (ambiguous decision making is involved in cognitive processes or involved in emotional processes) are not yet clear, and require further investigation. Interestingly, when information is too complex or deliberation is too effortful, individuals also favor an intuitive process to help make sound decisions (Dijksterhuis et al., 2006). It is likely that deliberation leads to suboptimal weighting of unrelated information when issues are too complex, and therefore results in progressively worse choices (Dijksterhuis et al., 2006). Thus, we suggest that individuals favor an intuitive response when information is incomplete or when it is too complex.

Time Constraint

Researchers often study decision making in situations where decision makers have adequate time to perform the task. However, in real-life situations, decisions must often be made under time pressure. Time pressure is related to processing speed, which is a widely used psychological feature to distinguish intuition from reflection (Shiffrin and Schneider, 1977; Rand et al., 2012). In a recent study (Rand et al., 2012), investigators explored individuals' cognitive mechanisms underlying cooperative behaviors by manipulating decision time. They assumed that if the individual was instinctively self-interested, then faster decisions would be less cooperative because prosocial decisions would require more deliberation to inhibit a selfish impulse; if the individual was instinctively cooperative, deliberation would lead to increased selfishness and faster decisions would be more cooperative. To test these competing hypotheses, they conducted a one-shot public good game (see **Figure 1A**) either with or without time constraints. Results showed a significantly higher contribution in the time pressure condition compared to the time delay condition, suggesting that faster decisions were associated with more prosociality (Rand and Nowak, 2013; Rand et al., 2014). Consistent findings are documented in other studies using the prisoner's dilemma game (see **Figure 1B**; Dreber et al., 2008; Fudenberg et al., 2012) and the dictator game (see **Figure 1C**; Cornelissen et al., 2011).

The relationship between time constraint and cooperation is interpreted through the lens of evolutionary theory which suggests that intuitive prosociality is an outcome of cultural evolution and natural selection. Humans internalize cooperative strategies because they help us to better adapt in social interaction (Rand et al., 2012; Rand and Nowak, 2013). However, an evolutionary interpretation does not clarify the underlying mechanism by which time constraints affect decision making. Why the intuitive system dominates in the time pressure condition and how it works require further investigation. Although it remains unclear whether our innate responses are always prosocial, it is reasonable to believe that our responses under time pressure are the product of intuitive process rather than effortful reasoning.

Ego Depletion

Cognitive resources and self-control are sometimes required during decision making. However, what if our cognitive resources are limited and our self-control is impaired? Ego depletion refers to a state in which acts of self-control draw on a resource that is limited, leading people to a depleted stage in which they are less able to exert self-regulation on a subsequent task (Baumeister et al., 1998; Hagger et al., 2010; Job et al., 2010). For example, subjects are forced to eat radishes instead of delicious chocolates leading to a subsequently faster quit on unsolvable puzzles than subjects who have not to exert cognitive control over eating (Baumeister et al., 1998). Individuals under ego depletion are more dishonest about their performance (Mead et al., 2009), less trustworthy in the trust game (see **Figure 1D**; Ainsworth et al., 2014), and more impulsive in making consumer choices (Baumeister, 2002) and other decisions (Bruyneel et al., 2009). A general explanation of the link between ego depletion and decision making is the limited resource model (Baumeister and Heatherton, 1996). This model indicates that there is a cognitive cost to resisting temptation; therefore, individuals under ego depletion do not have sufficient resources to override impulsive behavior (Bruyneel et al., 2009).

Though the limited resource model may help to explain the process of decision making under ego depletion, almost no data speak directly to the underlying mechanism of ego depletion's effect on decision making. A recent study (Wagner and Heatherton, 2012) provided new insights into the process underlying ego depletion, demonstrating that self-regulatory depletion increased emotional reactivity in the amygdala and reduced functional connectivity between the amygdala and the ventromedial PFC. These findings suggest that ego depletion might disrupt the regulatory balance, such that regions engaged in emotional stimuli detection are amplified and the prefrontal regions engaged in top-down control are impaired. The results cannot be fully explained by the limited resource model, because increased emotional reactivity in the amygdala is observed but no reduction in activity in prefrontal regions is found. Thus, in this review, we speculate that if ego depletion works the same way in the decision making domain as in the emotion domain, then individuals' performance in decision making may be due not to insufficient cognitive resources, but to dysregulation between cognition and impulses. Further research is needed to clarify how emotion and cognition fit together during self-regulation, using different scientific techniques such as functional neuroimaging and transcranial magnetic stimulation. These scientific techniques would help to directly explore the underlying mechanism of ego depletion and test the different theory demonstrating the effect.

Emotion Exaggeration: When Emotion is Strong

Emotion plays a unique role in decision making (Green and Myerson, 2004; Seymour and Dolan, 2008). When emotion is greatly enhanced (e.g., induced by a proximal threat), it may interfere with cognitive function and exert a bottom-up influence on our decision making. In this part, we describe how humans' tradeoffs are changed when emotion is exaggerated in decision settings such as proximity, social distance, and social instinct.

Proximity

Emotion may have evolved to solve proximal problems that require immediate responses and influence our immediate survival. The proximal problem, the imminent threat, and even the immediate reward always push us to react rapidly. The animal model of fight–flight (Cannon, 1929) proposes that animals react to perceived threat with a discharge of the sympathetic nervous system—an autonomic nervous system that stimulates the body's fighting and fleeing. More specifically, the adrenal medulla produces a hormonal cascade that results in the secretion of norepinephrine and epinephrine. This model also seems to apply to human beings when individuals confront something threatening. Imagine encountering a crawling spider nearby. Our instinctive defense reactions such as freeze and escape may be evoked for the sake of self-preservation. Using functional neuroimaging, researchers have begun to explore how the human brain responds to the proximity of threat (Mobbs et al., 2007, 2010). Data suggest that distal threat induces activity in the prefrontal cortices, reflecting the complex planning of avoidance strategies. When threat is proximal, midbrain structures (e.g., periaqueductal gray) become more active. Remarkably, the function of the amygdala is also well documented in fight–flight reactions to proximal threat (Mobbs et al., 2009; Volman et al., 2011a,b). In an approach-avoidance task (Volman et al., 2011a), inhibiting anterior PFC with continuous theta burst stimulation led individuals to commit more errors when they needed to select rule-driven responses (e.g., approach-angry) rather than automatic action tendencies (e.g., approach-happy) evoked by emotional faces. Concurrently, the inhibition of anterior PFC was accompanied by increasing activity in the amygdala during the approach-avoidance task. These findings show that imminent threat (e.g., angry emotional faces) results in autonomic and defensive reactions mediated by the amygdala. Taken together, the midbrain structures and the amygdala control reflexive escape behavior and fear-induced analgesia, suggesting that individuals are emotion dominated when facing proximal threat.

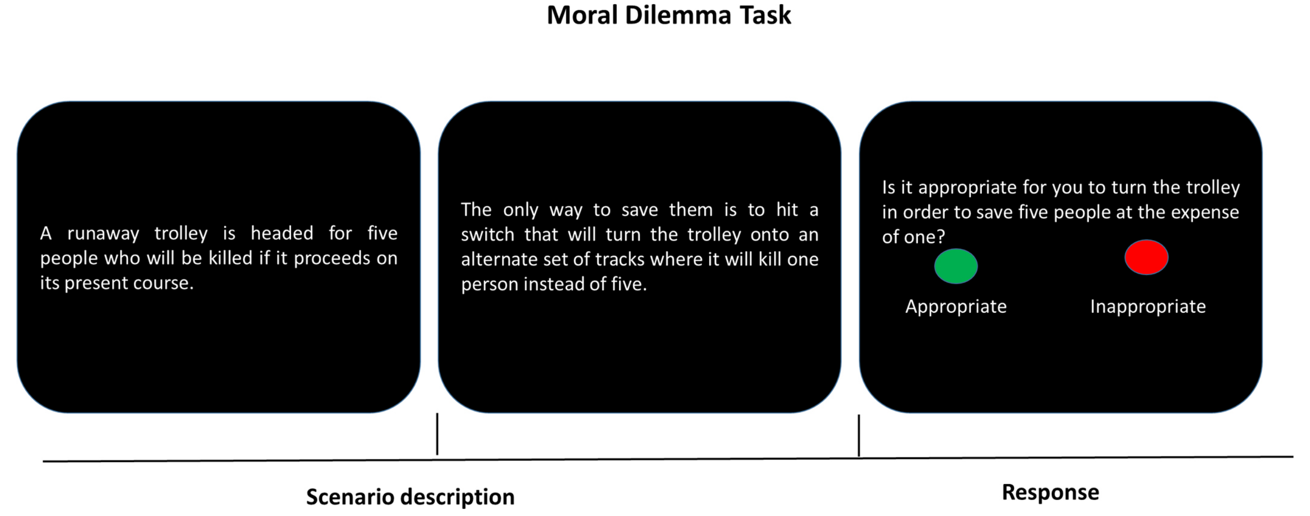

FIGURE 2 | A typical moral dilemma task. The first two screens describe a scenario and the last screen poses a question about the appropriateness of an action in the specific scenario (e.g., turning the trolley). Participants respond by pressing one of two buttons ("appropriate" or "inappropriate").

Emotional response to spatial distance can be extended to temporal distance (Kable and Glimcher, 2007). In an intertemporal choice task (Frederick et al., 2002; Green and Myerson, 2004), individuals are more impatient when choosing between an immediate reward and a delayed reward, than when choosing between a delayed and a more delayed reward. Neuroimaging research demonstrates that short-run impatience of this kind is mediated by the limbic system, which is implicated in reward processing (Breiter and Rosen, 1999). Notably, the limbic system has also been implicated in impulsive behavior and drug addiction (Bechara, 2005). For instance, individuals with drug addiction are over-responsive to drug-related cues, showing increasing activity in limbic components system such as the amygdala (Koob and Le Moal, 2007). It is possible that these affective signals can exert a bottom-up influence on the cognitive system. If the specific signals triggered by the emotion system are strong enough, they would have the capacity to override top-down cognitive control. In the proximal threat studies (Mobbs et al., 2007, 2010) and research on intertemporal choices (Kable and Glimcher, 2007), proximal threat and immediate reward seem to be these kinds of affective signals, which bias participants' attention to proximal distance. Thus, both spatial distance and temporal distance modulate individuals' reaction toward different stimuli. When stimuli are in proximal spatial distance and in the immediate time frame, individuals tend to switch from deliberative to intuitive processes and make instinctive responses.

Social Distance

The term social distance refers to the widely accepted and consciously expressed norms about who should be considered an "insider" or an "outsider." The norms, in other words, specify the distinctions between "self" and "others" (Akerlof, 1997; Bohnet and Frey, 1999). In social interaction, we are more emotionally involved in situations in which stimuli are self-relevant, but we are more analytic in situations where things are physically or psychologically distant from ourselves (Small and Loewenstein, 2003; Greene et al., 2004; Albrecht et al., 2010). For example, Albrecht et al. (2010) showed that when confronting a sooner-small and later-large reward, individuals chose more "sooner" options for themselves than for others. At the neural level, when choices included an immediate reward for self, brain regions including pregenual anterior cingulate cortex, ventral striatum, and anterior and posterior precuneus that were engaged in emotion and reward-related processing were activated; however, there were no neural activation differences between immediate and delay trials when individuals made choices for others. These findings suggest that choices for self and for others engage two distinct processes. Individuals hardly resist the temptation of meeting immediate gratification, while they focus more on long-term reward for others. This is in line with findings from research on moral judgment (see **Figure 2**). Personal moral judgment (e.g., pushing a stranger off a bridge onto the tracks to stop the trolley from hitting five people), as relative to impersonal moral judgment (e.g., turning the trolley away from five people but toward an alternative track on which stands one person), engages greater activity in brain areas associated with social-emotional processing, such as posterior cingulate gyrus and angular gyrus. In contrast, impersonal moral judgment, as relative to personal moral judgment, reveals a more prominent area of activation lying in the parietal lobe that is correlated with cognitive process (Greene et al., 2001, 2004).

Based on the aforementioned studies, we speculate that if making a choice for oneself and making a choice for others trigger different systems, then such distinct responses may generalize to other situations where there is no explicit but nevertheless an implicit "self" domain vs. "others" domain. Several studies support this hypothesis. For instance, subjects are more sympathetic with and generous toward specifically identified victims compared to "statistical" victims who are poorly identified, known as the "identifiable victim effect" (Small and Loewenstein, 2003; Kogut and Ritov, 2005). Moreover, when delving out punishment, people are more punitive toward identified wrongdoers than toward those who are unidentified (Small and Loewenstein, 2005). It is likely that vivid and concrete information is self-relevant to participants (Kogut and Ritov, 2005), leading to stronger emotional responses. Overall, social distance changes our decision making: the more self-relevant the situation is, the more emotions are involved when one makes decisions.

Social Instincts

Emotion may function as a social signaling system. Anger tells others, "If you continue to provoke, I am ready to fight and attack." This kind of anger implicates the inborn tendency (or drive) to react to the social interaction, and we define such a tendency and drive as social instincts. The ultimatum game (see **Figure 1E**; Güth et al., 1982) is widely used to study the association between social instincts (e.g., anger) and punishment. In this game, the proposer provides a proposal about how to divide the money while the responder has the option of accepting or rejecting the offer. If the responder accepts the offer, they both get the money as proposed; however, if the responder rejects the offer, neither player receives anything. An income-maximizing responder should accept any positive offer, and an income-maximizing proposer should offer the smallest possible amount to the responder (Xiao and Houser, 2005). However, studies using the ultimatum game demonstrate that when responders are offered 20% or so of the total amount, they are more likely choose to reject the proposal (Camerer, 2003). Even in advantage inequality situations (e.g., the responder receives a larger offer than the proposer in the ultimatum game), individuals dislike unequal outcomes and are willing to achieve a more equal reward distribution at their own personal financial cost (Tricomi et al., 2010; Yu et al., 2014).

Responders' rejection and punishment in the ultimatum game may directly link to their feelings of anger and disgust (Pillutla and Murnighan, 1996; Sanfey et al., 2003; Lerner et al., 2004; Polman and Kim, 2013). Neuroimaging studies have observed that the insula and the dorsolateral PFC are activated in the contrast between "unfair—fair" offers (Sanfey et al., 2003; Dawes et al., 2012). Both anger and disgust have been seen to engage a distinct region of the anterior insula (Damasio et al., 2000). The higher the activation of the insula, the higher rate at which participants reject an unfair offer, indicating that activation of the insula may be associated with the degree of participants' indignation and moral disgust in response to unfair offers (Sanfey et al., 2003; Dawes et al., 2012). By contrast, activation of the dorsolateral PFC suggests that individuals are trying to control their emotional impulses to reject unfair offers (Knoch et al., 2008; Tabibnia et al., 2008). During evolution, humans may have developed innate responses to emotionally charged situations such as being treated unfairly. Human brains might be hard-wired to react to certain social stimuli automatically and emotions such as disgust may facilitate such responses. Thus, social stimuli (e.g., unfairness) trigger emotions (e.g., disgust) that elicit impulsive responses (e.g., revenge).

Critical Summary

In summary, we highlighted two contexts (cognition reduction and emotion exaggeration) in which cognitive capability was either reduced or interfered with by emotion-related cues or prior cognitive tasks. In the cognition reduction context, the cognition capacity is reduced by incomplete information (ambiguity), limited decision time (time constraint), and impaired self-regulation (ego depletion). In the emotion exaggeration context, emotional function is enhanced by affective signals that can exert bottom-up influence. These specific signals include threatening cues or immediate reward (proximity), self-related information (social distance), and social stimuli (social instinct). One common feature across the two contexts is that decision making engages greater activation in emotion-related brain regions such as the amygdala, the hypothalamus and the insula. Moreover, at the behavioral level, individuals behave more impulsively and make a faster choice in these two contexts. Because cognition fails to exert control in decision making in these contexts, passion becomes dominant and plays a central role in subsequent behaviors.

In this section, the competition between passion and reason can be interpreted within the framework of "dual-process models" (Evans, 2008; Keren and Schul, 2009; Kahneman, 2011). Dual-process models suggest that emotion is automatic, heuristic, and reflexive; whereas reason is controlled, analytic, and reflective (Evans, 2008). A great deal of research pursuing the notion of a dorsal-cognition vs. ventral-emotion axis organization of the human brain (Dolcos and McCarthy, 2006; Haas et al., 2006; Anticevic et al., 2010) suggests that emotion and reason are involved in two distinct mental modes. For example, Greene et al. (2001) demonstrated that when confronted with sacrificial moral dilemmas in which one individual must be sacrificed to save more people's lives, participants often responded with an emotional reaction. Moreover, this gut reaction can be seen at the neural level that involving greater activation of emotion-related regions such as the posterior cingulate gyrus and the angular gyrus. However, when given enough time to analyze, individuals could shift from initial gut reactions to utilitarian responses. The researchers interpreted the results with the lens of divided mind—one system that produces an emotional judgment, and another deliberative system that can go against the intuitive initial reaction. The two contexts we mentioned in this section clearly show how the intuitive system produces strong emotional judgments that are powerful enough to constrain the functioning of the deliberative system.

How Does Cognition Regulate Emotion?

In the previous discussion, we delineated contexts in which emotion is likely to override reason to influence our behavior choices. However, intuitive responses, if unchecked, may turn out to be suboptimal and even destructive. Cognition can exert powerful modulation on emotion in many circumstances. Emotion regulation is a set of controlled processes that explicitly involve strategies to initiate, increase, maintain, or decrease the occurrence, intensity, or quality of experienced feeling states (Eisenberg et al., 2000; Gyurak et al., 2011; Webb et al., 2012). In contrast with the aforementioned definition of emotion regulation, some other research suggests that emotions are self-regulating implicitly. Emotions are not just regulated by other cognitive processes, but more importantly, emotions regulate themselves via learning and experience (Kappas, 2011a,b). To address the divergent results of earlier studies, Gyurak et al. (2011) provided a dual-process framework to integrate the research on explicit emotion regulation and implicit emotion regulation. According to Gyurak et al. (2011), explicit emotion regulation is made up of a set of processes that involve conscious effort for initiation and monitoring when implemented. Individuals are aware of what they are currently doing. Implicit emotion regulation is evoked automatically by the emotional stimulus itself, and it can occur without awareness. In this review, we focus more on explicit emotion regulation during which conscious effort modulates emotion. Notably, the most widely used model is the process model of emotion regulation (Gross, 1998). This model differentiates three major strategies as attentional deployment, cognitive change, and response modulation (D'Zurilla et al., 2003; Webb et al., 2012). In this section, we highlight how cognition modulates emotion and how these two processes cooperate to affect ongoing behavior.

Attentional Deployment

Attentional deployment includes two aspects, namely, distraction and concentration (Webb et al., 2012). Distraction means moving attention away from the current situation or directing attention to a different aspect of the situation (Gross and Thompson, 2007). This has been shown by instructing individuals to think of something else or to perform an unemotional task (Masuda et al., 2010). Concentration can be shown when participants are directed to focus on or make judgment about their emotional experience. One widely used concentration strategy is affect labeling (Hariri et al., 2000; Lieberman et al., 2007, 2011; Ramirez and Beilock, 2011). Typically, in affect labeling studies, participants are asked to choose either from a pair of pictures or a pair of words. The pictures or words are related to the emotional content of a target picture (Lieberman et al., 2011). A recent empirical study (Ramirez and Beilock, 2011) applied affect labeling in a school setting and found that writing about testing worries boosted exam performance in the classroom. It is likely that writing attenuates the burden that worries place on working memory, thus providing individuals an opportunity to reevaluate the anxious and stressful expression in a manner that reduces the necessity to worry altogether (Klein and Boals, 2001; Ramirez and Beilock, 2011).

Some neuroimaging studies show decreasing amygdala activity combined with an increasing lateral PFC when individuals attempt to evaluate emotion-related stimuli (Hariri et al., 2000, 2003). It is possible that judgment or evaluation itself might engage a greater attention load, limiting the process of perceptual input and as a result constraining amygdala activation (Bishop et al., 2004). If this is the potential mechanism of attentional deployment's effects on decision making, we assume that cognition and emotion engage common limited resources because paying less attention to the emotional stimuli modulates the processes of both cognitive evaluation (e.g., increased PFC activation) and emotional appraisal (e.g., reduced amygdala activation). Emotion and cognition travel opposite directions in attention manipulation, outlining a reciprocal PFC-amygdala relationship with one domain being strengthened and the other one weakened.

Cognitive Change

Cognitive change strategy, also termed reappraisal, refers to efforts that change the way individuals appraise the situation and alter its emotional significance (Aldao et al., 2010). Participants can modulate their current emotion, for example, by providing a less negative interpretation when they meet an undesirable picture content (Hajcak and Nieuwenhuis, 2006) or increasing the sense of objective distance by viewing picture content from a third-party perspective (Ochsner et al., 2004b). In general, data from fMRI studies have found that reappraisal of negative stimuli activates the dorsal PFC system, which facilitates the selection and application of cognitive change strategies and attenuates activity in the emotional system including the amygdala and insula (Ochsner et al., 2002; Phan et al., 2005; Buhle et al., 2014). We speculate that the PFC system modulates the amygdala response toward emotional stimuli, showing an interaction between emotion and cognition in stimuli reinterpretation. Notably, cognitive change does influence the reasoning process (cognitive process) beyond simply removing the emotion, extending its influence to change reward encoding and motivation processes (Staudinger et al., 2009, 2011; Martin et al., 2013). For example, in a behavioral economics study (Martin et al., 2013), participants engaged in two reappraisal strategies with different goals—to increase or decrease the importance of a coming decision. The results showed that emphasizing the perceived significance of the next decision decreased risk taking, whereas reducing the perceived importance of the coming decision increased the risk taking. However, there was no emotion arousal change when individuals engaged in reappraisal with opposite goals. These results suggest that cognitive change can flexibly alter reward encoding and economic behavior with regulation goals. Another neuroimaging study (Staudinger et al., 2011) revealed that reappraisal would modulate reward cue and motivation processing with increases of activity in the dorsolateral PFC and attenuation of anticipatory reward cue encoding in the putamen. The researchers suggested that emotion regulation areas such as dorsolateral PFC might exert modulatory control over the putamen to bring about such effects.

To recap the aforementioned studies, it seems that cognitive change results in amplified activation in the cognitive system (e.g., dorsolateral PFC), and reduced activation in the appraisal system (e.g., amygdala and insula). But this is not always the case. When anticipating responses that precede an upcoming emotional event, research also observes increasing, rather than decreasing, activation in emotional regions such as amygdala and insula (Ochsner et al., 2004a). The distinct directional nature of these observed interactions is still unclear. One possibility is that in regulating an existing or ongoing emotional response, the PFC system exerts a top-down inhibitory effect on amygdala response (Banks et al., 2007); whereas in anticipating how a stimulus might feel, strengthened amygdala-frontal coupling reflects an enhanced cognitive effect due to a failure to down-regulate amygdala activity. Another possibility is that using cognitive change to regulate an existing emotion and to anticipate an upcoming emotional response might involve two distinct neural modes. Although it remains unclear why cognitive change leads to distinct activation in the amygdala, it is clear that cognitive change depends on the interaction of a prefrontal system supporting cognitive process and a subcortical system engaging emotional information processing.

Response Modulation

Response modulation means enhancing or suppressing one's subjective feelings, behavioral responses, or physiological responses within an emotion-eliciting situation (Gross and Barrett, 2011; Webb et al., 2012). Researchers have manipulated response modulation in different ways (Webb et al., 2012). For example, Schmeichel et al. (2006) instructed subjects to view a disgust-eliciting film clip and exaggerate their reactions (enhance the expression of emotion); Gross and Levenson (1993) asked participants to watch a film clip, but to hide their emotion and act as if they did not feel anything at all (suppress the expression of emotion); Quartana and Burns (2007) instructed participants to suppress all of their feelings and try to push all their emotion out of their mind (suppress the experience of emotion); and Dalgleish and Yiend (2006) asked participants to inhibit thinking about a personal distressing event that had been described before (suppress thoughts of the emotion-eliciting event). Indeed, relative to emotion enhancement (exaggerate emotional reaction), emotion suppression (suppress expression and experience of emotion) is more widely explored. Many empirical studies have investigated the function of emotion suppression in health, well-being and social interaction (McCaul et al., 1979; Anderson and Green, 2001; Nørby et al., 2010). Evidence suggests that emotion suppression can slow down heart rate and breathing (McCaul et al., 1979) and help us to forget unwanted memories (Anderson and Green, 2001), but it may also increase blood pressure (Burns et al., 2007) and even lower individuals' social support and satisfaction (Srivastava et al., 2009).

Recent neuroimaging research has begun to examine the neural bases of emotion suppression (Davidson et al., 2000; Lévesque et al., 2003; Goldin et al., 2008). Consistent evidence suggests that suppression increases activation of the prefrontal regions such as the ventrolateral PFC, the dorsolateral PFC and the OFC (Davidson et al., 2000; Beauregard et al., 2001; Lévesque et al., 2003; Goldin et al., 2008). This increased response correlates with a simultaneous decreased response in limbic regions such as the amygdala and hypothalamus (Davidson et al., 2000; Beauregard et al., 2001). The PFC, especially the dorsolateral PFC, is implicated in executive process referring to the ability to control information processing. The amygdala is implicated in the evaluation of emotional significance of stimuli (Lane, 2000) and the hypothalamus is associated with expressing emotion (Carter, 1998). These results seem to outline neural circuitry underlying suppression of emotion, suggesting that the prefrontal regions constrain the evaluation and expression of emotion during the suppression task. In fact, it remains unclear whether the underlying mechanisms by which prefrontal regions regulate emotion evaluation and expression extend to the decision domain. Few studies have investigated how suppression affects our decision making. In a recent behavioral study, Heilman et al. (2010) found that suppression of positive emotion (but not negative emotion) could reduce individuals risk aversion. Building on Heilman et al.'s (2010) results, Panno et al. (2013) found that the habitual use of a suppression strategy (a naturally occurring individual difference in emotion regulation) was associated with decreased risk taking. The authors suggested that suppression induced less risky choices due to participants paying more attention to avoiding negative emotion elicited by negative potential outcomes. However, in this study, the relation of suppression and decision making is just correlational and comes from self-report. Thus, it is not clear how suppression itself influences decision making and what are the neural bases of suppression and decision making. Whether our assumption that prefrontal regions constrain the evaluation and expression of emotion during the suppression task can also extend to the decision domain awaits further investigation.

Critical Summary

In this section, we demonstrated that through emotion regulation strategies including attentional deployment, cognitive change and response modulation, cognition, as relative to emotion, may play a stronger role in judgment and decision making. More importantly, we also point out that the ability to regulate emotion depends upon the interaction between the PFC supporting cognitive control and a subcortical system that represents different types of emotion-related information. More specifically, subcortical regions facilitate processing of emotional information, and prefrontal regions can constrain the evaluation and expression of emotion during emotion regulation tasks. When concentrating on (attention deployment), reappraising (cognitive change), and suppressing (response modulation) emotion stimuli, cognition exerts a top-down regulation of the amygdala responses. The integration of passion and reason in decision making can be strongly confirmed by lesion studies from animals (Málková et al., 1997; Schoenbaum et al., 2003) and human beings (Hampton et al., 2007). For example, human subjects with amygdala lesions displayed a profound change in PFC activity related to reward expectation and behavioral choice, indicating that production of signals related to behavioral choice in PFC relies directly on input from the amygdala (Hampton et al., 2007). Thus, based on the aforementioned studies and other research confirming that emotion and cognition are integrated to determine ongoing behaviors (Phelps, 2006; Pessoa, 2008; Pessoa et al., 2012), it is reasonable to predict that emotion regulation depends on the interaction of a prefrontal system supporting cognitive process and a subcortical system engaging emotional information processing.

The Interactive Influence Model of Emotion and Cognition

The most influential arguments to account for the antagonism of emotion and reason in decision making come from "dual-process models" (Evans, 2008; Keren and Schul, 2009; Kahneman, 2011). The two processes are assumed to be engaged in distinct mental modes—one mental system that is emotional and intuitive, and another system that is rational and deliberative. According to the implication of dual-process models, intuitive process can produces an emotional judgment, and deliberative process may go against the intuitive initial reaction. Though the dual-process models can explain the antagonism of emotion and reason, there remain several limitations. For one, the idea of dual processes

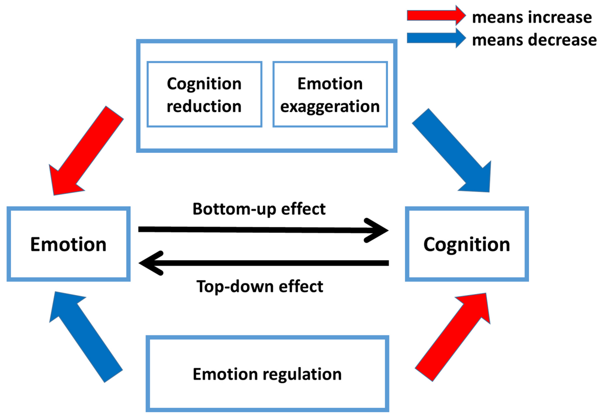

FIGURE 3 | The interactive influence model of emotion and cognition (IIEC). Decision making depends upon the interaction of emotion and cognition. Two typical contexts, namely cognition reduction (cognitive capacity is reduced) and emotion exaggeration (emotional reaction is enhanced), increase the power of emotion but decrease the power of cognition. The cognition reduction can be seen in decision setting such as ambiguity, time constraint, and ego depletion. The emotion exaggeration can be observed in decision settings such as proximity, social distance, and social instinct. In these two contexts, emotion can overwhelm cognition and exert a bottom-up influence on decision making. Cognition can modulate emotion reaction by consciously using emotion regulation strategies such as attention deployment, cognitive change, and response modulation. These emotion regulation strategies help to strengthen the capacity of cognition and constraint the power of emotion. With emotion regulation, cognition can exert a top-down effect during decision making.

is conceptually unclear and oversimplifying (Kruglanski et al., 2006; Keren and Schul, 2009). It seems that nearly all dual-process models embrace the dichotomy of intuition (emotion) and deliberation (reason), yet, whether there are two systems rather than one or more systems in mental processes remain unclear (Pessoa, 2014). For another, the dual processes fail to account for how emotion and reason interplay to influence our decisions in daily judgments. Take one example of the interaction of reason and intuition: a person may reason their way to a moral view (such as that verbal abuse is wrong), and this moral view might change to be intuitive overtime (Pizarro and Bloom, 2003). Take another example: individuals implementing emotion regulation show simultaneously increasing brain activity in the PFC, which supports cognitive process, and decreasing activity in limbic system, which is implicated in emotion process (Heilman et al., 2010; Sokol-Hessner et al., 2013). The above examples suggest that the mechanism by which a reasoned choice develops into an intuitive one, and the mechanism by which emotion regulation strategies engage the interconnection of cognitive process and emotional process, are not well elaborated in dual-process models.

In this review, drawing on findings mentioned in previous sections, we integrate the antagonism and integration of passion and reason in decision making within a framework, labeled "The interactive influence model of emotion and cognition (IIEC)" (see **Figure 3**). The IIEC model differs from previous accounts of how emotion (or cognition) overrides cognition (or emotion) as well as how they cooperate with each other to affect decision making. In this model, we postulate that (1) emotion transcends cognition to affect decision making by reducing cognitive capacity (cognition reduction) and enhancing emotional response (emotion exaggeration); (2) cognition overwhelms emotion to influence decision making by explicitly implementing cognitive control via emotion regulation strategies; (3) decision making depends upon the interaction of emotion and cognition.

More specifically, emotion exerts a bottom-up effect under two typical contexts—cognition reduction and emotion exaggeration. The cognition reduction context can be observed in decision settings where information is incomplete (ambiguity), decision time is limited (time constraint), and self-regulation is impaired (ego depletion). The emotion exaggeration can be seen when individuals meet threatening cues or immediate reward (proximity), self-related information (social distance), and social stimuli (social instinct). In these two contexts (cognition reduction and emotion exaggeration), the power of emotion is potentiated and the capacity of cognition is diminished, thus leading emotion to override cognition to affect decision making. As for cognition, it can exert a top-down effect through the conscious use of emotion regulation strategies. When concentrating on (attention deployment), reappraising (cognitive change), and suppressing (response modulation) emotional stimuli, cognition is able to alter emotion's evaluation and expression. That is, using emotion regulation strategies strengthens the capacity of cognition and reduces the power of emotion. Neither emotion nor cognition alone guarantees a sound decision making. This is because decision making depends upon the interaction of a subcortical system (e.g., amygdala, hypothalamus, thalamus, putamen, and hippocampus) engaging in emotional information processing and a prefrontal system (e.g., dorsal PFC, ventromedial PFC, dorsomedial PFC, OFC) supporting cognitive process. Such interaction is embedded at the perceptual and executive levels. Subcortical system components such as the amygdala are involved in processing of perceptual input (Bishop et al., 2004) that helps to generate and evaluate emotions such as anger, fear or disgust, while the prefrontal system exerts modulatory control on representation of perceptual stimuli (Buhle et al., 2014), and thus in turn changes the expression and evaluation of emotion.

The IIEC model can be supported by evidence from numerous behavioral studies, neuroimaging research, and lesion cases. First, data from research on impulsive behaviors indicate that emotion exerts a bottom-up effect on cognition. For example, healthy participants are more impulsive with an immediate reward than a delayed one (Frederick et al., 2002; Green and Myerson, 2004), and individuals with drug addiction are over-responsive to drug-related cues, showing increasing activity in the amygdala and other parts of the limbic system (Koob and Le Moal, 2007). It is possible that these affective signals (immediate reward and drug-related cues), exaggerate emotional responses, and consequently exert a bottom-up influence on the cognitive system as the IIEC model posits.

Second, research focusing on emotion regulation during decision making suggests that the prefrontal system exerts a top-down effect on emotion, outlining the integration of emotion and cognition in decision making (Sokol-Hessner et al., 2009, 2013; van't Wout et al., 2010; Miu and Crişan, 2011; Grecucci et al., 2013; Panno et al., 2013). For instance, the use of emotion regulation techniques (e.g., reappraisal) in behavioral economics and neuroeconomics studies suggests that emotion regulation helps to reduce loss aversion—a phenomenon in which individuals tend to strongly prefer avoiding losses to acquiring gains (Kahneman and Tversky, 1984). Moreover, emotion regulation also increases PFC responses accompanied by decreasing amygdala responses to losses (Sokol-Hessner et al., 2013). According to the IIEC model, it is likely that emotion regulation involves the use of cognitive control (reappraisal or suppression) that modulates representations of emotional stimuli and consequently attenuates activity in the amygdala.

Third, research on decisions about altruism, trust, and fairness shows the interaction of emotion and reason during social interaction (Moll et al., 2006; Spitzer et al., 2007; Buckholtz et al., 2008; Rilling and Sanfey, 2011; FeldmanHall et al., 2015). Charitable donation is a difficult social decision involving psychological conflict between self-interest and the interests of others (Rilling and Sanfey, 2011). In one study (Moll et al., 2006), researchers found that voluntarily donating money to a specific charity activated the mesolimbic dopamine system such as components of the ventral tegmental and the ventral striatum. The mesolimbic reward system engaged by donation was engaged in the same way when individuals accepted monetary reward, suggesting that donation and earning money shared a similar system of reward reinforcement (O'Doherty et al., 2006). Remarkably, the PFC was also recruited when individuals decided whether to donate or not, indicating that individuals exerted cognitive control over selfish material interests. The brain processes involved in donation decisions are analogous to brain processes involved in other costly altruistic decisions during which participants experience feelings of other-oriented empathy (FeldmanHall et al., 2015) or obtain more money than their partners in economic games (Yu et al., 2014). These results, according to the IIEC model, might suggest that the perceived joy (emotion) of donation (or helping others) facilitates exertion of cognitive control (cognition) over self-interests and thus guarantees prosocial behaviors. Indeed, not only social reward, but also punishment threat motivates participants to behave prosocially. When punishment is available, individuals' increases in norm compliance are positively correlated with activation in the caudate and the dorsolateral PFC (Spitzer et al., 2007). The caudate is involved in processing information about positive or negative reinforcers (Delgado et al., 2003; Spitzer et al., 2007). These results might indicate that the perceived threat (caudate) motivates individuals to override proponent impulses (dorsolateral PFC), therefore resulting in more fair decisions. Taken together, humans make altruistic and fair decisions based on the interaction of emotion and cognition—the perceived reward or punishment motivating individuals to override self-interested impulses.

Fourth, lesion studies further indicate how emotion and cognition cooperate to affect decision making (Davidson et al., 2000; Shiv et al., 2005; Clark et al., 2008). For example, as we mentioned earlier, humans with amygdala lesions exhibited a profound change in PFC activity related to reward expectation and behavioral choice, suggesting that production of signals related to behavioral choice in PFC relies directly on input from the amygdala (Hampton et al., 2007). Similarly, other research also documents that amygdala damage abolishes monetary loss aversion (De Martino et al., 2010). These results, according to the IIEC model, may suggest that deficits of amygdala constrain processing of perceptual stimuli, lower individuals' sensitive to loss or reward, and as a result interfere with reason processes that calculate the losses and gains based on existing information. Besides the amygdala, another prefrontal region, ventromedial PFC, is also well documented in decision making (Berlin et al., 2004). The Somatic Marker Hypothesis (Damasio, 2008) suggests that bodily states that were previously associated with choice alternatives are retrieved by the ventromedial PFC. Bodily states, according to Somatic Marker Hypothesis, can transform into emotions. Therefore, this hypothesis implies that ventromedial PFC connects emotion and cognition during decision making. Patients with ventromedial PFC damage increase betting and impulsive behaviors (Bechara et al., 2000; Berlin et al., 2004; Clark et al., 2008), and they exhibit more subjective anger but less subjective happiness than normal participants (Berlin et al., 2004). The IIEC model proposes that decision making depends upon the interaction of emotion and cognition, so it is reasonable to infer that dysfunction of ventromedial PFC disrupts the connection of emotion and cognition. Therefore, the prefrontal system fails to control the process of emotion, which makes emotional stimuli salient and in turn exaggerates emotional responses leading to emotion-dominated behaviors.

To sum up, the IIEC model we posit serves as a launching point for understanding the interplay of emotion and reason in decision making. First, the framework we established can be applied to understanding a diverse range of human decision making behaviors in which emotion plays a prominent role. We shift the question from "whether emotions affect decision making" to "when and how does emotion affect decision making." Our model suggests that when cognition capability is reduced or emotion reaction is enhanced, emotion can overwhelm reason to exert a bottom-up effect during decision making. Second, this model broadens our understanding on how cognition affects decision making by modulating emotional processes. Through the conscious use of emotion regulation strategies such as attention deployment, cognition change, and response modulation, cognition can modulate the expression and evaluation of emotion during decision making. Third, the IIEC model can also be applied to understanding the decision-making impairments that are associated with brain damages. The IIEC model suggests that decision making depends upon the interaction of emotion implicated in subcortical cortex and reason implicated in PFC. Damage in either prefrontal or subcortical regions leads to maladaptive behaviors and impaired decisions. Besides the contributions of IIEC model, two main limitations should be noted. For one, we put forth a framework about when emotion plays a prominent role in decision making and when reason does, but we fail to articulate the baseline balance between emotion and cognition during decision making. Kahneman and Tversky (1979) suggested that individuals usually use automatic processes to generate judgments and attitudes and then use controlled processes to make necessary adjustments; that is, emotion process may initiate some default action tendency and the reason process evaluates and modulates such tendency according to current goals and social interactions. If this is the case, we might assume that the default action tendency generated by emotion is the baseline of the interaction of passion and reason. Without this baseline, cognition might fail to exert cognitive control. However, this assumption has not been clearly elaborated. For another, we have applied this model to explain some research in the decision domain; however, whether this model can also apply to other domains remains unclear. A recent study conducted by Pessoa et al. (2012) showed that low-threat stimuli (fearful and happy face) improved response inhibition but high-threat stimuli (stimuli previously paired with mild shock) impaired performance. According to the IIEC model, we might suggest that high-threat stimuli exaggerate the emotional response, which strengthens the power of emotion and then interferes with the executive control system, leading to poor performance. However, this is just one example, and more research is needed to test our hypothesis.

Concluding Remarks

The conceptual framework model we have put forth—IIEC—posits that emotion and reason cooperate to shape our decision making. In this model, we suggest that decision making depends upon the interaction of a subcortical system engaging emotional information processing and a prefrontal system supporting cognitive process. We emphasize that emotion plays a more important role when cognitive capacity is reduced (cognition reduction) or when emotion is greatly strengthened (emotion exaggeration) by emotional stimuli or cognitive tasks. We also highlight that cognition can regulate emotion through strategies including attentional deployment, cognitive change, and response modulation. This model is important because it takes into account both antagonism and integration of emotion and reason in a more dynamic framework as contrast to previous dual-process models which embrace the competition of passion and reason. This model reinterprets evidence that until now was used to support the dual-process models, suggesting that decision making relies on the interaction of emotion and cognition and that whether emotion or cognition makes a more prominent role depends on specific decision contexts.

Author Contributions

JL wrote the first draft of the paper. RY provided critical revisions. Both authors reviewed the manuscript.

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Transcutaneous Vagus Nerve Stimulation (tVNS) does not increase prosocial behavior in Cyberball

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Emerging research suggests that individuals experience vicarious social pain (i.e., ostracism). It has been proposed that observing ostracism increases activity in the insula and in the prefrontal cortex (PFC), two key brain regions activated by directly experiencing ostracism. Here, we assessed the causal role of the insula and PFC in modulating neural activity in these areas by applying transcutaneous Vagus Nerve Stimulation (tVNS), a new non-invasive and safe method to stimulate the vagus nerve that has been shown to activate the insula and PFC. A single-blind, sham-controlled, within-subjects design was used to assess the effect of on-line (i.e., stimulation overlapping with the critical task) tVNS in healthy young volunteers ($n = 24$) on the prosocial Cyberball game, a virtual ball-tossing game designed to measure prosocial compensation of ostracism. Active tVNS did not increase prosocial helping behavior toward an ostracized person, as compared to sham (placebo) stimulation. Corroborated by Bayesian inference, we conclude that tVNS does not modulate reactions to vicarious ostracism, as indexed by performance in a Cyberball game.

Keywords: Vagus Nerve Stimulation, insula, Cyberball, vicarious ostracism, PFC

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Introduction

People vicariously experience others' (social) pain. Several recent studies have demonstrated vicarious ostracism (i.e., the observation of other people being socially ignored and excluded). These studies show that spectators identify with an ostracized individual's pain and also feel ostracized themselves (Over and Carpenter, 2009; Wesselmann et al., 2009; Masten et al., 2010, 2011a, 2013a,b; Beeney et al., 2011; Meyer et al., 2012; Will et al., 2013). As pointed out by Wesselmann et al. (2013a), not only adults (Wesselmann et al., 2009; Beeney et al., 2011; Masten et al., 2011a; Meyer et al., 2012; Will et al., 2013) but also children and adolescents (Over and Carpenter, 2009; Masten et al., 2010, 2013a,b; Will et al., 2013) exhibit vicarious ostracism.

In the literature, a reliable index of vicarious ostracism is an adapted version of the Cyberball game (Williams, 2009), a virtual ball-tossing game in which participants observe someone else being ostracized. Perceiving someone being ostracized during the Cyberball game presents the participant with a moral conflict: helping the ostracized person by throwing the ball to the victim more often, or following the other computer-controlled confederates by excluding the victim (Williams and Jarvis, 2006). Using this version of the Cyberball game, previous research has shown that people typically tend to compensate for other individuals' ostracism by throwing the ball toward the ostracized person more often (Riem et al., 2013; Wesselmann et al., 2013b), unless they are induced to think that the ostracized individual deserved this treatment (Wesselmann et al., 2013b). Interestingly, observing ostracism increases activity in the insula and anterior cingulate cortex, the key social pain-related regions that are activated also by directly experiencing ostracism (Eisenberger and Lieberman, 2004). Moreover, observing ostracism activates the prefrontal cortex (PFC) and precuneus—brain regions associated with mentalization (i.e., ability to understand the mental state of oneself and others; Masten et al., 2010, 2011a,b, 2013b). Brain activation of both the mentalization areas and social pain-related regions correlates with individual differences in empathy when observing ostracism and with prosocial behavior toward the victim, which has been taken to suggest that differences in experiencing vicarious ostracism may also reflect individual differences in trait empathy (Masten et al., 2010, 2011a,b, 2013a).

Here, we assessed the causal role of this PFC-insula network in mediating vicarious ostracism by applying transcutaneous Vagus Nerve Stimulation (tVNS), a new non-invasive and safe method to stimulate the vagus nerve, introduced for the first time by Ventureyra (2000; for a recent review see Vonck et al., 2014). tVNS stimulates the afferent auricular branch of the vagus nerve located medial of the tragus at the entry of the acoustic meatus (Kreuzer et al., 2012). tVNS is safe and is accompanied only with minor side effects such as an itching sensation under the electrodes. Very recently, it has been suggested that tVNS may be a valuable tool for modulating cognitive processes in healthy humans (van Leusden et al., 2015). Two functional magnetic resonance imaging (MRI) studies in healthy humans have shown increased activation during active tVNS in the locus coeruleus and the solitary tract, as an indication of effective stimulation of the vagal afferences and both the insula and PFC (Dietrich et al., 2008; Kraus et al., 2013), which are key areas related to social pain and mentalization, and linked to vicarious ostracism.

Given the available correlational evidence that vicarious ostracism involves the PFC-insula network, we tested whether tVNS enhances prosocial helping behavior toward an ostracized person who was unknown to the participant. This hypothesis is supported by the findings that tVNS produces a reliable activation in both the insula and the PFC (Dietrich et al., 2008; Kraus et al., 2013). Accordingly, we assessed the effect of on-line (i.e., stimulation overlapping with the critical task) tVNS on an adapted version of the Cyberball game to measure compensation for other players' ostracism. A positive effect of tVNS during Cyberball would be indicated by an increased number of tosses toward the ostracized person.

Experimental Procedures

Participants

Twenty-four Leiden University undergraduate students (21 females, three males, mean age = 19.13 years, range 18–22) participated in the experiment. Participants were recruited via an on-line recruiting system and were offered course credit for participating in a study on the effects of brain stimulation on social decision-making. Participants were screened individually via a phone interview by the same lab-assistant using the Mini International Neuropsychiatric Interview (M.I.N.I.). The M.I.N.I. is a short, structured interview of about 15 min that screens for several psychiatric disorders and drug use, often used in clinical and pharmacological research (Sheehan et al., 1998; Colzato and Hommel, 2008; Colzato et al., 2009). Participants were considered suitable to participate in this study if they fulfilled the following criteria: (i) age between 18 and 30 years; (ii) no history of neurological or psychiatric disorders; (iii) no history of substance abuse or dependence; (iv) no history of brain surgery, tumors, or intracranial metal implantation; (v) no chronic or acute medications; (vi) no pregnancy; (vii) no susceptibility to seizures or migraine; (viii) no pacemaker or other implanted devices.

All participants were naïve to tVNS. Prior to the testing session, they received a verbal and written explanation of the procedure and of the typical adverse effects (i.e., itching and tingling skin sensation, skin reddening, and headache). No information was provided about the different types of stimulation (active vs. sham) or about the hypotheses concerning the experiment. The study conformed to the ethical standards of the Declaration of Helsinki and the protocol was approved by the medical ethics committee (Leiden University Medical Center).

Apparatus and Procedure

A single-blinded, sham/placebo-controlled, randomized cross-over within-subjects study with counterbalanced order of conditions was used to assess the effect of on-line (i.e., stimulation overlapping with the critical task) tVNS on a prosocial Cyberball game in healthy young volunteers.

All participants took part in two sessions (active vs. sham) and were tested individually. In both sessions, upon arrival, participants were asked to rate their mood on a 9 × 9 Pleasure × Arousal grid (Russell et al., 1989) with values ranging from −4 to 4. Heart rate (HR) and systolic and diastolic blood pressure (SBP and DBP) were collected from the non-dominant arm with an OSZ 3 Automatic Digital Electronic Wrist Blood Pressure Monitor (Speidel & Keller) for the first time (T1). Immediately after, participants performed either the Empathy Quotient (EQ; in session 1) or the interpersonal reactivity index (IRI; in session 2). The EQ is a self-report questionnaire designed to assess empathy in normal adult populations (Cronbach's alpha is 0.92; Baron-Cohen and Wheelwright, 2004). It comprises 60 questions (20 items are filler questions) that, taken together, provide an overall measure of cognitive perspective taking, affective empathy, and social skills (range 0–80, higher scores = more empathy). The IRI is a self-report questionnaire that assesses perceived individual differences in the tendency to be empathetic. It consists of 28 Likert-type items on a response scale with five alternatives ranging from 0 (Does not describe me well) to 4 (Describes me very well). It comprises four subscales assessing affective (empathic concern and personal distress) and cognitive (fantasy and perspective taking) components of empathy (Davis, 1980, 1983). Cronbach' s alphas are 0.73, 0.77, 0.83, and 0.73 for the emphatic concern, personal distress, fantasy, and perspective taking subscales, respectively (De Corte et al., 2007). Afterwards,

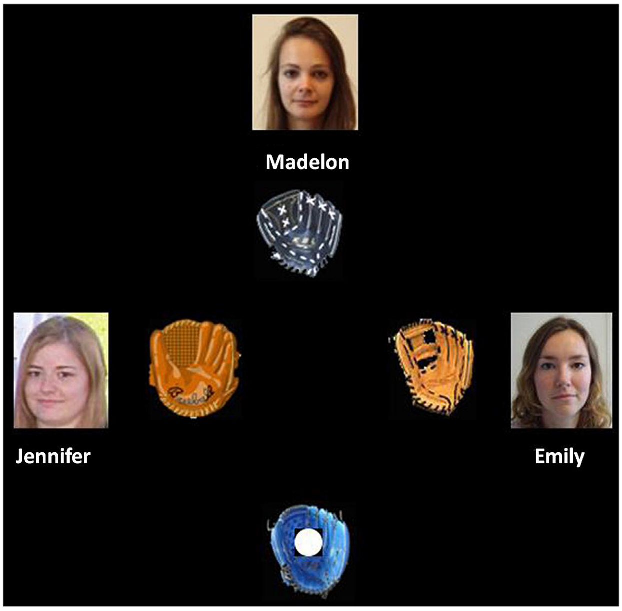

FIGURE 1 | Set-up Cyberball task in the neutral condition. The participants' glove was at the bottom of the screen. The glove, name, and picture of the unknown victim with a neutral or sad expression were at the upper part of the screen. The gloves, names, and pictures of the other unknown players were to the left and right of the screen center. Figure taken from Riem et al. (2013).

participants rated again their mood and HR, SBP, and DBP were collected for the second time (T2). Then, they performed for 8 min each two unrelated computer tasks tapping into emotional working memory and implicit biased attitudes (data not reported here) before rating their mood and having HR, SBP, and DBP measured for the third time (T3). After that, participants performed the prosocial Cyberball game, which lasted for 10 min. Once completed the Cyberball, mood, HR, SBP, and DBP were measured for the fourth time (T4). tVNS was applied throughout all three computer tasks.

Transcutaneous Vagus Nerve Stimulation (tVNS)

We used a tVNS wired neurostimulating device connected with two titan electrodes fastened on a gel frame (CM02, Cerbomed, Erlangen, Germany). Following the suggestions by Dietrich et al. (2008) and Steenbergen et al. (2015) for optimal stimulation, the tVNS®device was programmed to a stimulus intensity at 0.5 mA, delivered with a pulse width of 200–300 μs at 25 Hz. Stimulation alternated between On/Off periods every 30 s. In the sham (placebo) condition, the stimulation electrodes were placed on the center of the left ear lobe instead of the outer auditory canal. Indeed, the ear lobe has been found to be free of cutaneous vagal innervation (Peuker and Filler, 2002; Fallgatter et al., 2003) and a recent fMRI study showed that this sham condition produced no activation in the cortex and brain stem (Kraus et al., 2013).

Importantly, following safety criteria to avoid cardiac side effects, the stimulation was always applied to the left ear (Nemeroff et al., 2006; Cristancho et al., 2011). Indeed, although efferent fibers of the vagus nerve modulate cardiac function, such a modulation seems to relate only to the efferent vagal fibers connected to the right ear (Nemeroff et al., 2006). Consistently, a clinical trial showed no arrhythmic effects of tVNS when applied to the left ear (Kreuzer et al., 2012).

Prosocial Cyberball

The Cyberball game was an adapted version of the task used in the study by Riem et al. (2013). The game was a virtual online group interaction involving four players throwing a ball to each other. Participants were led to believe that they would play this game via Internet with three other unknown peers. In reality, the other players were virtual computer-controlled confederates. The participants' glove was at the bottom of the screen. The gloves, names, and pictures of the unknown victim and of the other two unknown players were displayed in the upper part of the screen, and to the left and to right of the screen, respectively (see **Figure 1**). A computer keyboard was used by the participants to throw the ball to the other players.

The game consisted of two parts with a short break in between, each comprising three 48-trial blocks. The first block was programmed to create a fair situation where all players received the ball equally often (i.e., fair play block). The second (i.e., unfair play block 1) and the third (i.e., unfair play block 2) blocks were programmed to establish an unfair situation in which one of the players (i.e., the victim) never received any throw from the two unknown players. The third block included an additional manipulation: the facial expression of the ostracized player changed from neutral to sad (i.e., unfair play block 2 with sad victim), or remained neutral (i.e., unfair play block 2 with neutral victim). Half of the participants were confronted with the ostracized player showing a sad expression in the third block of the first part, and with the ostracized player showing a neutral expression in the third block of the second part. The remaining participants experienced the two conditions in the reversed order. The sad facial expression did not change when the participant threw the ball to the ostracized victim.

The dependent variable was the number of ball tossing to the victim, calculated as the ratio between the number of throws of the participant to the victim and the total number of throws by the participant to any of the players. Ratios were calculated for each play block. A ratio larger than 0.33 in the unfair play block indicates that participants compensate for the other player' ostracism by throwing the ball to the victim more often.

Statistical Analyses

To examine whether active tVNS, as compared to sham (placebo) stimulation, influenced prosocial behavior, as indexed by the number of tossing to the ostracized player, repeated-measures analysis of variance (ANOVA) was carried out with the ratio of ball throws to the victim as dependent variable and play block (fair play blocks, unfair play block 1, unfair play block 2 with neutral victim, unfair play block 2 with sad victim) and session (active vs. sham) as within-participants factors. Mood (i.e., pleasure and arousal scores), HR, SBP, and DBP were analyzed separately by means of repeated-measures ANOVAs with effect of time (first vs. second vs. third vs. fourth measurement) and session (active vs. sham) as within-participants factors.

A significance level of $p < 0.05$ was adopted for all statistical tests. Tukey HSD *post hoc* tests were performed to clarify mean differences.

Furthermore, we calculated Bayesian (posterior) probabilities associated with the occurrence of the null [$p(H_0|\ D)$] and alternative [$p(H_1|\ D)$] hypotheses, given the observed data. Bayesian analyses allow making inferences about both significant and non-significant effects by estimating the probability of their occurrence, with values ranging from 0 (i.e., no evidence) to 1 (i.e., very strong evidence; see Raftery, 1995). To calculate Bayesian probabilities we used the method proposed by Wagenmakers (2007) and Masson (2011). This method uses Bayesian information criteria (BIC), calculated using a simple transformation of sum-of-squares values generated by the standard ANOVA, to estimate Bayes factors and generate $p(H_0|\ D)$ and $p(H_1|\ D)$, assuming a "unit information prior" (for further details, see Kass and Wasserman, 1995; see also Jarosz and Wiley, 2014).

Results

Cyberball Task

ANOVA revealed a significant effect of play block [$F(3,69) = 29.58$, $p < 0.001$, $\eta_p^2 = 0.56$, $p(H_1|\ D) = 0.83$]. *Post hoc* tests showed that participants threw the ball more often to the victim in the unfair blocks compared to the fair block ($p_s < 0.001$, Cohen's $d_s \geq 1.45$). There were no significant differences between the three types of unfair blocks ($p_s \geq 0.36$, Cohen's $d_s \leq 0.27$). Importantly, neither the main effect of session [$F(1,23) < 1$, $p = 0.99$, $\eta_p^2 < 0.001$, $p(H_0|\ D) > 0.99$] nor the session by play block interaction [$F(3,69) < 1$, $p = 0.76$, $\eta_p^2 = 0.02$, $p(H_0|\ D) > 0.99$] reached statistical significance, see **Figure 2**.

Empathy Quotient (EQ) and Interpersonal Reactivity Index (IRI)

For both the EQ and IRI, participants' scores were comparable to the values typically observed in healthy participants: EQ (47.96, SD = 9.8); $\text{IRI}_{\text{total score}}$ (66.75, SD = 12.11); $\text{IRI}_{\text{perspective taking}}$ (18.42, SD = 4.8); $\text{IRI}_{\text{fantasy scale}}$ (16.79, SD = 5.8); $\text{IRI}_{\text{emphatic concern}}$ (18.79, SD = 4.0); $\text{IRI}_{\text{personal distress}}$ (12.75, SD = 3.3). In order to examine the possible role of individual differences in empathy, Pearson correlations

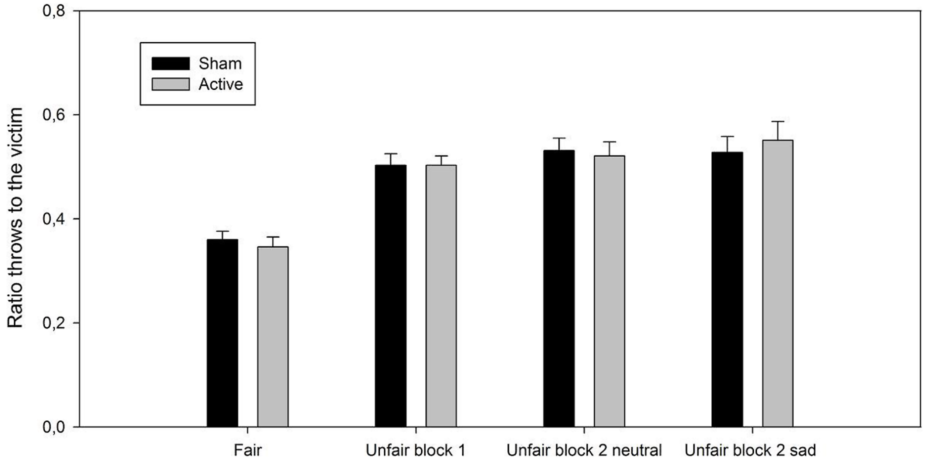

FIGURE 2 | Ratio of throws (M, SEM) to the excluded player as a function of play block (fair play block, unfair play block 1, and unfair block 2 with the neutral and sad victim) and session (active and sham).

TABLE 1 | Mean heart rate (HR) values (in beats per minute), systolic and diastolic blood pressure (SBP and DBP; in mmHg), and arousal and pleasure scores as function of effect of time [first (T1) vs. second (T2) vs. third (T3) vs. forth (T4) measurement; see text for more details] for active and sham (placebo) sessions.

	T1		T2		T3		T4	
	Active	Sham	Active	Sham	Active	Sham	Active	Sham
HR	79.9 (2.8)	81.5 (2.7)	82.4 (3.0)	76.1 (1.8)	78.6 (2.6)	79.4 (4.2)	79.8 (2.8)	74.0 (2.3)
SBP	118.0 (3.1)	118.5 (3.3)	116.7 (3.0)	114.0 (2.8)	118.8 (2.6)	117.2 (3.0)	116.3 (3.1)	118.8 (2.8)
DBP	70.4 (2.1)	72.1 (2.1)	72.9 (2.1)	72.6 (2.8)	72.8 (1.8)	70.0 (1.6)	71.4 (1.8)	72.5 (2.1)
Arousal	0.8 (0.3)	0.7 (0.2)	0.5 (0.3)	0.8 (0.2)	0.4 (0.3)	0.7 (0.3)	0.4 (0.3)	0.5 (0.3)
Pleasure	1.5 (0.2)	1.5 (0.2)	1.6 (0.2)	1.5 (0.2)	1.3 (0.2)	1.0 (0.3)	1.5 (0.2)	1.5 (0.2)

SEM are shown in parentheses.

coefficients were computed between the ratio of ball throws to the victim and participants' EQ and IRI scores, separately for the four blocks (fair play blocks, unfair play block 1, unfair play block 2 with neutral victim, unfair play block 2 with sad victim) and the two sessions (active and sham). No significant correlations were observed ($p_s \geq 0.07$).

Physiological and Mood Measurements

Table 1 provides an overview of the outcomes for physiological and mood measurements. ANOVAs showed a main effect of timing for pleasure [$F(3,69) = 4.15$, $p = 0.009$, $\eta^2_p = 0.15$, but $p(H_1| D) = 0.39$], but not for the other variables ($F_s \leq 1.0$, $p_s \geq 0.39$, $\eta^2_{ps} \leq 0.04$, $p_s(H_0| D) \geq 0.99$). Pleasure levels dropped at the third measurement and rose again at the fourth one (1.5 vs. 1.5 vs. 1.2 vs. 1.5). Indeed, *post hoc* tests revealed that pleasure levels at the third measurement were significantly different from levels at the first, second, and forth measurements ($p_s \leq 0.05$, Cohen's $d_s \geq 0.42$). No significant differences were observed when comparing scores at the first, second, and forth measurements to each other ($p_s \geq 0.99$, Cohen's $d_s \leq 0.11$). Importantly, HR, DBP, SBP, pleasure, and arousal did not significantly differ between the two sessions. Indeed, neither the main effects of session nor the two-way interactions involving session and time were significant [$F_s \leq 1.76$, $p_s \geq 0.16$, $\eta^2_{ps} \leq 0.07$, $p_s(H_0| D) \geq 0.71$]. Significant differences between the two sessions were not observed either when considering only participants' scores measured immediately before (T3) and at the end of the Cyberball game (T4) [$F_s \leq 2.7$, $p_s \geq 0.12$, $\eta^2_{ps} \leq 0.11$, $p_s(H_0| D) \geq 0.60$].

Discussion

Our results, corroborated by Bayesian inference, suggest that tVNS does not directly modulate reactions to vicarious ostracism in a Cyberball game: participants did not throw more balls toward the unknown ostracized person in the active stimulation compared to sham (placebo). Given that the insula and the PFC seem to be involved in vicarious ostracism (Masten et al., 2011a, 2013a) and that tVNS produces a reliable activation in both the insula and the PFC (Dietrich et al., 2008; Kraus et al., 2013), we expected active tVNS to enhance prosocial helping behavior, leading participants to increase their tendency to compensate the victim for the other players' ostracism. We can only speculate what the reasons for this outcome pattern are. First, we considered just one index of vicarious ostracism. Even though this index is frequently used and well-established, it remains to be seen whether other measurements of vicarious ostracism can be affected by tVNS. In our current study the victim was unknown to the participant, and an interesting example to consider would be to use a Cyberball game in which the ostracized player is known to the participant and/or to manipulate the group membership (in-group vs. out-group) of the victim. That being said, it is possible that the version of the task we used was not sensitive enough to allow possible tVNS-induced modulations to be detected. Second, and related to the previous point, the lack of a tVNS modulation on vicarious ostracism may be related to the sample of participants tested in the current study, who showed high empathy. As mentioned in the introduction, compensatory behavior following vicarious ostracism is reckoned to reflect trait empathy (Masten et al., 2010). Indeed, people high in trait empathy tend to experience augmented vicarious ostracism and show higher activation in empathy-related brain regions, that is, in the same regions that are activated when observing ostracism (Masten et al., 2010, 2011a,b, 2013a) and that were targeted by tVNS stimulation. Thus, it is plausible that tVNS was not effective at modulating reactions to vicarious ostracism because participants already displayed a lot of empathy (i.e., hitting a ceiling effect), which prevented a possible tVNS-induced effect from emerging. This may also explain why we failed to observe any significant correlation between trait empathy and compensatory behavior. Furthermore, individual differences in family background may at least partially account for the lack of effectiveness of our manipulation. For instance, in a previous study applying intranasal oxytocin, behavioral effects were only found in participants with rather warm relationships with their parents (Riem et al., 2013), and similar neural effects moderated by childhood experiences have also been suggested (Bakermans-Kranenburg and Van IJzendoorn, 2013). Thus, it would be crucial for follow-up studies to assess the role of past experiences and/or the quality of early relationships in moderating the possible effectiveness of tVNS in promoting prosocial behavior. Third, in our study we used a current of 0.5 mA. While this intensity was sufficient to enhance response selection (Steenbergen et al., 2015), changing vicarious ostracism may require greater intensities.

Finally, there are some limitations of the current study that warrant discussion. First, it would have been optimal to have linked the implementation of tVNS with appropriate physiological assays, such as the vagus-evoked potentials (see Bestmann et al., 2014, for a related discussion). Follow-up studies might consider a more thorough exploration of vicarious ostracism through scalp-EEG measures, such as P3b component and frontal EEG asymmetry, two cortical correlates of ostracism (Kawamoto et al., 2013). Second, we did not explicitly assess participants' blinding by asking them if they could guess the stimulation received.

In sum, we failed to obtain any evidence that tVNS, by increasing insula and PFC neural activity, is effective at modulating reactions to vicarious ostracism in a Cyberball game. Notwithstanding, our results may be useful. First, they can inform future studies on how to better design tVNS experiments to possibly affect vicarious ostracism and prosocial compensation and, second, to suggest potential future directions in this field.

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GENERAL COMMENTARY
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Corrigendum: A question of scent: lavender aroma promotes interpersonal trust

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A Corrigendum on

A question of scent: lavender aroma promotes interpersonal trust
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Mistakenly, the trust scores were reported in Euros, whereas the SD and CI were reported in Eurocents.

Please find below a list of corrections made to this article:

- On page 2, right column, under RESULTS—TRUST GAME, the first sentence should read "The dependent measure was the trust score, computed as the amount of money transferred to the trustee (in Eurocents), for each experimental group (Lavender, Peppermint, Control)."
- On page 3, left column, 7th row, the text "$M = 3.90$" should read "$M = 390$."
- On page 3, left column, 8th row, the text "$M = 3.23$" should read "$M = 323$."
- On page 3, left column, 9th row, the text "$M = 3.20$" should read "$M = 320$."

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.

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A question of scent: lavender aroma promotes interpersonal trust

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A previous study has shown that the degree of trust into others might be biased by inducing either a more "inclusive" or a more "exclusive" cognitive-control mode. Here, we investigated whether the degree of interpersonal trust can be biased by environmental factors, such as odors, that are likely to impact cognitive-control states. Arousing olfactory fragrances (e.g., peppermint) are supposed to induce a more exclusive, and calming olfactory fragrances (e.g., lavender) a more inclusive state. Participants performed the Trust Game, which provides an index of interpersonal trust by assessing the money units one participant (the trustor) transfers to another participant (the trustee), while being exposed to either peppermint or lavender aroma. All participants played the role of trustor. As expected, participants transferred significantly more money to the alleged trustee in the lavender as compared to the peppermint and control (no aroma) conditions. This observation might have various serious implications for a broad range of situations in which interpersonal trust is an essential element, such as cooperation (e.g., mixed-motives situations), bargaining and negotiation, consumer behavior, and group performance.

Keywords: interpersonal trust, cognitive-control state, aromas, lavender, peppermint

INTRODUCTION

Interpersonal trust is one of the most important determinants of initiating, forming, and maintaining social relationships (Balliet and Van Lange, 2013). As it facilitates important social behaviors, such as social bonding and cooperative behavior, it is often regarded as the social glue of society (Pruit and Kimmel, 1977; Yamagishi, 1986; Grovier, 1997; Van Lange et al., 2011). Therefore, increasing our knowledge about the factors that influence interpersonal trust is crucial for a better understanding of social life.

Earlier studies indicate that interpersonal trust is a rather volatile state that is sensitive to and adjusts to the situation at hand. Research has shown that the degree to which people trust each other is influenced, for example, by their mood (Capra, 2004) or self-construal (Maddux and Brewer, 2005). More recent studies have demonstrated that interpersonal trust increases by administering the food supplement L-Tryptophan, the biochemical precursor of serotonin (Colzato et al., 2013), and the neuropeptide oxytocin (Kosfeld et al., 2005). Moreover, Tops et al. (2013) reported trust scores to increase with salivary oxytocin levels under conditions of social novelty, but to decrease with such levels under conditions of social familiarity.

In a seminal study, Baron (1997) showed that prosocial behavior (i.e., by retrieving a dropped pen or providing change for money) was significantly greater in the presence of pleasant fragrances than in their absence.

In the present research, we examined whether interpersonal trust can be influenced by specific odors in the environment that are likely to impact cognitive-control states. Research has suggested that calming scents, like lavender (Diego et al., 1998; Field et al., 2005; Lehrner et al., 2005), bias individuals' attention toward inclusive representational levels, whereas stimulating scents, such as peppermint (Kovar et al., 1987; Warm and Dember, 1990), bias it to exclusive ones (see Herz, 2009; Johnson, 2011, for reviews). For instance, peppermint aroma has been found to improve memory (Moss et al., 2008), sustained visual attention (Warm et al., 1991), alertness in a driving simulator task (Raudenbush et al., 2009), and athletic task performance (Raudenbush et al., 2001). In contrast, lavender aroma has been shown to attenuate fatigue (Sakamoto et al., 2005), to promote behavior commitment (Grimes, 1999), and to increase the amount of time customers spend in a restaurant and the amount of purchasing (Guéguen and Petr, 2006).

Recent studies have shown that inducing particular (non-social) cognitive-control states or control styles by means of creativity tasks affects the processing of social information in a systematic ways (Colzato et al., 2013; Sellaro et al., 2014). As shown elsewhere, tasks tapping into divergent thinking are accompanied with a more "inclusive/integrative" thinking style, whereas convergent thinking has been found to be linked with a sort of "exclusive" thinking (Fischer and Hommel, 2012; Hommel, 2012). By exploiting this property, Colzato et al. (2013) showed that people are more likely to relate their own actions to that of a co-actor in the context of a divergent-thinking task than in the context of a convergent-thinking task. This implies that divergent thinking involves a cognitive-control state that promotes self-other integration. Interestingly for our purposes, Sellaro et al. (2014) showed that adopting such thinking styles affects interpersonal trust as well: interpersonal trust is more pronounced after engaging in divergent thinking as compared to convergent thinking. Considering that interpersonal trust can be enhanced by inducing a more inclusive cognitive-control state (Sellaro et al., 2014), this suggests that being exposed to the (calming) scent of lavender will result in higher interpersonal trust, while being exposed to the (stimulating) scent of peppermint will reduce it.

We tested the link between aromas and interpersonal trust by exposing healthy young adults to the scent of either lavender (i.e., relaxing aroma) or peppermint (i.e., stimulating aroma), while engaging in a social interaction (a behavioral Trust Game). As a control condition, a third group of participants was required to perform the Trust Game in a non-scented room (cf. e.g., Guéguen and Petr, 2006; Moss et al., 2008).

Given that interpersonal trust has been found to be enhanced by positive mood (Capra, 2004) and that the exposure to pleasant aromas is reckoned to increase mood (Herz, 2009), we also assessed participants' subjective affective states, and we did so before and after the Trust Game. To this end, we used the Affect Grid (Russell et al., 1989), a single-item scale that is particularly suitable for rapid and repeated assessment of people's subjective affective states. The scale consists of a 9 × 9 grid, where the horizontal axis represents affective valence (ranging from unpleasantness to pleasantness), and the vertical axis represents perceived activation (ranging from high arousal to sleepiness; see **Figure 1**). Thus, two scores can be derived from the scale, one for pleasure and one for arousal. The Affect Grid has been shown to have good reliability, convergent validity, and discriminant validity (Russell et al., 1989).

MATERIALS AND METHODS

PARTICIPANTS

Ninety healthy young adults (mean age = 20.20 years, SD = 1.80, range = 18–24 years; 68 females) came to the lab as unacquainted same-sex dyads. Participants were screened via a phone call by the experimenter before inclusion, using the Mini International Neuropsychiatric Interview (M.I.N.I.; Sheehan et al., 1998). The M.I.N.I. is a short, structured, interview of about 15 min that screens for several psychiatric disorders and drug use, often used in clinical and pharmacological research (Sheehan et al., 1998; Colzato and Hommel, 2008; Colzato et al., 2009).

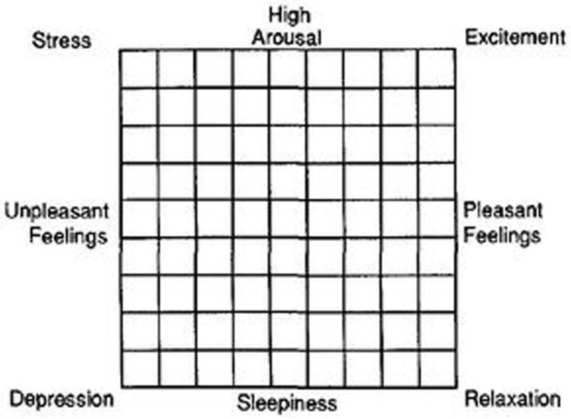

FIGURE 1 | The Affect Grid (taken from Russell et al., 1989). The scale requires participants to rate their current affective state by placing an "X" in one of the 81 cells of the matrix. The horizontal axis represents variations in unpleasant–pleasant feelings (ranging from −4 to +4), whereas the vertical axis represents variations in arousal–sleepiness feelings (ranging from +4 to −4). The scale provides two scores, one for pleasure and one for arousal, which indicate the location of the participant's affective state within a two-dimensional space defined by hedonic tone and activation.

Participants were equally and randomly distributed over three experimental groups. Thirty participants played the Trust Game in a lavender-scented room, 30 in a peppermint-scented room, and the remaining participants performed the task in a non-scented room.

Prior to the testing session, participants received a verbal and written explanation of the procedure, and they were told to take part in a study investigating decision-making processes. No information was provided about the presence of aromas. At the end of the testing session participants were debriefed. Only four participants (two in the peppermint group and two in the lavender group) asked the experimenter spontaneously whether there were any aromas in the testing room but were naïve about the hypotheses concerning the outcome of the experiment.

Written informed consent was obtained from all subjects; the protocol was approved by the local ethical committee (Leiden University, Institute for Psychological Research).

PROCEDURE

The three experimental groups [lavender, peppermint, and control (no aroma)] were tested in three different cubicles identical in size. "De Tuinen^{TM}" pure essential oils (De Tuinen Aromatherapie) of peppermint and lavender were used to generate the ambient aromas. The smell of the non-scented room was odor-neutral. Following Colzato et al. (2014), four drops of the appropriate oil were applied to a candle diffuser, diluted in 30 ml of water. Two separate diffusers were used for spreading the two aromas. The diffuser was out of participants' sight and the candle was lighted 20 min before the testing session started to assure a uniform diffusion in the testing room.

Participants came to the lab as unacquainted same-sex dyads. Upon arrival, members of each dyad were seated in separate cubicles where, after having read and signed the informed consent, they were asked to rate their affective state on a 9 × 9 Pleasure × Arousal grid (values ranging from −4 to 4; i.e., The Affect Grid; Russell et al., 1989). Once they filled out the Affect Grid (i.e., after 5 min of exposure to the specific aroma), they played a behavioral Trust Game (Camerer and Weigelt, 1988; see **Figure 2**) and, immediately after, they rated again their affective state. The trust game lasted about 3 min (including instructions).

TRUST GAME

Participants were led to believe that one of them would play the role of trustor and the other the role of trustee (in reality, all participants were trustors). Participants were endowed with **€** 5, which they could keep or (partially) transfer to the trustee (allegedly the other member of their dyad). Participants were told that the transferred money would be tripled and that the trustee then must decide if and how to share the new amount. In this game, the amount transferred by the trustor is an indicator of interpersonal trust (Camerer, 2003).

RESULTS

TRUST GAME

The dependent measure was the trust score, computed as the amount of money transferred to the trustee, for each experimental group (Lavender, Peppermint, Control). To assess the effect of

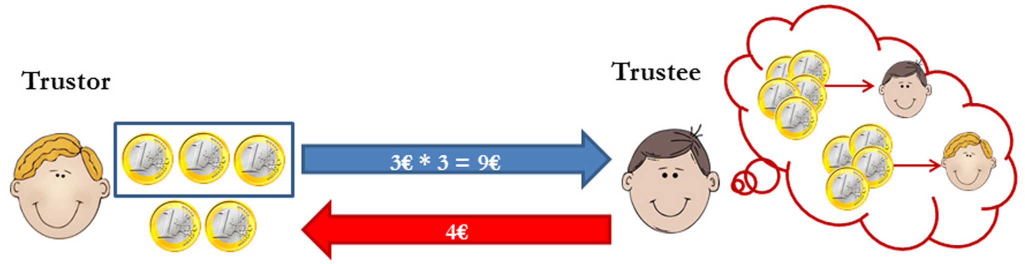

FIGURE 2 | Schematic representation of the Trust Game. In the trust game the trustor is endowed with a certain amount of money (e.g., € 5), which s/he can keep or (partially) transfer to the trustee. Participants are told that the transferred money would be tripled and that the trustee then must decide if and how to share the new amount. The amount of money the trustor transfers to the trustee is an indicator of interpersonal trust.

aroma, trust scores were submitted to a one-way analysis of variance (ANOVA) with condition (Lavender, Peppermint, Control) as between-subjects factor. As expected, aroma modulated participants' performance in the Trust Game, $F(2,87) = 3.53$, $p = 0.03$, $\eta_p^2 = 0.08$. Fisher LSD *post hoc* tests showed that participants in the lavender-scented room transferred more money to the trustee ($M = 3.90$, $SD = 125.5$) than participants in both the peppermint-scented room ($M = 3.23$, $SD = 115.0$) [95% CI = (7.48, 125.85), $p = 0.03$], and the non-scented room ($M = 3.20$, $SD = 104.5$) [95% CI = (11.08, 129.45), $p = 0.02$], whose performance was comparable [95% CI = (−55.59, 62.79), $p = 0.90$].

AFFECT GRID

Pleasure and Arousal scores were analyzed separately by means of two repeated-measures ANOVAs with effect of time (first vs. second measurement) as a within-participants factor and group (Lavender, Peppermint, Control) as a between-participants factor.

The ANOVA performed on the Pleasure scale did not reveal any significant effect or interaction between time and group, $Fs \leq 1.90$, $ps \geq 0.15$. Pleasure levels were thus comparable across group and time: the mean scores at the two time points were 1.20 ($SD = 1.5$) and 1.40 ($SD = 1.6$) for participants in the Lavender group, 1.30 ($SD = 1.1$) and 1.20 ($SD = 1.4$) for participants in the Peppermint group, and 1.70 ($SD = 1.0$) and 1.80 ($SD = 0.9$) for participants in the Control group.

The ANOVA performed on the Arousal scale revealed a significant main effect of group, $F(2,87) = 7.04$, $p = 0.005$, $\eta_p^2 = 0.14$. Fisher LSD *post hoc* analyses showed that arousal scores were lower in the Lavender group ($M = -0.07$, $SD = 1.3$) than in both the Peppermint ($M = 0.90$, $SD = 1.3$) [95% CI = (−1.62, −0.24), $p = 0.008$] and the Control ($M = 1.20$, $SD = 1.3$) [95% CI = (−1.94, −0.56), $p < 0.001$] groups. Arousal levels for the Peppermint and Control groups were comparable [95% CI = (−1.01, 0.37), $p = 0.36$]. Neither a main effect of time nor an interaction between group and time was significant, $Fs \leq 1.50$, $ps \geq 0.25$, reflecting stable arousal levels across time in all groups: the mean scores at the two time points were −0.10 ($SD = 1.5$) and 0.0 ($SD = 1.7$) for participants in the Lavender group, 0.77 ($SD = 1.5$) and 0.97 ($SD = 2.0$) for participants in the Peppermint group, and 1.07 ($SD = 1.1$) and 1.30 ($SD = 1.3$) for participants in the Control group.

To rule out the possible influence of arousal and pleasure levels in mediating the observed relationship between the degree of interpersonal trust and scent, Pearson correlations coefficients were computed between the amount of money transferred and the levels of arousal and pleasure at the first and second measurements, separately for the three groups. No significant correlations were found, $ps \geq 0.18$, suggesting that levels of (conscious) arousal or pleasure did not affect participants' money transfers.

DISCUSSION

This study is the first to demonstrate that scent can have an impact on interpersonal trust. Indeed, we observed that, compared to peppermint and control (no aroma) exposure, being exposed to lavender aroma increased interpersonal trust, as indexed by the Trust Game. We argue that the calming scent of lavender temporarily induces a more inclusive cognitive-control state that, in turn, influences the extent to which people trust others. By comparison, being exposed to peppermint aroma did not reduce interpersonal trust compared to the control (no aroma) condition. This might be due to the ineffectiveness of the selected aroma to induce a more exclusive cognitive-control state to affect interpersonal trust accordingly. Alternatively, it is also possible that interpersonal trust is affected selectively by a more inclusive cognitive-control state, but not by a more exclusive cognitive-control state. Future studies might consider the idea to test whether interpersonal trust can be influenced by other aromas that, similar to peppermint, are suspected to bias cognitive-control toward a more exclusive state.

It is interesting to note that we did not find any evidence that pleasure or arousal changes might be directly responsible for the observed outcome. However, our measures relied on conscious self-assessment and thus reflect merely conscious aspects of the participant's affective state. This does not allow us to exclude the possible impact of more implicit pleasure and arousal changes that future studies might consider by including physiological measurements, such as galvanic skin response, heart rate, and diastolic and systolic blood pressure.

The present study has some limitations that deserve discussion. First of all, we did not assess participants' olfactory sensitivity, which would have allowed us to exclude anosmic participants and to control for potential differences in participants' smell threshold. Thus, it is crucial for future studies to asses participants' olfactory threshold, for example, by means of dilution-to-threshold techniques in which an odor sample is diluted with odorless air at a number of levels, and the dilution series is presented in ascending order of odor concentration. Second, we did not address explicitly whether participants were aware of the presence of the aroma, whether they could identify the specific aroma they were exposed to, and/or whether they found the scent really calming (vs. arousing). Future studies should take into consideration these important aspects. Third, it would be useful to include more objective measures to verify whether the two selected aromas differentially affected participants' cognitive-control state. However, given that a previous study has shown that interpersonal trust may be increased by inducing a more inclusive cognitive-control state (Sellaro et al., 2014), we have reasons to believe that at least lavender aroma worked as expected. Finally, in order to control for expectancy effects, besides blinding the participants to the type of odor exposure, follow-up studies should consider to blind the experimenter in this regard as well. Moreover, given that in the current study participants met the other member of the dyad, i.e., the participant with whom they supposedly played the Trust Game, it is important for future studies to obtain evaluations regarding trustworthiness and likeability of the other member.

To sum up, these findings provide converging support for the idea that interpersonal trust is a volatile state that is, at least to some extent, controlled by domain-general (i.e., not socially dedicated) cognitive states. Moreover, the present findings reinforce the idea that interpersonal trust is sensitive to situational and environmental factors (Buchan et al., 2002; Capra, 2004; Maddux and Brewer, 2005; Colzato et al., 2013). Our results might have various serious implications for a broad range of situations in which interpersonal trust is an essential element, such as cooperation (e.g., mixed-motives situations), bargaining and negotiation, consumer behavior, social bonding, and group performance. As in the case of a previous study (Baron, 1997), which showed that prosocial behavior was significantly greater in the presence of "sweet" fragrances (e.g., baking cookies, roasting coffee), smelling the aroma of lavender may help a seller to establish more easily a trusting negotiation to sell a car, or in a grocery store it may induce consumers to spend more money buying products. The smell of lavender may also be helpful in sport psychology to enhance trust and build team spirit, for example in the case of team games such as soccer and volleyball.

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Tryptophan promotes charitable donating

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The link between serotonin (5-HT) and one of the most important elements of prosocial behavior, charity, has remained largely uninvestigated. In the present study, we tested whether charitable donating can be promoted by administering the food supplement L-Tryptophan (TRP), the biochemical precursor of 5-HT. Participants were compared with respect to the amount of money they donated when given the opportunity to make a charitable donation. As expected, compared to a neutral placebo, TRP appears to increase the participants' willingness to donate money to a charity. This result supports the idea that the food we eat may act as a cognitive enhancer modulating the way we think and perceive the world and others.

Keywords: tryptophan, serotonin, charity

INTRODUCTION

"Every good act is charity. A man's true wealth hereafter is the good that he does in this world to his fellow", Molière once said. Indeed, charitable donating is an essential component of prosocial behavior and a key determinant of social reliability (Milinski et al., 2002).

Pharmacological studies in rats and humans suggest that the neurotransmitter serotonin (5-HT) plays a crucial role in promoting prosocial behavior (Crockett, 2009). Indeed, as pointed out by Siegel and Crockett (2013), serotonergic levels tend to be negatively correlated with antisocial behaviors such as social isolation and aggression, and tend to be positively correlated with prosocial behaviors such as cooperation and affiliation. Prosocial behavior can be reduced by lowering 5-HT levels through tryptophan depletion (Wood et al., 2006; Crockett et al., 2008, 2009) and enhanced through administering the food supplement L-Tryptophan (TRP), the biochemical precursor of 5-HT (Colzato et al., 2013) or through administering selective serotonin reuptake inhibitors (Knutson et al., 1998; Tse and Bond, 2002).

Here, for the first time, we investigated whether the administration of the essential amino acid TRP, contained in food such as fish, eggs, soy, and milk, can promote charitable donating. TRP supplementation is known to increase plasma TRP levels and to influence brain 5-HT synthesis (Markus et al., 2008). We expected to find a beneficial effect of TRP on charitable donating because donating was found to selectively activate the subgenual–septal area (Moll et al., 2006), which shares reciprocal anatomical connections with raphe nuclei (Drevets, 2001), the principal release center of 5-HT in the brain. Hence, it is likely that the activation of the subgenual–septal area is modulated through serotonergic projections—which we aimed to target by the supplementation of TRP.

MATERIALS AND METHODS

PARTICIPANTS

Thirty-two healthy international south European students (mean age = 21.8; 4 male, 28 female; mean Body Mass Index = 21.5, range 17.8–30.8) with no cardiac, hepatic, renal, neurological, or psychiatric disorders, personal or family history of depression, migraine and medication or drug use participated in the experiment. Participants were screened via a phone call by the experiment leader before inclusion, using the mini international neuropsychiatric interview (MINI; Sheehan et al., 1998). The MINI is a short, structured, interview of about 15 minutes that screens for several psychiatric disorders and drug use, often used in clinical and pharmacological research (Sheehan et al., 1998; Colzato and Hommel, 2008; Colzato et al., 2009). Participants were randomly assigned to two experimental groups. Sixteen participants (2 male, 14 female) were exposed to an oral dose (powder) of 0.8 grams of TRP (supplied by AOV International Ltd.)—which roughly corresponds to the amount of TRP contained in 3 eggs–and 16 (2 male, 14 female) to 0.8 grams of microcrystalline cellulose (Sigma-Aldrich Co. LLC), a neutral placebo. These doses were always dissolved in 200 ml of orange juice. Following Markus et al. (2008) and Colzato et al. (2013) women using contraception were tested when they actually used the contraception pill. On each experimental morning, participants arrived at the laboratory at 9:30 am. Participants had been instructed to fast overnight (eating was not allowed after 11:00 pm); only water or tea without sugar was permitted. In addition, subjects were not allowed to use any kind of drugs before or during the experiment, or to drink alcohol from the day before their participation until their completion of the study.

Written informed consent was obtained from all subjects; the protocol and the remuneration arrangements of 10 Euros were approved by the local ethical committee (Leiden University, Institute for Psychological Research).

PROCEDURE

All participants were tested individually. Upon arrival, following Colzato et al. (2013), participants were asked to rate their mood on a 9 × 9 Pleasure × Arousal grid (Russell et al., 1989) with values ranging from –4 to 4. Heart rate (HR; in beats per minute) and systolic and diastolic blood pressure (SBP and DBP) were collected from the non-dominant arm with an OSZ 3 Automatic Digital Electronic Wrist Blood Pressure Monitor (Spiedel & Keller). One hour following the administration of TRP (corresponding to the beginning of the 1 hour-peak of the plasma concentration; Markus et al., 2008) or placebo, participants again rated their mood, before having HR, SBP, and DBP measured for the second time.

Next, after having performed an unrelated computer-based attentional blink task that requires the detection of two targets in a rapid visual on-screen presentation, which took about 30 minutes, participants were presented with the donating task. After the donating task, participants again rated their mood, before having HR, SBP, and DBP measured for the third time.

DONATING TASK

Following van IJzendoorn et al. (2011), participants were not informed beforehand that the donating task was part of the experiment. Donating behavior was measured by the amount of money the participant donated. After having received 10 Euros (one 5-Euronote, two 1-Euro coins, and 6 Fifty-cent coins) for their participation in the study, participants were left alone and asked whether they were willing to donate part of their financial reward to charity. Four money boxes (Unicef, Amnesty International, Greenpeace, and World Wildlife Fund) had been positioned on the table. All money boxes were filled with four Fifty-cent coins in order to enhance credibility (see van IJzendoorn et al., 2010, 2011, for a similar task).

Hence, the donating task was standardized, without the presence of an experimenter, and with a fixed amount of money in a fixed number of notes and coins. The donating task used in the van IJzendoorn et al. (2011) study was similar in terms of participants donating their own money to a real charity but it differed in terms of having the choice between four different charities compared to solely Unicef. Donated money was transferred to the bank accounts of the charities after data collection.

STATISTICAL ANALYSIS

Heart rate, systolic and diastolic blood pressure, mood, and arousal were analyzed separately by means of repeated-measures analyses of variance (ANOVAs) with effect of time (first vs. second vs. third measurement) as within-subjects factor and with group (Placebo vs. TRP) as between-group factor. A t-test for independent groups was performed to assess differences between the two groups (Placebo vs. TRP) in the amount of money donated. Effect magnitudes were assessed by calculating Cohen's d (Cohen, 1988). A significance level of $p < 0.05$ was adopted for all statistical tests.

RESULTS

PARTICIPANTS

No significant differences were found among group with respect to age (21.7, SD = 1.4 vs. 21.8, SD = 2.9, for the placebo and TRP group respectively), $t(30) = 0.15$, $p > 0.88$, and sex, $\chi 2$ (1, $N = 32$) = 0.00, $p = 1.00$.

DONATING TASK

As expected, participants donated significantly more euros to the charities in the TRP condition (1.00, SD = 0.79) than in the placebo condition (0.47, SD = 0.59), $t(30) = 2.14$, $p < 0.05$, Cohen's $\delta = 0.78$.

PHYSIOLOGICAL AND MOOD MEASUREMENTS

Analysis of variance s revealed that HR (78, SD = 10.9 vs. 72, SD = 9.4 vs. 69, SD = 9.2 and 75, SD = 13.1 vs. 71, SD = 8.5 vs. 68, SD = 11.2, after placebo and TRP, respectively), DBP (68, SD = 10.4 vs. 63, SD = 9.0 vs. 64, SD = 10.6 and 71, SD = 8.5 vs. 66, SD = 7.2 vs. 70, SD = 9.4, after placebo and TRP), SBP (110, SD = 12.8 vs. 104, SD = 11.2 vs. 106, SD = 11.8 and 114, SD = 8.1 vs. 109, SD = 10.3 vs. 112, SD = 9.7, after placebo and TRP), mood (0.9, SD = 1.4 vs. 1.4, SD = 1.4 vs. 1.2, SD = 1.4 and 0.9, SD = 1.6 vs. 1.0, SD = 1.6 vs. 1.2, SD = 1.6, after placebo and TRP), and arousal (0.6, SD = 1.8 vs. 1.1, SD = 1.5 vs. 0.4, SD = 1.8 and 0.5, SD = 1.6 vs. 0.5, SD = 1.5 vs. 0.2, SD = 1.3, after placebo and TRP) did not significantly change after the intake of TRP, F's < 1.

DISCUSSION

The present study is the first demonstration that charitable donating can be enhanced by serotonin-related food supplements. We argued that TRP supplementation, and the resulting boost in 5-HT should be beneficial for the participants' willingness to donate money to a charity.

One may wonder how this novel finding relates to the observation of Barraza et al. (2011) and van IJzendoorn et al. (2011) that the neuropeptide oxytocin (OT) also increases charitable donation. Serotonergic terminals, mainly originating from the dorsal and median raphe nuclei of the brainstem, project to the paraventricular nuclei (Larsen et al., 1996), where the neurons release OT. So, comparable effects on prosocial behavior of TRP and OT are conceivable if one considers the functional and anatomical interactions between serotonergic and oxytocinergic systems. Further, the administration of the serotonergic agonist fenfluramine to healthy subjects increases plasma OT levels (Lee et al., 2003). Thus, it may be likely that the willingness to donate money to a charity is modulated by the effect that 5-HT exerts on OT levels.

More research is needed to extend and replicate our preliminary findings with a bigger sample size. Follow-up studies should correlate the amount of money donated with plasma levels of TRP. Finally, to evaluate the effect of the TRP administration on the brain, it would be interesting to investigate whether TRP supplementation is associated with increased blood oxygenation level dependent (BOLD) changes in the fronto-mesolimbic networks, which are associated with charitable donating (Moll et al., 2006).

The present study is the first to show that TRP promotes charitable donating, an important element of prosocial behavior. Our results support the materialist approach that "you are what you eat" (Feuerbach, 1960)—the idea that the food one eats has a bearing on one's state of mind. The food we eat may thus act as a cognitive enhancer that modulates the way we deal with the "social" world. In particular, the supplementation of TRP, or TRP-containing diets, may support the prosocial behavior of charity that Molière was concerned about.

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