MENTAL IMAGERY IN CLINICAL DISORDERS

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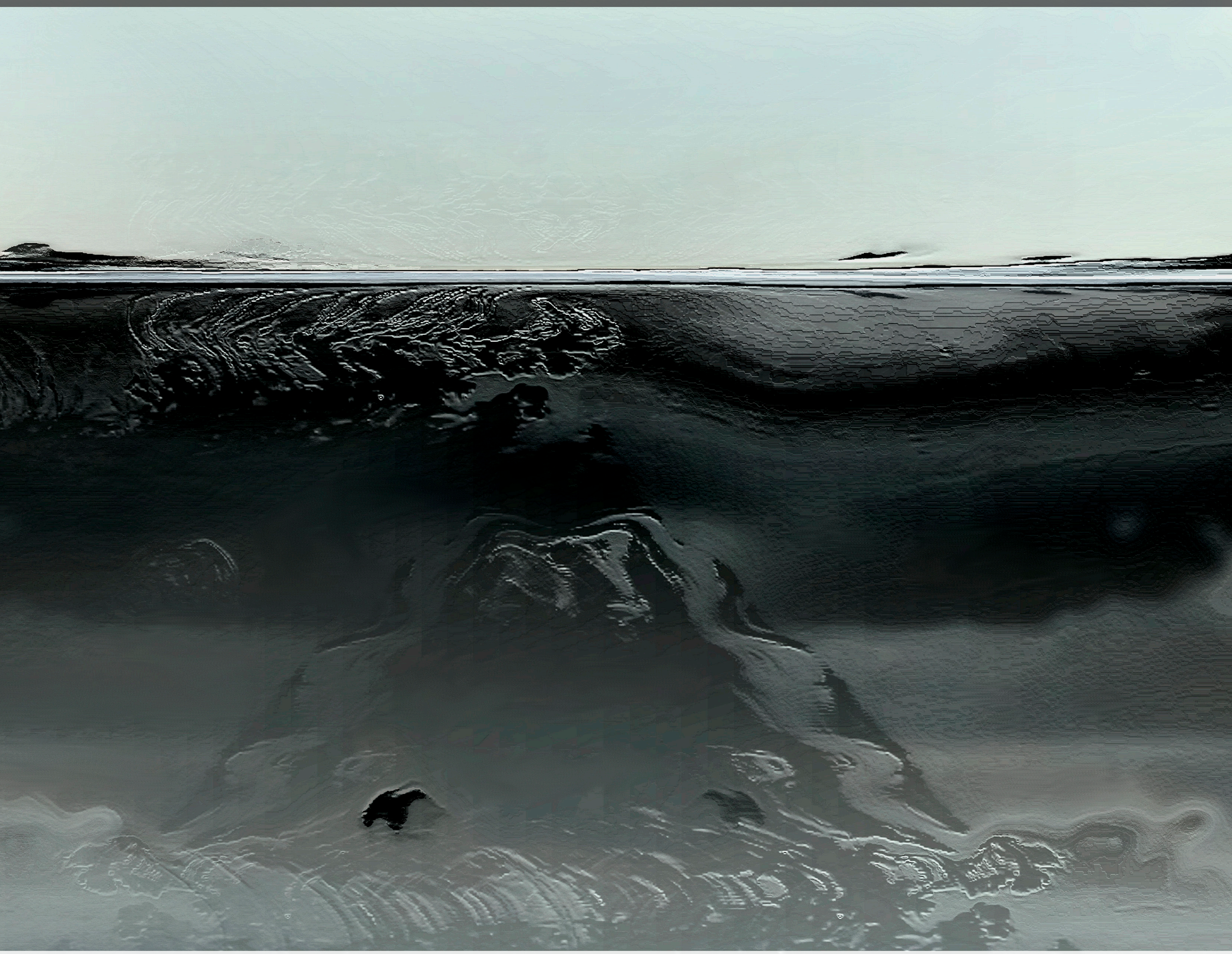

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MENTAL IMAGERY IN CLINICAL DISORDERS

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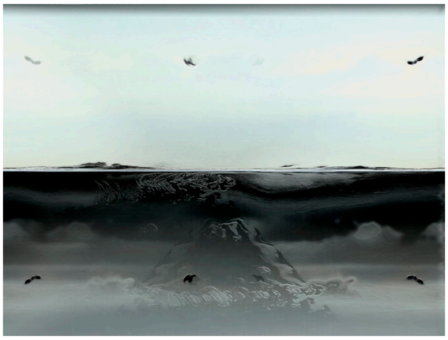

'Under the surface' by Aaf Woldinga

Mental imagery refers to the mental simulation or recreation of perceptual experience across different sensory modalities. The exploration of mental imagery represents a new and important area within clinical psychology, but arguably one still in its infancy. While mental imagery has featured prominently in recent theoretical accounts of disorders as diverse as post-traumatic stress disorder, phobia, body dysmorphic disorder, mood disorders, and psychosis, there remains an insufficiently strong theoretical and methodological foundation to enable comparison of the role of imagery across such different disorders. The current research topic presents a diverse range of cutting-edge papers focusing on investigating the underlying mechanisms and/or treatment interventions associated with mental imagery in clinical disorders, with the goal of helping establish those common elements most clinically relevant when investigating mental imagery.

The research topic comprises fifteen articles drawn from the fields of psychiatry, psychology, and neuroscience. This is a unique collection of articles that combine different perspectives from the field of clinical psychology with more diverse perspectives drawn from the wider literature on mental imagery. The original research studies and theoretical articles presented are organised around four main chapters that cover imagery and eye movements, imagery and craving, imagery and autobiographical memory, and imagery and clinical disorders. We believe that the range of submissions presented in the research topic make a strong contribution to helping establish a theoretical and methodological foundation that can enable the effective study of imagery across different disorders and domains.

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EDITORIAL
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Editorial: Mental Imagery in Clinical Disorders

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Keywords: mental imagery, clinical disorders, clinical psychology, eye movements, intrusive cognitions

Editorial on the Research Topic

Mental Imagery in Clinical Disorders

Mental imagery refers to the simulation or recreation of perceptual experience across different sensory modalities (1, 2). The study of mental imagery has clinical relevance because such imagery has been increasingly shown to play a key role across various psychological disorders (3, 4). The current research topic presents a diverse range of cutting-edge papers focusing on investigating the underlying mechanisms and/or treatment interventions associated with mental imagery in clinical disorders. We are very pleased with the final result, which comprises 15 articles drawn from the fields of psychiatry, psychology, and neuroscience. This topic provides a unique collection of articles that combine different perspectives from the field of clinical psychology with more diverse perspectives drawn from the wider literature on mental imagery.

One central theme across the topic is articles that have focused on the role of mental imagery in memories for negative events. Over the last decade, there has been a considerable impact in this area of, for example, working memory theory and dual task methodology [e.g., Ref. (5, 6)] on procedures associated with reducing intrusive cognitions. Two articles consider the potential limitations of this approach. van Veen et al. report two studies that examine how the speed of eye movement (EM) interacts with the emotionality and vividness of negative memories. Although a high rate of EM was associated with significant reduction in emotionality and vividness, contrary to expectation, the rate of EM did not interact with the extent of reported image vividness. The study reported by van Schie et al. examines the effect of EM on the retrieval of cued negative images acquired through word–image paired association. Dual-task EMs were found to have no effect on both self-rated vividness and emotionality of the images or latency responses. These studies highlight the importance of achieving greater understanding of the complex relationship between increased working memory load and selective interference effects on trauma-related imagery.

The research article by Nelis et al. takes a different but equally important approach by examining the recall of positive rather than negative life events. Two studies are reported in which participants are asked to retrieve positive autobiographical memories followed by induction of either image- or verbal-based processing styles. A concrete/imagery-based processing style was associated with a larger increase in positive effect in comparison to verbal processing, which is consistent with the perspective that mental imagery can serve as an "emotional amplifier" of personal memories (7).

In the Hypothesis and Theory article by Clark and MacKay, they propose a framework in which mental imagery is just one component part of an intrusive memory, with others including the autobiographical trauma memory itself, the process of involuntary recall, negative emotions, and attention hijacking. Mental imagery is identified as playing a key role in bridging the experience, memory, and intrusive recollection elements associated with a traumatic event. The opinion article by

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Strange and Takarangi also discusses the role played by mental imagery in trauma memory, but this time within the context of memory distortion for traumatic events. They argue that mental imagery contributes to source monitoring failures during retrieval, in which intrusive mental images contribute new false details, which over time become assimilated into people's memory for the trauma event itself. Both of these theoretical contributions offer an important reminder that the strong sensory–perceptual nature of intrusive recollection should not be interpreted as a literal "replaying" of perceptual experience encoded during original trauma, and that memory intrusions need not be synonymous with the trauma memory itself.

A second theme represented in the topic explores the contribution of mental imagery across more diverse clinical disorders than those associated with trauma memory. Kearns and Engelhard's study required students with public speaking anxiety to complete a script-driven imagery procedure depicting a future public speaking scenario. Eye movements performed concurrently while participants held the image of the scenario in mind significantly reduced heart rate in comparison to a control condition, suggesting that EM's can produce a psychophysiological reduction in experienced emotion for future-oriented fearful events ("flash-forwards").

In the opinion article by Klein and Moritz, they argue that intrusive mental imagery lies on a continuum where the boundary between experiences associated with clinical disorders and those experienced by the wider population is not clearly defined. They discuss the findings from recent online studies investigating major depressive disorder (MDD) and obsessive–compulsive disorder (OCD), which find 1 in 5 patients with OCD and 1 in 10 patients with mild-to-moderate MDD report strong to extreme mental imagery associated with their pathological cognitions. The opinion article by May et al. focuses on the Elaborated Intrusion Theory (EI), originally developed as a theoretical framework to account for substance-related craving, but here considered in relation to understanding clinical disorders such as PTSD and suicidal imagery. They argue that EI theory can provide a "roadmap" to help treat mental imagery of maladaptive goals across a range of different clinical disorders. This approach includes identifying those situations associated with greater risk for temptation and loss of control and methods for reducing attention to intrusive imagery such as mindfulness or acceptance training.

A further theoretical framework is discussed by Cili and Stopa who apply the self-memory system (SMS) theory of autobiographical memory (8) to understand how intrusive imagery can help maintain psychological disorders. They argue a critical way in which intrusive imagery maintains disorders through their representation and relationship with a patient's sense of self, particularly through the "working self" component of the SMS framework. They also propose that therapeutic techniques, such as imagery rescripting, may be beneficial specifically because they are thought to target patients' self-images and their associated meaning. The discussion of intrusive imagery is further broadened in the piece by Moran et al. who consider the importance of motor imagery in clinical disorders. They discuss the theoretical perspective that the brain is a dynamic predictive system that uses imagery-based simulation to integrate imagination, perception, and action processes, and they apply this framework in the context of clinical disorders such as PTSD, personality disorders, and social anxiety disorder. This article is a valuable reminder of the importance of non-visual imagery processes to clinical disorders.

A third theme in the research topic is articles that focus on imagery in healthy populations but have direct relevance to understanding clinical disorders. Hagenaars et al. present two experiments on healthy participants that examine whether mental imagery as a pre-trauma manipulation can influence fear bradycardia during subsequent viewing of affective pictures. Their findings are important for demonstrating that a highly automatic defense behavior such as bradycardia can successfully be influenced by pre-trauma mental imagery manipulations.

Intrusive memory processes in non-clinical groups are explored in articles by Krans et al. and Mace. Krans et al. report a questionnaire study conducted on undergraduate students assessing the quality, type, content, and potential function of involuntary cognitions experienced during the preceding month. Their findings show that, in relation to the subjective experience of involuntary cognitions by individuals, the specific subtype of cognition (i.e., fantasy, memory, and rumination) appears less important than its valence or content. The opinion article by Mace summarizes his work on involuntary autobiographical memory chains, in which the involuntary retrieval of one memory triggers other additional memories to quickly spring to mind. Mace's theoretical account has been very useful in understanding how contextual priming of involuntary trauma memory might occur [e.g., Ref. (9, 10)].

The opinion articles by Missbach et al. and Kemps and Tiggemann both discuss the function of mental imagery in the context of food consumption and food cravings. Missbach et al. argue that research on mental imagery can help better understand the eating behavior and also aid the design of more effective individual-level interventions. It can also help explain why some individuals are more successful self-regulators in their consumption of food than others. In a similar vein, Kemps and Tiggemann discuss the growing evidence that mental imagery plays a key role during the subjective experience of food craving, including an evaluation of imagery-based craving reduction techniques. These techniques use modality-specific cognitive tasks to interfere with mental imagery and help suppress associated craving. This field of research is valuable in relation to understanding mental imagery in clinical disorders as it helps suggest new avenues to explore for effective clinical interventions for treating involuntary imagery-based cognitions.

In conclusion, we believe that the range of submissions presented in this research topic make a strong contribution to help in establishing a theoretical and methodological foundation that can enable the effective comparison of imagery across different disorders and across different domains. There are informative parallels that can be drawn between the literature on clinical disorders and current theoretical models that assign a functional role for intrusive imagery during craving and addiction. Mental imagery processes may also underlie the effectiveness of clinical interventions such as imagery rescripting, imaginal exposure in Cognitive Behavioral Therapy, schema-focused therapy, and cognitive bias modification training. Nonetheless, there still remains an ongoing need for further systematic comparison of the role of imagery across different disorders, with the goal of establishing those common elements, which are most relevant to investigate mental imagery within the context of clinical psychology.

AUTHOR CONTRIBUTIONS

All authors drafted the manuscript and provided critical revisions. All authors approved the final version of the manuscript for submission.

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ORIGINAL RESEARCH
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Psychophysiological responsivity to script-driven imagery: an exploratory study of the effects of eye movements on public speaking flashforwards

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A principle characteristic of public speaking anxiety relates to intrusive mental images of potential future disasters. Previous research has found that the self-reported emotionality of such "flashforwards" can be reduced by a cognitively demanding, dual-task (e.g., making eye movements) performed whilst holding the mental image in-mind. The outcome measure in these earlier studies was participants' self-reported emotional intensity of the mental image. The current study ($N = 34$) explored whether an objective measure of emotionality would yield similar results in students with public speaking anxiety. A script-driven imagery procedure was used to measure psychophysiological responsivity to an audio script depicting a feared (public speaking) scenario before and after an eye movement intervention. Relative to the control condition (imagery only), those who made eye movements whilst holding a mental image of this scenario in-mind demonstrated a significant decrease in heart rate, which acted as a measure of emotionality. These findings add to a previous body of research demonstrating the beneficial qualities of dual-tasks and their potential for treatment of both past and future-oriented anxieties.

Keywords: flashforwards, eye movements, experiment, heart rate, anxiety, dual-task

Introduction

Many of us know that feeling of standing in front of a crowded room, all eyes on you, waiting expectantly for enlightenment on your chosen subject matter. Your hands begin to tremble, your heart starts racing, and beads of perspiration form on your forehead. Not many people enjoy public speaking, but for some even the thought of giving a presentation induces intense fear and a wide range of unwanted physiological responses. Public speaking anxiety is one of the most prevalent anxiety disorders today, with estimates suggesting that 75% of individuals experience some degree of unease in public speaking (1). Considering then that oral presentations embody such an important and unavoidable element of student and working life, as well as being of significant importance in terms of employability and upward mobility (2), investigating how this fear can be overcome represents a worthwhile pursuit.

Public speaking anxiety is a specific type of social and communication-based anxiety which can result in physiological arousal, negative self-focused cognitions, and accompanying behavioral demonstrations such as trembling or shaking (3, 4). Often referred to under a wide variety of different labels from speech fear, social speech fright, or speech anxiety to umbrella labels such as stage fright, audience anxiety, or performance anxiety [e.g., in Ref. (5, 6)], this particular phobia has its own individual qualities that contribute to its status as a stand-alone fear. For instance, individuals with speaking anxiety show stronger psychophysiological responses [greater heart rate (HR) response] when delivering a speech compared to those with generalized social anxiety disorder (6). Previous research employing varying methods to provoke anxiety has also demonstrated that the anxiety levels generated by public speaking tasks is generally higher than those for alternate tasks performed in similarly stressful situations [e.g., performing mental arithmetic in front of an audience; (7)]. Bodie (4) outlines how the combination of an audience presence and expectations particular to public speaking provide a situation-specific classification of public speaking anxiety, with apprehension of the threat of unsatisfactory evaluations from a defined public representing a key component of the phobia.

Although at times, a degree of nervousness has been shown to be beneficial to the performance of an individual [e.g., in Ref. (8)], high levels of anxiety can result in poor speech preparation and decision-making, and negatively affect performance [(9); see also in Ref. (10)]. If left untreated, public speaking anxiety will frequently persist and cause individuals to become avoidant, potentially hindering their success at both an academic level and in the workplace (11). Exploring potential intervention methods is therefore of significant importance, with one such method – eye movements targeting mental imagery – forming the primary pillar of investigation in this paper.

Mental Imagery and Eye Movements

A principle characteristic of public speaking anxiety and performance anxiety in general relates not only to intrusive thoughts and cognitions causing a dip in the execution of a particular tasks [e.g., in Ref. (12, 13)], but also to vivid and intrusive mental images of potential future disasters. Imagery about performing badly and being negatively evaluated has been shown to be commonplace amongst those with social phobia and varying types of anxiety disorders [e.g., in Ref. (14–16)]. One such example demonstrated in previous research is a woman who visualizes her mouth moving but no words coming out, and being perceived as very strange as a result (16). These unwanted flashforwards are similar in nature to "flashbacks" demonstrated by posttraumatic stress disorder (PTSD) patients; negative mental images loaded with sensory information, and resulting in the elicitation of substantial arousal and distress (17). In fact, neurobiological mechanisms that mediate the capacity to retrieve specific memories also mediate one's capacity to envision the future (18). It has been shown that in some cases mental imagery may evoke greater emotional responses than related verbal cognitions, and thus represents a prime target for interventions (17, 19); an observation that has not been overlooked.

A substantial body of research has previously demonstrated that self-rated vividness and emotionality of flashbacks can be reduced through the engagement of cognitively demanding dual-tasks [for a review, see Ref. (20)]. Dual-task trials, where, for instance, eye movements are made whilst simultaneously holding an image in-mind, are thought to attenuate the sensory qualities of these images as a result of working memory taxation. Indeed, previous studies have shown that dual-tasks that tax working memory are effective [e.g., in Ref. (21)], and tasks that barely tax working memory (such as passively listening to sounds) are not effective (22). Through the process of reconsolidation into long-term store, the memory should become less vivid and less distressing (23–25). Gunter and Bodner (25) found that the effects of memory taxation via eye movements persist for one week. This dual-task practice forms the central component of Eye Movement Desensitization and Reprocessing (EMDR) treatment, which is now recommended as one of the first-line treatment methods for PTSD by several organizations [e.g., in Ref. (26, 27)]. It has recently been established that this dual-task technique is not just effective on past memories however, but that it can also successfully degrade future-oriented images, including flashforwards related to performance anxiety (28, 29). The present study will attempt to build upon these findings by altering the experimental paradigm used to include an objective measure, thus overcoming some limitations of earlier studies relying on self-report alone.

Adaptation of Experimental Paradigm

In the majority of previous studies examining the effects of dual-tasks, efficacy of the treatment has been gaged through use of subjective measures – for example, asking participants to report pre- and post-test levels of vividness and emotionality in respect to targeted mental images [e.g., in Ref. (28, 29)]. Though in theory this practice may be sound, as the primary aim of the treatment is to reduce the subjective emotionality of such images, relying wholly on subjective measures can be problematic in some instances. It is possible that self-reports may be affected by experimental demand, and thus sole reliance on such measures may potentially jeopardize the scientific integrity of study findings. The possible limitations of self-report measures in experiments investigating the effects of dual-tasks have already been recognized and addressed in two prior studies. Engelhard et al. (30) found that, relative to those in a recall only condition, startle responses decreased in participants who completed a dual-task. van den Hout et al. (31), meanwhile, used a behavioral reaction time task to demonstrate attenuated vividness of a neutral image in those who made eye movements whilst holding this image in-mind. The current study will attempt to overcome similar demand characteristics by using different objective measures to assess the effectiveness of a dual-task in reducing emotionality toward a feared scenario.

Given that increased arousal has a well-documented relationship with performance anxiety [e.g., in Ref. (3, 4)], physiological reactivity to the feared scenario will be used as a determinant of emotional valence rather than relying on self-report alone. This is a particularly relevant assessment tool for gaging emotional response to imagery, as research has shown that mental imagery elicits physiological responses akin to the arousal experienced upon anticipation of actual exposure to a feared stimulus [e.g., in Ref. (32)].

An additional alteration to the experimental paradigm in the present study relates to the source of target imagery for the dual-task. Pre-recorded audio scripts depicting the feared scenario (speaking in public) will be utilized instead of participants conjuring up their own mental image. The format for presenting these scripts is based upon the script-driven imagery procedure originally used by Lang et al. (12) to investigate physiological reactivity to fear imagery, and perfected by Pitman and his colleagues (33–36) in a series of studies investigating the physiological underpinnings of PTSD. Use of this procedure will eliminate a lack of control over memory recall during self-report gages and ensure that both self-reports of emotional intensity and vividness, and the physiological responses recorded, are directed at the same mental image both before and after the dual-task intervention.

In the current study, eye movements will be used as the cognitively demanding task performed whilst participants engage in mental imagery. Eye movements are just one of the number of methods that have previously been used to good effect in dual-task trials, with other cognitive tasks that have previously been shown to reduce the vividness and emotionality of mental images including auditory shadowing (25), drawing a complex figure (25), attentional breathing (21), playing Tetris (30), and counting (37–39). It is therefore important to note that although this study discusses the effects of eye movements with mental imagery, this term is used to represent the entire dual-task trial process; any potential intervention effects will stem from the taxing of working memory rather than simply the act of making eye movements.

The effectiveness of the eye movement intervention will be primarily determined from differences in pre- vs. post-test physiological measures [i.e., HR; (6)] and self-reports ratings (emotional intensity and vividness). It is expected that participants who have made eye movements whilst simultaneously holding a negative mental image in-mind will give lower subjective self-report ratings of emotional intensity of the mental image and demonstrate attenuated physiological reactivity toward the imagery depicted in the script, indicating a decline in the emotional intensity experienced.

Materials and Methods

Participants

The study sample consisted of students from Utrecht University and Hogeschool Utrecht (higher vocational school) who participated in return for course credit or a financial reward. The study was approved by the institutional review board of the Faculty of Social and Behavioural Sciences at Utrecht University. The sample size was set before data analysis, and all measures that were collected are reported. In total, 442 students were administered a six-item screening scale for public anxiety. This was a Dutch Translation of the Public Speaking sub-scale (PSA) of the Personal Report of Communication Apprehension (PRCA-24) (40), which was found to generally produce reliability estimates in the range of 0.80–0.85 (41). Although not originally designed for clinical use, the PRCA-24 has been has since been recommended as a clinical tool (42) and is the most widely used self-report scale of communication apprehension because of its consistent reliability and validity (43, 44). Researchers have suggested the sole use of the PSA sub-scale of the PRCA-24 if the research is concerned with the cognitive trait of public speaking anxiety (4), as is the case in this study. The questionnaire consists of the following items: (1) I have no fear of giving a speech, (2) Certain parts of my body feel very tense and rigid while giving a speech, (3) I feel relaxed while giving a speech, (4) My thoughts become confused and jumbled when I am giving a speech, (5) I face the prospect of giving a speech with confidence, and (6) While giving a speech, I get so nervous I forget facts I really know. Items are rated on a 5-point scale based on the degree to which participants agree with each statement (1 = *strongly disagree* to 5 = *strongly agree*). Items 1, 3, and 5 were reversely scored; for scoring procedure see McCroskey (40). Sixty-eight students with a score of 20 or higher[1] were invited to take part in the study, with McCroskey (45) advising that those with a score of 18 or higher experience significant apprehension in public speaking. Twenty-three of these declined the offer, primarily due to the main testing period coinciding with the exam and study period of the university. The exclusion criterion was having prior knowledge of EMDR ($n = 11$). The final sample consisted of 34 participants (9 males) with a mean age of 21.4 years (SD = 2.99) and a mean PRCA-24 Public Speaking Sub-score of 22.9 (SD = 2.67, range: 20–30).

Script Preparation

The audio scripts used in this study consisted of Dutch translations of standardized fear (public speaking) and neutral (looking out a living room window) scripts that have been utilized in several previous experiments [e.g., in Ref. (12, 33, 36)]. Each script of approximately 30 s in length was recorded in a neutral voice for playback in the laboratory, and depicted the scenario in detail. For instance, the public speaking script was as follows: "You have volunteered to give a presentation to a class in which you badly need to improve your grade/Your palms have become sweaty, and you tense up the muscles of your forehead/As you walk to the front of the room, you breathe rapidly and glance around at the faces of the audience." Prior to the main experiment, a pilot study consisting of nine participants with a fear of public speaking was run to ensure that (1) participants demonstrated higher levels of physiological reactivity to the fear (public speaking) script than to the neutral script and (2) participants still demonstrated heightened responses to the fear script on the second time of listening.

Procedure

Laboratory Procedure

The laboratory session consisted of individual testing sessions for each participant in a quiet, light attenuated room. Upon entering they received verbal and written information about the study and signed a consent form. Next, they were asked whether they were familiar with several treatments, including EMDR, and, if so, to describe them. At this point, anyone with prior knowledge of EMDR was excluded from the study and did not complete the

[1] McCroskey (40) advise that a score of 24 or higher generally denotes a high fear of public speaking, and a score of lower than 14 generally denotes a low fear of public speaking. Because we were interested in anxious apprehension of public speaking (and not just high levels), we decided to use the cut-off score of 20. Eight participants with PRCA-24 Public Speaking sub-scores ranging from 20 to 23 were found to rate the public speaking script as being sufficiently unpleasant to warrant a lowering of the inclusion criterion for the main experiment, with a mean rating of 80 on a 100 mm visual analog scale.

experiment. The participant's skin was cleaned using an alcohol wipe, and electrodes were prepared and attached. Participants were then seated at a desk with personal computer which was used to present all of the stimuli used during the experiment via E-Prime 2.0 Professional software. Once seated comfortably, a relaxation exercise was played.

Script-Driven Imagery Procedure

Upon completion of the relaxation exercise, a 30-s recording of baseline physiological responses was taken. This was followed by the presentation of the neutral (looking out a window) and fear (public speaking) scripts in line with the well-established script-driven imagery procedure developed by Lang et al. (12) and Pitman et al. (33). Each script presentation consisted of (1) a 30-s script presentation, (2) a 30-s imagery period where participants were instructed to continue imagining the experience presented in the script from beginning to end, (3) an assessment period that consisted of emotional intensity and vividness visual analog scale (VAS) ratings, and (4) a 30-s recovery period. In all cases, the neutral script was presented prior to the fear script to eliminate the possibility of a carryover of negative affect.

Mental Imagery Experiment

After the first script-driven imagery procedure was complete, participants undertook a mental imagery experiment based on the protocol for unpleasant images designed by van den Hout et al. (46) and modified by Engelhard et al. (28, 29) to future-oriented images. Participants were randomly assigned to either the experimental condition or to the control condition, with 17 participants in each group. The experimental condition involved six identical 24-s phases of imagery with eye movements, separated by 10-s breaks during which participants were instructed to think of something else. This set-up mirrors an established paradigm used in several previous studies [e.g., in Ref. (25, 28, 29, 46, 47)]. For each of the six eye movement phases, participants were told to continuously visualize the public speaking scenario (giving a speech in front of their class) that they listened to on the audio recording and at the same time to follow a 1-cm light gray circle with their eyes as it moved horizontally from one side of the screen to the other at a rate of one movement per second, all the while keeping their head still. The control condition followed the same paradigm, but with participants focusing on a stationary rather than a moving circle.

A second presentation of the neutral and fear scripts followed the mental imagery experiment, with an identical format to the script-driven imagery procedure outlined above. The experiment ended with a 4-min relaxation exercise in order to reduce any possible distress that resulted from participation. Participants were then debriefed, thanked, and given their reward (course credit or a small financial reward).

Measures

Physiological Measures

A BIOPAC MP150 system connected to a separate computer running AcqKnowledge 4.1 software was used to measure HR, skin conductance (SC), and electromyograms (EMGs) of the lateral frontalis and corrugator facial muscles. HR was the main measure of interest [see Ref. (6)], and SC and EMG were measured for exploratory purposes. SC level was obtained through 13/8 mm Ag/AgCl electrodes filled with isotonic paste and placed on the volar side of the wrist. The transducer was connected to a BIOPAC-GSR100C module with a sampling rate of 200 times per second. The EDA signal was transformed into microsiemens (μS) units before being analyzed. Activity of the lateral frontalis and corrugator was recorded on the left side of the face using bipolar placements of 7/4 mm Ag/AgCl surface electrodes in accordance with published guidelines (48). The EMG raw signal was measured in microvolts using a BIOPAC-EMG100A module with a sampling frequency of 2000 Hz. Online transformation was used to acquire the integrated [root mean square (RMS)] EMG for both measures. HR was measured with a BIOPAC-PPG100C Pulse Plethysmogram Amplifier via a transducer attached by Velcro to the participant's index finger. The PPG signal was transformed online to pulse rate, measured in beats per minute, before being analyzed.

Self-Report Measures

Self-report measures of emotional intensity and vividness were obtained using two 100 mm VAS. Vividness ratings were collected for exploratory purpose; we did not expect that they would decrease due to the fact that participants would listen to the fear script in its entirety for a second time after completing the mental imagery experiment. Immediately after each imagery period of the script-driven imagery procedure, participants were asked to indicate their subjective feelings toward each script on a scale that ranged from 0 = not vivid (unpleasant) at all to 100 = extremely vivid (unpleasant).

Results

Self-Reports

The mean emotional intensity and vividness ratings are depicted in **Figures 1** and **2**, respectively. Both of the self-report ratings were analyzed with repeated measures ANOVAs with Condition (imagery with eye movements vs. imagery only) as the between-subjects factor and Time (pre-test vs. post-test) as the within-subjects factor. Emotionality ratings increased from pre-test to post-test level for the imagery only condition, and decreased

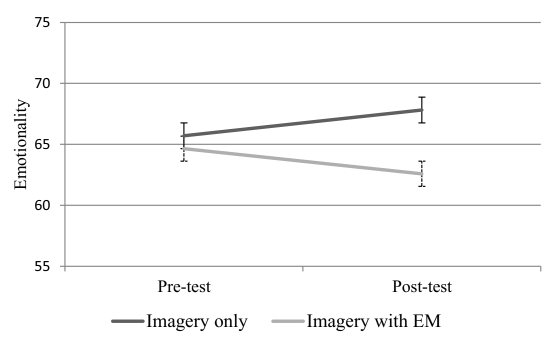

FIGURE 1 | Mean emotionality ratings with standard error bars for imagery only ($n = 17$) and imagery with eye movements (EM; $n = 17$) conditions.

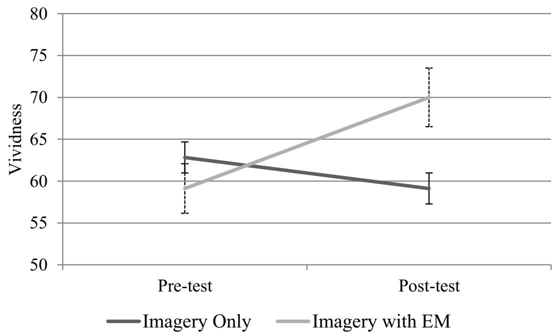

FIGURE 2 | Mean vividness ratings with standard error bars for imagery only ($n = 17$) and imagery with eye movements (EM; $n = 17$) conditions.

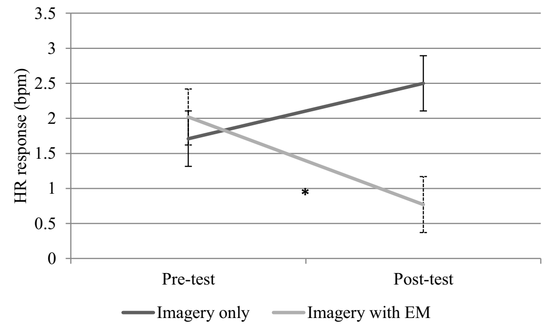

FIGURE 3 | Mean heart rate (HR) change scores with standard error bars measured in beats per minute (bpm) during imagery of fear (public speaking) script for imagery only ($n = 17$) and imagery with eye movements (EM; $n = 17$) conditions. *Statistically significant difference between pre- and post-test change scores, $p < 0.05$.

for the imagery with eye movements condition (see **Figure 2**), however, neither of the main effects of Time or Condition, or the interaction between Time and Condition proved significant, all $Fs(1,32) < 1$.

Vividness scores were tested for normal distribution and, using the methods outlined by Hoaglin and Iglewicz (49), one outlier was detected and transformed. It was found that neither of the main effects of Time [$F(1,32) < 1$, $p = 0.50$, $\eta_p^2 = 0.02$] or Condition [$F(1,32) < 1$, $p = 0.42$, $\eta_p^2 = 0.02$], or the interaction between Time and Condition [$F(1,32) = 2.79$, $p = 0.11$, $\eta_p^2 = 0.08$] were significant.

Physiological Measures

Pre- and post-test response (change) scores were calculated for the physiological dependent variables by subtracting a baseline mean score from the mean score during imagery (33). Response scores from neutral scripts where a non-stressful scene was visualized served as a control to ensure that the fear script elicited higher levels of physiological arousal, and that this arousal could be attributed to increased anxiety. HR, SC, and EMG of the frontalis and corrugator responses to fear imagery were examined separately using 2 × 2 repeated measures ANOVAs with Condition (Imagery with eye movements vs. imagery only) as the between-subjects factor and Time (pre-test vs. post-test) as the within-subjects factor.

There was no difference in baseline HR scores between the imagery only ($M = 79.98$, $SD = 14.53$) and imagery with eye movements conditions ($M = 81.15$, $SD = 11.60$, $t(32) = 0.70$, $p = 0.49$), whilst a paired samples t-test revealed that HR response to the fear script was significantly greater than that to the neutral script, $t(33) = 0.29$, $p = 0.01$, in the pre-test reading. **Table 1** shows the mean response scores to neutral and fear imagery, and **Figure 3** depicts the HR response to fear scripts for pre- and post-test measures. A 2 × 2 ANVOVA with HR response to fear imagery as the dependent variable revealed that neither of the main effects of Time or Condition were significant, both $Fs(1,32) < 1$. As predicted however, the crucial interaction between Time and Condition proved significant, $F(1,32) = 5.87$, $p = 0.02$, $\eta_p^2 = 0.16$. An independent samples t-test showed that HR response scores to fear imagery did not differ between conditions in the pre-test, $t(32) < 1$. Paired t-tests revealed that response scores decreased significantly from the pre-test to the post-test for the eye movements condition, $t(16) = 2.73$, $p = 0.01$ (one-tailed), but not for the imagery only condition, $t(16) = 1.18$, $p = 0.13$.

Although both SC and EMG of the corrugator demonstrated significantly higher response rates to the fear script than to the neutral script, no other significant results were found for either measure, or for EMG of the frontalis, so they will not be reported; mean response scores are presented in **Table 1**.

Discussion

Previous studies have found that taxing working memory with dual-tasks of mental imagery combined with eye movements can reduce the emotionality and vividness of both negative flashforwards and autobiographical memories, relative to a control condition of mental imagery alone [see Ref. (20)]. The main goal of the present study was to garner additional support for the effectiveness of this procedure by addressing two shortcomings identified in the experimental paradigms of earlier research. First, the majority of previous studies relied solely on self-report as a measure of emotionality. The present study aimed to develop a more objective measure of emotional intensity, which was achieved by testing whether a dual-task during mental imagery of a feared scenario would result in attenuated physiological responses. Second, in prior research the mental image rated during self-reports was formulated by the participant on each rating occasion, meaning that there was uncertainty over whether the same image was being assessed during pre- and post-test measures. This study drew upon a script-driven imagery procedure using audio recordings of a feared scenario to ensure that physiological responses and self-report ratings were focused on the same mental image on each measurement occasion.

The main finding of this study was that imagery with eye movements, which was the cognitively demanding task chosen, decreased HR response to the fear script from pre- to post-test measures. Self-report scores for emotionality demonstrated a small – but not significant – decrease for the experimental condition, whilst the control condition (imagery only) demonstrated a relative increase. These findings partially support the

TABLE 1 | Mean change scores for physiological measures during imagery of neutral and fear scripts.

		Imagery only ($n = 17$)		Imagery with EM ($n = 17$)	
		Neutral	Fear	Neutral	Fear
HR	Pre-test	−0.31 (5.39)	1.71 (3.30)	−0.01 (2.90)	2.03 (2.02)
	Post-test	−1.53 (4.10)	2.50 (3.86)	−3.70 (3.45)	0.77 (2.48)
SC	Pre-test	−0.00047 (0.0056)	0.00011 (0.0055)	−0.00902 (0.0380)	−0.00797 (0.0391)
	Post-test	0.00160 (0.0064)	0.00110 (0.0071)	−0.01200 (0.0392)	−0.00810 (0.0390)
EMG frontalis	Pre-test	−0.00100 (0.0020)	−0.00110 (0.0020)	−0.00180 (0.0013)	−0.00183 (0.0013)
	Post-test	−0.00012 (0.0021)	−0.00012 (0.0023)	−0.00191 (0.0019)	−0.00221 (0.0018)
EMG corrugator	Pre-test	0.00021 (0.0012)	0.00021 (0.0014)	−0.00055 (0.0016)	0.00001 (0.0017)
	Post-test	−0.00041 (0.0015)	0.00011 (0.0019)	0.00022 (0.0053)	0.00116 (0.0072)

SDs of the mean are in parentheses. Heart rate (HR) is measured in beats per minute, skin conductance (SC) is measured in microsiemens and electromyography (EMG) root mean square response scores for the corrugator and frontalis are measured in microvolts.

hypothesis that participants who have made eye movements whilst simultaneously holding a negative mental image in-mind will exhibit attenuated physiological reactivity toward the imagery depicted in the script. If HR is taken as a stand-alone assessment of emotionality [as in Ref. (50, 51)], then it can be said that these findings are consistent with prior research which found that dual-tasks cause reductions in emotional intensity for negative mental images. The current study also adds support to earlier findings (28) demonstrating that dual-tasks not only affect past memories, but also future-oriented mental images about feared scenarios.

The lack of significant results for SC and EMG measures may be partly attributed to the fact that measurements were taken over relatively long time periods (30 s), with such dimensions generally better suited to measuring immediate response to stimuli (52). It is possible that by averaging measures over this time period, any discrete differences in emotional valence may have been diminished. In regard to electrodermal response, this extended time period meant that SC level, which measures tonic change in electrical conductivity of skin, was used rather than the more informative measure of SC response measuring phasic change. As SC level generates a constantly moving baseline that is all the time changing within an individual, some researchers have suggested that as a measure it is difficult to derive and not overly informative (53, 54). Such problems have led to some researchers overlooking the standardized format for measuring psychophysiological responses used in Pitman and colleagues series of script-driven imagery studies [e.g., in Ref. (33–36)], and instead relying on HR alone as a measure of physiological reactivity to scripts [e.g., in Ref. (50, 51)]. In studies where significant differences in EMG and SC levels were found, the study format was generally comprised of a single measurement period comparing a clinical population, who demonstrated inflated levels of physiological reactivity, to non-clinical controls [e.g., in Ref. (12, 33, 35)].

In regard to gender, although our sample included a greater representation of females than males, this is reflective of the prevalence of public speaking anxiety in the general public. A number of studies to date have highlighted a fear of public speaking and social phobias more generally as having a higher prevalence amongst females (55–57). Thus, the fact that a larger proportion of females reached the inclusion threshold for the current study is unsurprising.

An additional finding in need of consideration was the fact that self-reports of emotional intensity were not affected by imagery with eye movements, in contrast to earlier research [e.g., in Ref. (28)]. The present study differed from previous research however in that, due to methodological reasons, mental imagery was based on a standardized fear script rather than encouraging participants to visualize a personalized fear scenario. As flashforwards related to a fear of public speaking are generally situation specific, with certain key details pertinent to an individual's fear, this may have meant that what a participant finds to be most unpleasant about giving a presentation was missing from the script, resulting in low personal relevance and lower ratings. Supporting this theory are the self-report mean scores for emotionality of fear imagery, which in this study were lower than those in previous studies at the pre-test measure. For example, in Engelhard et al.'s (30) study examining flashforwards to feared future events in a non-clinical population, the mean rating participants gave for the emotionality of their personal fear imagery was 75; in the present study, the mean score was 65. This left less room for a decline in the subjective unpleasantness of mental images and could partially account for the measure failing to reach significance. For this reason, it is recommended that, in future research, individualized scripts targeting specific elements of fears should be formulated for each participant prior to partaking in the experiment. The possibility of irrelevant cognitive process and thoughts taking place during the imagery phase has also been noted, and may be addressed in future studies by including a manipulation check to verify that participants did indeed focus on the script presented to them during the imagery phase.

The use of a standardized fear script rather than personalized mental imagery also lends to the possibility that the underlying processes at play during the current study differed from those in previous studies. In the majority of prior research, participants were required to recall a mental image from long-term memory; either autobiographical or of a personal fear. Eye movements and other cognitively demanding tasks have been shown to result in the "blurring" of mental imagery through working memory taxation, and thus may alter these memories before their return to long-term store [e.g., in Ref. (20, 24)]. In the present study however, mental imagery was based upon a standardized fear script and so was recalled immediately after encoding. Memories can take several hours to solidify after initially being encoded, in what is referred to as a "consolidation period" [e.g., in Ref. (58)]. During this time, memories are subject to change, meaning it is possible that in this study eye movements interfered with consolidation rather than reconsolidation. van den Hout et al. (31) faced a similar issue in their study which demonstrated attenuation in the vividness of neutral pictures which were presented to participants for the first time during the experimental session. They deemed, however, that as memory performance was not affected and that the effects of the dual-task trial were still demonstrated, the underlying processes, though interesting, were not important to interpretation of the study. With the current study also demonstrating effects of dual-tasks on some dimensions of emotionality, it thus remains unclear whether an individualized script would have resulted in a different outcome. However, the possibility that distinct underlying processes exist for the effects of dual-tasks on long-term memories and recently encoded memories is something that may warrant future investigation.

The processes underlying the effects of dual-tasks are also of relevance when taking into consideration the self-report findings for vividness. Subjective vividness ratings were not expected to decrease in the present study due to the fact that participants listen to the fear script in its entirety for a second time after completing the mental imagery experiment, and before giving their post-test rating. As was outlined above, when a memory is recalled it is subject to interference, and listening to the fear scenario described in vivid terms during the post-test may have negated the blurring effects of the dual-task. If it can be shown that the post-intervention script-driven imagery procedure does indeed interfere with the effects of dual-tasks, an imagery period without a prior reading of the script could be one solution. Although this would again resurface the possibility that the mental image under consideration may differ between pre- and post-test measures, this option could be seen as the lesser of two evils if the effects of the dual-task are maintained. Script-driven imagery with corresponding psychophysiological measurements has the potential to be an invaluable assessment tool as an objective measure of the effectiveness of dual-task trials in future studies; however in order to establish a best practice method for use in the laboratory, it is important that this issue be resolved.[2]

An assumption of the working memory taxation theory is that demanding dual-tasks leave fewer resources available for maintaining a vivid mental image and for emotional reactions to it. These tasks typically lead to decreases in vividness as well as emotionality of the mental image, but some studies found only effects for vividness, and not emotional intensity (59), or the other way around (60). In the present study, attenuated HR response was demonstrated with no corresponding reduction in vividness. These findings raise interesting questions about how dual-tasks influence mental images. It has been hypothesized that decreased emotionality is a consequence of the decreased vividness of a mental image (25). However, another possibility is that it results directly from cognitive load. Research has shown that performing a cognitive demanding task modulates emotional responses in the brain: when task-load is increased, increased activity in the frontal cortex is associated with decreased activation in the emotional regions [amygdala and right insula; (61)]. For both theoretical and clinical reasons, an important direction for future research is to investigate the underlying mechanisms linking dual-tasks to effects on emotional mental images. This knowledge can be used to further optimize the intervention. A limitation of the current study was that we did not measure the effects of the dual-task intervention on public speaking fear with a clinical scale. Another important direction for future research is to test whether the intervention has direct effects on fear/anxiety. Nevertheless, as noted by Hackman and Holmes (62), it may be very useful to have a therapeutic tool that could at least initially reduce emotionality, as this may facilitate a patient's willingness to engage in exposure therapy. A dual-task could be such a "cognitive performance aid" (63) that targets past or future-oriented aversive images related to public speaking anxiety and other anxiety disorders.

[2]This is primarily a problem for experimental laboratory studies, as patients receiving EMDR treatment in accordance with the guidelines set out by Shapiro (64) undergo eye movements for a period that far exceeds any lab-based studies, and on multiple occasions. Therefore, the treatment effects are a lot more durable and long-lasting, and are unlikely to be affected by listening to a script reading.

Conclusion

In summary, although further work is required to perfect a script-driven imagery procedure suitable for use in combination with dual-task interventions, the current study produced some interesting findings. The fact that HR response to fear scripts resulted in a significant decrease from pre- to post-test measures proves that the effects of dual-tasks extend beyond the parameters of self-report. Furthermore, the present study provides additional support to previous findings demonstrating the utility of dual-tasks for future-oriented fear imagery as well as past negative memories. Given that future-oriented anxieties such as public speaking fear represent a substantial portion of clinical populations, these findings are encouraging. Popular interventions for combating public speaking fear are currently heavily based on either exposure, which can be distressing for the individual, or on skills training, which demonstrates little success in targeting avoidance (4). If long-term clinical effects of dual-tasks can be demonstrated in future research, this relatively non-evasive intervention could be seen as a viable alternative to established treatment methods, with positive implications for those struggling with this restrictive fear.

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Speed matters: relationship between speed of eye movements and modification of aversive autobiographical memories

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Eye movement desensitization and reprocessing (EMDR) is an efficacious treatment for post-traumatic stress disorder. In EMDR, patients recall a distressing memory and simultaneously make eye movements (EM). Both tasks are considered to require limited working memory (WM) resources. Because this leaves fewer resources available for memory retrieval, the memory should become less vivid and less emotional during future recall. In EMDR analogue studies, a standardized procedure has been used, in which participants receive the same dual task manipulation of 1 EM cycle per second (1 Hz). From a WM perspective, the WM taxation of the dual task might be titrated to the WM taxation of the memory image. We hypothesized that highly vivid images are more affected by high WM taxation and less vivid images are more affected by low WM taxation. In study 1, 34 participants performed a reaction time task, and rated image vividness, and difficulty of retrieving an image, during five speeds of EM and no EM. Both a high WM taxing frequency (fast EM; 1.2 Hz) and a low WM taxing frequency (slow EM; 0.8 Hz) were selected. In study 2, 72 participants recalled three highly vivid aversive autobiographical memory images ($n = 36$) or three less vivid images ($n = 36$) under each of three conditions: recall + fast EM, recall + slow EM, or recall only. Multi-level modeling revealed a consistent pattern for all outcome measures: recall + fast EM led to less emotional, less vivid and more difficult to retrieve images than recall + slow EM and recall only, and the effects of recall + slow EM felt consistently in between the effects of recall + fast EM and recall only, but only differed significantly from recall + fast EM. Crucially, image vividness did not interact with condition on the decrease of emotionality over time, which was inconsistent with the prediction. Implications for understanding the mechanisms of action in memory modification and directions for future research are discussed.

Keywords: EMDR, eye movements, autobiographical memory, working memory, vividness, emotionality

INTRODUCTION

Trauma-exposed individuals may suffer from distressing and intrusive memories of their traumatic experience and some even develop post-traumatic stress disorder [PTSD; (1)]. Eye movement desensitization and reprocessing (EMDR) is a psychological treatment for PTSD, and its efficacy is comparable to cognitive behavioral therapy (2, 3). A key aspect of EMDR is that the patient makes bilateral eye movements (EM) during the retrieval of traumatic memory images. Empirical research has confirmed that this dual-task approach reduces the image vividness and emotional intensity of an aversive memory, both in healthy persons and in patients with PTSD [for a meta-analysis, see Ref. (4)]. Note that in EMDR analogue studies, a standard "dose" is typically used: EM with a speed of 1 cycle per second (1 Hz), in sets of 24 s [e.g., Ref. (5)]. This presumes that patients and aversive memories respond equally well to the same dual-task manipulation. Recent insights from experimental studies challenge the efficacy of this standardized procedure [e.g., Ref. (6–8)]. Therefore, the aim of the current research was to test whether titration based on image vividness enhances the effects of dual-task manipulation on aversive memories.

A range of experimental studies provides support for a working memory (WM) account to explain how EM decrease the image vividness and emotional intensity of negative memories [for an overview, see Ref. (8)]. More specifically, holding an emotional memory image in mind and performing EM will both tax the limited resources of WM (6, 9). Consequently, competition between these tasks should impair retrieval of the image with its accompanied details and emotions, and result in immediate decreased image vividness and emotional intensity of the memory before its return to long-term store. A laboratory model has been used to critically test this WM account. In this model, participants recall a

Abbreviations: EM, eye movements; EMDR, eye movement desensitization and reprocessing; RO, recall only; WM, working memory.

negative memory image with or without simultaneously making EM. Image vividness and emotional intensity are measured before and after this intervention. Studies with healthy participants have shown that recall + EM decreases the vividness and/or emotionality of the recalled memory image, while recall without EM [recall only (RO)] does not (8). This effect has been replicated with other cognitively demanding tasks, such as counting backwards (10), attentional breathing (11), drawing a complex figure (6), and playing the computer game Tetris (12). Furthermore, it has not only been found for mental images of adverse past events, but also for mental images of imagined, aversive future events [e.g., Ref. (13)]. As predicted, tasks that barely tax WM, such as passively listening to sounds, are less effective than more cognitively demanding tasks [e.g., Ref. (14)]. These studies suggest that any dual-task that sufficiently taxes WM may decrease the vividness and/or emotionality of the recalled memory image.

Although many studies have shown that various dual-tasks affect emotional memory images, less is known about boundary conditions and optimization of the dual-task manipulation. The degree to which competition will occur between the WM load of the memory image and the WM load of the dual task partly depends on a person's WM capacity. Individuals with a large WM capacity are expected to be relatively proficient in performing tasks simultaneously (multitasking). Because there will be less competition between the two tasks (memory image recall and dual task) for them, compared to individuals with a low WM capacity, the effects on memory image should be smaller. Evidence for a correlation between WM capacity and memory effects comes from a study by Gunter and Bodner (6) who found medium negative correlations between automated reading span scores – an indicator of WM span – and decreases of vividness and emotionality within the recall + EM condition. This finding was replicated by two other studies that showed that individual differences in WM span are negative related to beneficial effects of dual taxation of memory image recall + WM taxing: the larger the WM span, the smaller the benefits of recall + WM taxing (11, 15). To test the feasibility of the WM theory, Maxfield et al. (7) manipulated the speed of EM. As predicted, they found that fast EM (1.25 Hz) resulted in larger decreases in image vividness and emotional intensity than slow EM (1 Hz), and both EM conditions led to larger decreases than a control condition. The authors argue that fast EM are more difficult to perform (i.e., they are more taxing), which leads to larger effects on memory images. Although this is plausible, the actual WM load of the two speeds of EM was not measured. Also, the stimulus presentation was a repetition of short intervals of dual-task manipulation (left-right-left appearance of a stimulus). One could argue that this procedure tested the capability of task switching, rather than ongoing dual-task performance.

Contrary to the prediction that the higher the WM load of the dual task, the larger the dual-task manipulation effects, Gunter and Bodner (6) hypothesized that this relationship may not be linear. A task that is slightly taxing may not disrupt the memory image enough, and a task that is overly taxing might preclude holding the memory image in mind, thereby preventing competition effects. Therefore, they proposed an inverted U-shape function. In other words, too little or too much WM taxing may lead to smaller effects than WM taxing that is intermediate. This was tested and partially confirmed by Engelhard et al. (10), who found an inverted U-shape function for emotionality, but not for vividness. Participants recalled a negative memory image and performed one of four arithmetic tasks: exposure alone, or exposure with "simple" subtraction, "intermediate" subtraction, or "complex" subtraction. Prior to the memory experiment, the WM taxation of the four tasks was assessed using a discriminative reaction time (RT) task and the results indicated that the subtraction tasks indeed increasingly taxed the WM, with simple subtraction taxing WM the least and complex subtraction taxing the most. In line with the inverted U-shape hypothesis, emotional intensity of the memory image decreased more after recall during simple or intermediate subtraction than when after recall during complex subtraction or no subtraction. Results for vividness were in the expected direction, but were not significant. Variation was larger for vividness ratings than for emotionality ratings, and this latter may have caused the difference between the dependent variables. To sum up, research indicated that the WM load of that dual task is related to the effectiveness of the intervention, and that this relation presumably follows an inverted U-shape function. It is unclear, however, whether these effects are translated to various speeds of EM.

From a theoretical perspective, the effectiveness of the dual-task manipulation depends not only on the WM load of the dual task, but also on its interaction with the WM load of the memory. The WM load of the memory may be affected by variation in memory image vividness: highly vivid images are presumed to tax the WM more than less vivid images (16). Obviously, the degree of image vividness of aversive memories varies between individuals who have experienced the same situation and within one individual over time. These variations in image vividness may therefore influence the variation in WM load. According to the inverted U-shape hypothesis, if a memory image is highly vivid, a relative low degree of taxing WM by the dual task may produce insufficient blurring. Conversely, if the memory image is less vivid, strong WM taxing may preclude memory recall. Therefore, in order to maximize memory effects, the WM theory implies that there is a need for titration: highly vivid memories require a relatively high WM load and less vivid memories a lower load.

The current study used the WM framework to investigate the interaction between the WM load of the memory image and the WM load of the dual task. In study 1, we examined the WM load of five different speeds of EM. We hypothesized that faster EM are more taxing. This study resulted in the selection of two conditions: fast EM and slow EM. In study 2, participants recalled three highly vivid distressing memory images or three distressing memory images that were less vivid. These memories were randomized to each of three conditions: recall + fast EM, recall + slow EM, or RO. We predicted that (1) relative to RO, both EM conditions result in memory images that are less emotional, less vivid, and more difficult to retrieve, and more importantly (2) highly vivid memory images benefit more from fast than slow EM during recall, while less vivid memory images benefit more from slow than fast EM during recall.

STUDY 1: WM TAXATION OF DIFFERENT SPEEDS OF EM

In order to select two speeds of EM that significantly differ in WM taxation, we tested the WM load of different speeds of EM in a within-subjects design. Participants performed a discrimination RT task during the performance of six tasks: five different speeds of EM and no EM. Slower RTs indicate the degree of taxation (17). In addition, participants were asked to hold six well-known images in mind (e.g., "your own kitchen"), while carrying out the same six tasks, and rated the vividness and difficulty to hold an image in mind during each task. We included vividness and difficulty ratings to test whether participants were still able to recall an image while simultaneously making the EM. We hypothesized that EM are more taxing than no EM, and that faster EM are more taxing than slower EM, resulting in larger RTs.

METHODS

Participants

Participants were recruited through advertisements at Utrecht University and the University of Applied Sciences (Hogeschool Utrecht), located at the same campus. Thirty-six participants (8 men, 28 women, $M_{age} = 21.89$, SD = 2.08) were tested, using no exclusion criteria. Two participants were removed from analyses due to technical problems. Participants received course credit or financial compensation for participation.

Materials and procedure

Participants were seated in front of a computer screen with a screen resolution of 1280 × 1024 at a distance of approximately 45 cm. OpenSesame 2.8.3 (18) was used to present stimuli. First, the low tone and high tone 1 s beeps (44.1 kHz) of the discrimination RT task were introduced. Beeps were administered to both ears through headphones using a constant volume. Participants pressed the *z*-key with their left index finger for low beeps and the /-key with their right index finger for high beeps. Beeps were presented randomly with a mean stimulus-onset asynchrony of 2.6 s (SD = 0.4). After a practice trial of 10 beeps, the experiment started. Participants were asked to categorize 20 low and 20 high beeps with or without making EM. In the EM conditions, a white 20 pixel dot appeared in the middle of a black screen and moved horizontally from side-to-side, with a movement amplitude of 461 pixel. The EM conditions had speeds of 0.4, 0.6, 0.8, 1.0, and 1.2 Hz (number of left-right-left cycles per second). Participants in the EM conditions were instructed to keep their head still and follow the dot with their eyes, and participants in the no EM were instructed to look at the middle of the screen (no dot was shown). The experimenter sat next to the participant and checked whether the EM were in accordance to the manipulation. If needed, the experimenter shortly repeated the instruction. In all conditions, the task was presented for a period of 106.6 s, adjusted to the average total time of beeps plus one (41 s × 2.6 s). The order of the speed of EM was randomly assigned, but each participant completed all six conditions.

To test whether participants were still able to recall a mental image while they simultaneously made EM, participants received the same condition again immediately after the RT trial, but instead of responding to beeps, they were instructed to simultaneously hold a well-known image in mind as vividly as possible. After 24 s, participants rated the vividness and difficulty of that image during manipulation on a visual analog scale (VAS), ranging from 0 (*not vivid/difficult at all*) to 100 (*very vivid/difficult*). The well-known mental images were the participant's kitchen, bathroom, bed, wardrobe, front door, and bicycle. Latin-square counterbalancing was used to order the sequence of these six images.

Design and data analyses

To test the WM taxation of the various speeds of EM, relative to no EM, a repeated measure analysis of variance (ANOVA) was performed with speed of EM as within-subjects factor and average RT as outcome measure. The first and last beeps were excluded from the calculation of the average RT, to exclude potential transition delays. Differences in vividness and difficulty of holding an image in mind between conditions were analyzed by two repeated measures ANOVAs with speed of EM as within-subjects factor and vividness or difficulty as outcome measure. Alpha levels of 0.05 were used; they were one-tailed for tests crucial to the hypothesis. For small violations of sphericity, the degrees of freedom of the *F*-distribution were corrected with either Green–Geisser ($0.70 \geq \varepsilon < 0.75$) or Huynh–Feldt corrections ($\varepsilon \geq 0.75$). More severe violations ($0.70 < \varepsilon$) were corrected using a multivariate test statistic (Pillai-Bartlett trace; *V*).

RESULTS

The average RT varied significantly across conditions, $V = 0.48$, $F(5, 29) = 5.40$, $p = 0.001$, $\eta_p^2 = 0.48$ (see **Figure 1**). Pairwise comparisons showed that all EM conditions during the RTT yielded increased RTs compared to no EM, range $M_{dif} = 60$–100, *p*s < 0.001. Furthermore, simple contrasts indicated that RTs in the fastest condition (1.2 Hz) were significantly greater than in the 0.8 Hz EM condition, $F(1, 33) = 4.50$, $p = 0.02$, $\eta_p^2 = 0.12$, or 1.0 Hz EM condition, $F(1, 33) = 4.22$, $p = 0.03$, $\eta_p^2 = 0.11$. The average number of correct items was high ($M_{range} = 36$–37 out of 39) and did not differ between the conditions.

Average vividness scores differed between conditions, $F(5, 29) = 11.42$, $p < 0.001$, $\eta_p^2 = 0.26$ (see **Figure 2**). Pairwise comparisons showed that all EM conditions decreased the vividness of the image compared with no EM, $M_{dif} = 15$–31, *p*s < 0.002. The relation between WM taxation and vividness indicated a clear negative linear relationship: vividness decreased as WM taxation increased. Difficulty retrieving the image while performing the dual-task

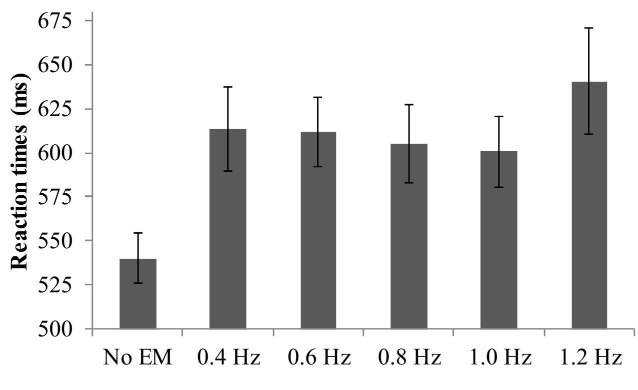

FIGURE 1 | Mean reaction times (ms) and SEs for the different speeds of EM and no EM.

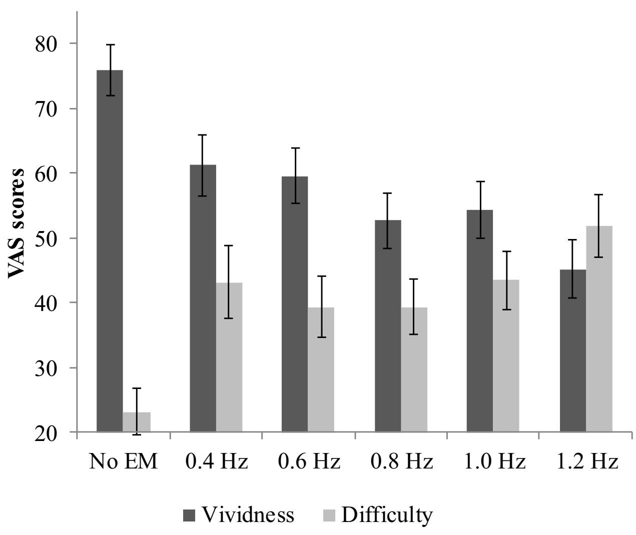

FIGURE 2 | Mean VAS scores and SEs for vividness and difficulty for the different speeds of EM and no EM.

differed between the conditions, $F(3.58, 118.15) = 9.25$, $p < 0.001$, $\eta_p^2 = 0.22$ (see **Figure 2**). Pairwise comparisons showed that it increased for all EM conditions compared with no EM, $M_{\text{dif}} = 16$–29, $ps < 0.002$. Simple contrasts indicated that for both vividness and difficulty ratings, the 1.2 Hz EM condition differed significantly from the 0.8 and 1.0 Hz condition, $ps < 0.05$. The highest speed (1.2 Hz) resulted in a mean vividness of 45.20 (SD = 26.46) and mean difficulty of 51.90 (SD = 27.91).

DISCUSSION STUDY 1 AND INTRODUCTION STUDY 2

In line with previous research [e.g., Ref. (11)], all EM conditions resulted in slower RTs compared to no EM, indicating that performing EM indeed taxes WM. Between the EM conditions, EM of 1.2 Hz produced more WM taxation, lower image vividness, and higher difficulty to retrieve the image during manipulation compared to EM of 0.8 and 1.0 Hz. The 0.8 and 1.0 Hz conditions did not differ from each other on any of the outcome measurements. Since 1.0 Hz is the standard EM speed in EMDR, this could be considered an "intermediate" speed of EM. To keep the amount of variation equal on both ends, we selected 0.8 Hz for the slow EM condition and 1.2 Hz for the fast EM condition. Study 2 tested whether the WM load of EM interacts with the image vividness of a negative memory.

STUDY 2: INTERACTION BETWEEN SPEED OF EM AND IMAGE VIVIDNESS

METHODS

Participants

We recruited 92 undergraduate students through advertisements at the Utrecht University and the University of Applied Sciences (Hogeschool Utrecht). Exclusion criteria were knowledge about EMDR, prior participation in an experiment from our laboratory that required participants to recall memories, or medication use that may affect concentration, such as benzodiazepines. We excluded 20 students based on these exclusion criteria. The final sample consisted of 72 participants (22 male, 50 female, $M_{\text{age}} = 22.40$, SD = 3.81). They were randomly assigned to one of two groups: "highly vivid memories," $n = 36$; "less vivid memories," $n = 36$. Participants received course credit or financial compensation.

Materials and general procedure

Participants were tested individually in a quiet room. After providing written informed consent, participants were interviewed by the experimenter (see below). Participants selected three negative memories following the procedure used by van den Hout et al. (5). Next, in line with the Dutch EMDR standard protocol (19), they selected a target image of each memory. During the second half of the experiment, participants were seated behind a computer with a screen resolution of 1280 × 1024 at a distance of about 45 cm. OpenSesame 2.8.3 (18) was used to present stimuli.

Memory selection

During the first half of the experiment, participants selected three negative memories that were at least 1 week old and still evoked relevant feelings (i.e., fear/anxiety/sadness). Participants in the highly vivid memories group were instructed to select three negative "memories that are very clear and detailed," and participants in the less vivid memories group were instructed to select three negative "memories that are relatively vague and low on details." If participants found it difficult to select memories, the experimenter presented a list of examples (e.g., eye-witness of a traffic-accident, a job rejection, an argument with a family member), and stressed that vividness of memories is subjective, so the example memories were merely given to stimulate the selecting process. Participants wrote down the content of each memory on a card and indicated the vividness (with 0 *not at all vivid* to 100 *very vivid*) and emotionality (0 *not at all unpleasant* to 100 *very unpleasant*) of each memory. The experimenter checked if these ratings were within the intended range, which was 70–100 for vividness in the highly vivid memories group, 30–60 for vividness in the less vivid memories group, and 50–90 for emotionality in both groups. If it was not, the experimenter asked the participants to select another memory. Memories were ranked based on vividness ratings (1 = *most vivid*, 3 = *least vivid*, 2 = *in between*). The order of the target image selection, as well as the order of the conditions, was counterbalanced based on this ranking.

Target image selection

Next, the experimenter asked the participants to describe the memory in global story lines. Then, the experimenter asked the participant to identify the worst moment of this memory and describe this moment as a still image (i.e., "target image"). The participants assigned a descriptive, relatively neutral label to each target image, to act as a cue during the experiment.

Experiment

Then, the participants performed a pre-test, an intervention phase, and a post-test for each condition. In the pre-test, participants recalled their target image for 10 s and gave ratings of emotional valence, vividness, and difficulty of retrieving the target image on the VAS (ranging from 0 *not at all unpleasant/vivid/difficult* to

100 *very unpleasant/vivid/difficult*). In the intervention phase, they recalled their target image six times for 24 s, with 10 s rest periods in between. Each rest period ended with a 2 s instruction to recall the target image again. In each EM condition, participants held their head still and looked at a horizontally moving white dot (20 pixel) on a black screen. The dot had a movement amplitude of 461 pixel, and a speed of 0.8 Hz in the slow EM condition and 1.2 Hz in the fast EM condition. In the RO condition, participants recalled the target image and looked at the black screen. If participants moved their head or eyes incorrectly, the experimenter briefly repeated the instructions. The post-test was immediately after the intervention. In the post-test, participants again brought the target image to mind for a 10 s period and rated the same VAS.

RESULTS

Manipulation check

During memory selection, all participants managed to select three memories that matched the vividness criteria. However, a manipulation check based on the vividness ratings in the pre-test indicated that only 33 participants (45.8%) had three target images within the vividness range of their condition. For the less vivid memories group, vividness scores during the memory selection were significantly lower ($M = 50.31$, $SD = 6.07$) compared to the pre-test ratings of the target image [$M = 63.64$, $SD = 13.05$; $t(35) = -5.82$, $p < 0.001$]. For the highly vivid memories group, vividness scores during memory selection and the pre-test did not differ from each other ($M_{selection} = 79.85$, $SD = 5.24$; $M_{pre\text{-}test} = 79.67$, $SD = 8.13$, $p = 0.91$). Because our manipulation check indicated that target image vividness did not match the intended group criteria (highly vivid memories vs. less vivid memories), we analyzed the data on the memory level instead of on the participant (group) level.

Analysis strategy

Memories were nested within participants. Therefore, we analyzed the data with multilevel modeling using three levels: 432 repeated measures (level 1) of 216 memories (level 2), nested within 72 participants (level 3). We conducted the analyses with Hierarchical Linear and Non-linear Modeling, version 6 [HLM6, Ref. (20)]. For our first hypothesis that EM would decrease emotionality and vividness, and increase the difficulty of retrieving the memory image more than RO, we analyzed emotionality, vividness, and difficulty over time between the conditions. **Figure 3** shows the mean difference scores (post-test minus pre-test) and SEs of all three conditions on emotionality, vividness, and difficulty. **Table 1** shows the fixed and random parts of the same multilevel model applied to each outcome measure. Condition was coded as dummy variable, with RO as reference condition. Therefore, the variable *RO_slowEM* indicated the difference between RO and the slow EM condition, and *RO_fastEM* indicated the difference between RO and the fast EM condition. The mixed equation for each model was: outcome $\text{variable}_{ijk} = \beta_{00} + \beta_{10}\ (time)_{ijk} + \beta_{01}\ (RO\_slowEM)_{jk} + \beta_{02}\ (RO\_fastEM)_{jk,} + \beta_{11}\ [(RO\_slowEM)_{ijk} \times (time)_{ijk}] + \beta_{12}\ [(RO\_fastEM)_{ijk} \times (time)_{ijk}] + v_{0k} + u_{0jk} + u_{1jk}$ ($i = \text{time}$, $j = \text{memory}$, $k = \text{person}$).

The second hypothesis was that highly vivid memory images benefit more from fast EM than slow EM during recall, and less vivid memory images benefit more from slow EM than fast EM during recall. To test the difference between slow and fast EM, we used slow EM as reference condition. Accordingly, the dummy *slowEM_RO* indicated the difference between slow EM and RO, and the dummy *slowEM_fastEM* indicated the difference between slow EM and fast EM. To observe the three-way interaction between pre-test vividness, condition and time, interaction variables between the centered *pre-test vividness* variable and the dummy condition variables were added as predictor for the intercept at the second level and as predictor for the slope of time

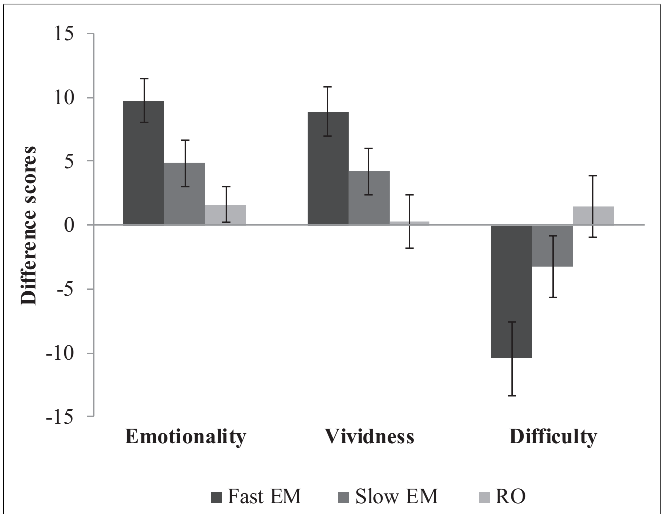

FIGURE 3 | Mean difference scores (post-test minus pre-test) and SEs of fast EM, slow EM, and RO on emotionality, vividness, and difficulty.

Table 1 | Fixed and random parts of Model 1 (emotionality over time between conditions), Model 2 (vividness over time between conditions), and Model 3 (difficulty over time between conditions).

		Model 1		Model 2		Model 3	
		Emotionality		Vividness		Difficulty	
		β	SE	β	SE	β	SE
FIXED PART							
Intercept	β_{00}	72.59*	1.54	72.69*	1.97	40.17*	2.88
RO_slowEM	β_{01}	−2.31	1.87	−1.94	2.18	0.28	3.02
RO_fastEM	β_{02}	1.46	1.87	−1.17	2.18	−2.47	3.02
Time	β_{10}	−1.57	1.63	−0.28	1.92	−1.57	2.54
RO_slowEM	β_{11}	−3.28	2.32	−3.91	2.72	4.83	3.60
RO_fastEM	β_{12}	−8.16*	2.32	−8.63*	2.72	12.04*	3.60
RANDOM PART							
σ^2_{v0k}		45.99*		107.67*		267.98*	
σ^2_{u0jk}		125.74*		171.10*		328.41*	
σ^2_{u1jk}		193.09*		265.42*		467.83*	
Deviance		3457.23		3567.08		3819.20	

In all models, RO was the reference condition.
$^*p < 0.05$.

at the first level (Model 4). Support for the hypothesis should materialize as a significant negative coefficient in predicting the slope of time for the variable *pre-test vividness × slowEM_fastEM*: the higher the vividness of the target image at pre-test, the more decrease in emotionality for the fast EM condition compared to the slow EM condition. Likewise, the lower the vividness of the target image at pre-test, the less decrease in emotionality for the fast EM condition when compared to the slow EM condition.

The mean pre-score vividness was 71.66 with a pile-up of scores on the right of the distribution (range 30.75–98.63, SD = 16.82, $N = 216$, $z_{\text{skewness}} = -3.68$, $z_{\text{kurtosis}} = -1.39$). To establish that there was no detrimental effect of the skewed distribution on the analyses, the distribution of errors of the second and third level were inspected for the final models. No abnormalities were detected.

Emotionality over time between conditions

Memories in the RO condition were stable in emotionality over time, $\beta_{10} = -1.57$, $p = 0.340$. Contrary to expectations, memories in slow EM did not decrease emotionality when compared to RO, $\beta_{11} = -3.28$, $p = 0.158$. However, fast EM did result in a larger decrease of emotionality over time than RO, $\beta_{12} = -8.16$; $t(213) = -3.52$, $p = 0.001$: post-test scores were lower (predicted mean = 65.89) than pre-test scores (predicted mean = 74.04). Next, to test whether the fast EM condition differed from the slow EM condition, we analyzed the same model with slow EM as reference condition. This revealed that fast EM led to larger decreases in emotionality than did slow EM, $\beta_{12} = -4.87$; $t(213) = -2.10$, $p = 0.04$. This means that fast EM were superior to both RO and slow EM in decreasing the emotional intensity of memory images. Finally, **Table 1** (Model 1) summarizes the random components of the model. Emotionality ratings of the memories varied significantly across participants (σ^2_{v0k}), across memories within participants $\left(\sigma^2_{u0jk}\right)$, and across time within memories within participants $\left(\sigma^2_{u1jk}\right)$, $ps < 0.001$.

Vividness over time between conditions

Similar to the differences between conditions on emotionality, memories in RO showed stable vividness ratings over time, $\beta_{10} = -0.28$, $p = 0.885$, memories in slow EM did not decrease vividness compared to RO, $\beta_{11} = -3.91$, $p = 0.151$, while memories in fast EM yielded a significant difference compared to RO, $\beta_{12} = -8.63$; $t(213) = -3.18$, $p = 0.002$: post-test scores were lower (predicted mean = 62.89) than pre-test scores (predicted mean = 71.52; Model 2, **Table 1**). A re-run of the model with slow EM as reference condition revealed that fast EM showed a non-significant trend toward larger decreases in vividness ratings, $\beta_{12} = -4.72$; $t(213) = -1.74$, $p = 0.083$. So, it seems that memory images that were recalled while making fast EM decreased more in vividness than images that were recalled while making slow EM or were only recalled without dual task. Vividness ratings of the memories varied significantly across participants (σ^2_{v0k}), across memories within participants $\left(\sigma^2_{u0jk}\right)$, and across time within memories within participants $\left(\sigma^2_{u1jk}\right)$, $ps < 0.001$.

Difficulty over time between conditions

Likewise, the same pattern between the conditions was found for the difficulty of retrieving the target image. Memories in RO showed a stable score over time, $\beta_{10} = -1.57$, $p = 0.539$, slow EM did not increase difficulty more than RO, $\beta_{11} = 4.83$, $p = 0.182$, but fast EM did increase difficulty recalling the memory compared to RO, $\beta_{12} = 12.04$; $t(213) = 3.34$, $p = 0.001$: post-test scores were higher (predicted mean = 49.74) than pre-test scores (predicted mean = 37.70; Model 3, **Table 1**). A re-run of the model with slow EM as reference condition revealed that fast EM led to larger increases in difficulty than did slow EM, $\beta_{12} = -4.83$; $t(213) = 2.00$, $p = 0.046$. So, fast EM caused more difficulty in retrieving the memory image after intervention than both RO and slow EM. Again, difficulty ratings varied significantly across participants (σ^2_{v0k}), across memories within participants $\left(\sigma^2_{u0jk}\right)$, and across time within memories within participants $\left(\sigma^2_{u1jk}\right)$, $ps < 0.001$.

Interaction between pre-test vividness, condition, and emotionality over time

Model 4 revealed that the coefficient of *pre-test vividness × slowEM_fastEM* in predicting the slope for time was −0.14 (SE = 0.14) and not significant, $t(210) = -1.05$, $p = 0.297$. So, inconsistent with our predictions, pre-test vividness did not interact with condition on changes in emotionality ratings.

DISCUSSION

This study aimed to examine whether WM load of a dual-task carried out during memory image recall interacts with WM load of that memory on reducing its emotional intensity. We found a consistent pattern for all outcome measures: high WM taxation (recall + fast EM) was superior to low WM taxation (recall + slow EM) and no WM taxation (recall only; RO), and the effects of low taxation felt consistently in between the effects of high taxation and RO, but only differed significantly from high taxation. High WM taxation during recall produced memory images that were less vivid, less emotional, and were more difficult to retrieve after the intervention. This is in line with WM theory: the more taxing a dual-task is, the more a memory image degrades. Crucially, image vividness did not interact with condition (high taxation vs. low taxation) with regard to the decrease of emotionality over time. Thus highly vivid and less vivid images showed the same responsiveness to dual-task manipulation: both images benefited the most from high WM taxation during recall.

The finding that recall + dual WM taxing reduced memory image vividness and emotionality, compared to RO, is in line with a large body of experiments [see Ref. (8), for an overview]. More specifically, this study replicated the findings of Maxfield et al. [Ref. (7); experiment 2], who also found that fast EM (1.25 Hz) yielded stronger reductions in memory image vividness and emotional intensity than slow EM (1.0 Hz) and no EM. They contributed this difference in effects to presumed variation in WM taxation, but did not experimentally assess the WM taxation of both EM tasks. We extended their design and used RT methods to select two speeds of EM that significantly differed in WM taxation (study 1).

We found the same superiority effects of fast EM compared to slow EM on image vividness and emotional intensity. Furthermore, we measured the difficulty of retrieving the memory image before and after the intervention and found that the higher the WM taxation, the more difficult it was to retrieve the memory image after intervention. Together these studies provide strong evidence for the WM theory in explaining the effectiveness of dual-task manipulation on memory modification. Low WM taxation produced memory effects in the same direction as high WM taxation; however, only high WM taxation was effective enough to produce memory effects that differed significantly from a control condition after a short intervention (6×24 s).

The superiority of the 1.25 Hz condition over the 1.0 Hz condition in the study of Maxfield et al. (7) suggests a linear relationship: higher WM taxing results in larger memory effects than lower WM taxing. However, according to the inverted U-curve hypothesis (6), strongest effects are found when competition between memory recall and the dual-task use approximately the same amount of WM resources. Too little taxation of the dual task will leave too many resources available for vivid memory recall and its accompanying emotions, while too much taxation of the dual task prevents the memory from being recalled. In a recent study, an inverted U-curve pattern was observed for emotionality, but not for vividness (13). In the current study, we examined whether the EM intervention would be more effective if the load of the dual task is matched with the load of the memory. We hypothesized that highly vivid memory images would benefit more from fast EM than from slow EM, and less vivid memory images would benefit more from slow EM than from fast EM. Contrary to these hypotheses, there were no interactions between image vividness and dual task WM taxation. Several explanations will be discussed.

First, it could be argued that slow EM were not sufficiently demanding and did not trigger the hypothetical threshold of the inverted U-curve. However, results of study 1 showed that slow EM tax WM more than no EM. Furthermore, EM with a speed of 0.8 Hz had comparable WM taxation as EM with a speed of 1.0 Hz. Because of these results, and because many laboratory studies have found memory effects with 1.0 Hz, which can be considered the "standard speed" (4), the argument that slow EM were not taxing enough seems not plausible. The fact that in study 2 slow EM was attended by effects on memory that were in the same direction as fast EM could indicate a dosage effect: the more cognitive demanding a dual task, the larger the memory effects. It could be hypothesized that an extended duration (e.g., more sets of recall + EM) would lead to a difference between slow EM and RO. For example, Leer et al. (21) found that eight sets of recall with EM, compared to RO, caused a decrease in emotionality at a 24 h follow-up test, while four sets did not.

There may be a second explanation for the absence of an interaction effect between dual task load condition and image vividness. Possibly, image vividness does not influence the amount of WM load. In the present study, WM load of the memory image itself was not measured. However, the relation between WM and vividness of imagery was examined in series of experiments with dual task manipulations by Baddeley and Andrade (16). It was concluded that vividness of imagery reflects the richness of representation in WM. Moreover, more recent evidence indicates that emotional memories tax WM to a greater extent than neutral memories [Ref. (22); see Discussion]. Based on these previous studies, it seems justified to presume that image vividness affects the degree of WM taxation. In order to fully clarify this issue, it would be interesting to have participants recall images with a wide variation of vividness while performing a simple RT task. This would enable us to measure the cognitive demanding qualities of the memory image.

Alternatively, because WM load of the dual task did not interact with WM load of the memory image, one may question whether individuals are actually able to hold a memory image in mind while performing a dual task. The WM account is derived from the WM theory by Baddeley and Hitch (23) in which three memory components are described: an attentional control system (central executive) and two slave storage systems (visuospatial sketch path and phonological loop). Later, Baddeley and Andrade (16) added a fourth component: the episodic buffer, which is a limited-capacity temporary storage system that allows integration from both the slave systems with material from long-term memory. The central executive is thought to control the retrieval and modification of information that is temporally stored in the episodic buffer. The central executive may therefore influence the content of information, by directing attention to a specific source: the slave systems or long-term memory. Based on this model, it seems likely that during a dual-task manipulation, the central executive is involved in attending to both tasks, while the temporal storage and integration of information takes place in the episodic buffer. During dual-task manipulation in our study, information is retrieved from long-term memory and maintains active in the episodic buffer. This process of constant reactivation to maintain an image active requires much effort [see Ref. (24)]. A crucial question is whether performing EM *interferes* with the memory material due to integration of both tasks in the episodic buffer or whether division of attention between the two tasks by the central executive *inhibits* the memory material to be fully activated. If the former is true, then maximizing the complexity of a cognitive demanding task may leave almost no resources available for active recall of material from long-term memory and therefore there will be little interference. If the latter is true, then maximizing the complexity of a cognitive demanding task may lead to memory retrieval strategies, such as rapid shifting between tasks, which could lead to partial exposure to the memory and result in devaluation of the memory. More fundamental studies are needed to investigate these hypotheses about the cognitive processes that underlie the effects of dual task procedures on emotional memories.

Finally, there were some short-comings of the current study. First, we selected memories high or low in vividness, but the image vividness changed during the experiment prior to the intervention. This may have resulted in unreliable conditions. That is, selecting the target image seemed to inflate its vividness. We therefore analyzed the data on the memory level instead of on the person level and used multilevel modeling to correct for the assumption violation of independent data. A strength of multilevel modeling is that it allowed the use of vividness as a continuous predictor, and therefore provides more detailed information than a dichotomous division in target image vividness. Second, the general ability to use mental imagery was not measured. Individual differences in imagery may influence the effectivity of dual task manipulation. Future studies could test this influence through assessment of the ability to use mental imagery with the Spontaneous Use of Imagery Scale [SUIS; Ref. (25)] or, more specified to visual imagery, the revised version of the Vividness of Visual Imagery Questionnaire [VVIQ-2; Ref. (26)]. Third, vividness and emotionality ratings were based on subjective ratings. Psychophysiological measures could be used as objective indicator of memory emotionality [e.g., Ref. (12, 27, Kearns & Engelhard, Submitted)]. Fourth, the current study did not use standardized compliance measures: we manipulated the speed of the dot moving from left to right and corrected the participant if they did not follow the dot properly, but we did not test the actual speed of participants' EM. Using electro-oculogram analysis might help here. Finally, we only analyzed the immediate influence of dual-task manipulation on memory modification. Research has yet to determine whether memory modification effects are maintained over time (21).

In sum, we found consistent effect patterns that are in line with WM theory: the more cognitively demanding the dual task, the more an aversive memory image can be modified, in that these images become less emotional, less vivid, and more difficult to retrieve. In our study, WM load of the memory – operationalized by image vividness – did not interact with the WM load of the dual task. Therefore, we found no evidence for the inverted U-curve hypothesis proposed by Gunter and Bodner (6). Further research is needed to critically test whether the inverted U-curve hypothesis does occur for other intra-individual variables, such as differences in WM capacity. Unraveling the complexities of WM theory may provide a better idea of how titration between the recalled memory image and the WM load of the dual task may be optimized.

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Taxing working memory during retrieval of emotional memories does not reduce memory accessibility when cued with reminders

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Earlier studies have shown that when individuals recall an emotional memory while simultaneously doing a demanding dual-task [e.g., playing Tetris, mental arithmetic, making eye movements (EM)], this reduces self-reported vividness and emotionality of the memory. These effects have been found up to 1 week later, but have largely been confined to self-report ratings. This study examined whether this dual-tasking intervention reduces memory performance (i.e., accessibility of emotional memories). Undergraduates ($N = 60$) studied word-image pairs and rated the retrieved image on vividness and emotionality when cued with the word. Then they viewed the cues and recalled the images with or without making EM. Finally, they re-rated the images on vividness and emotionality. Additionally, fragments from images from all conditions were presented and participants identified which fragment was paired earlier with which cue. Findings showed no effect of the dual-task manipulation on self-reported ratings and latency responses. Several possible explanations for the lack of effects are discussed, but the cued recall procedure in our experiment seems to explain the absence of effects best. The study demonstrates boundaries to the effects of the "dual-tasking" procedure.

Keywords: dual taxation, memory accessibility, reaction time task, working memory, visual imagery

INTRODUCTION

Eye movement desensitization and reprocessing (EMDR) is an evidence-based treatment for posttraumatic stress disorder (1–3). In EMDR, patients are asked to recall traumatic memories while they simultaneously make eye movements (EM). Although EMDR's scientific and practical value was questioned at first (4), EMDR has proven to be as effective as trauma-based cognitive-behavioral therapy [For meta-analyses, see, e.g., Ref. (5, 6)].

For a long time, it has been controversial whether making EM while recalling the distressing memory added anything to the procedure (7). A recent meta-analysis of clinical and laboratory studies on the role of EM has shown that EM during recall of negative memories do have additional effects (8). For laboratory studies, this additive effect is evident by larger reductions in subjective vividness and emotionality ratings of the distressing memory for recall + EM conditions, compared to a control condition in which participants merely recall the memory (i.e., recall only). Clinical studies have mainly found effects of EM on Subjective Units of Distress. There are some findings of EM effects on Subjective Units of Distress combined with symptom measures, such as the Impact of Events Scale [see Ref. (8)].

The effectiveness of EM in EMDR can be explained by dual taxation of the limited resources of working memory [WM, e.g., Ref. (9)]. This dual taxation takes place when an individual recalls a distressing memory while also performing a secondary task, such as making EM, mental arithmetic, or drawing complex figures. When individuals perform the secondary task and simultaneously recall a memory, both tasks compete for scarce WM resources. During this competition, the distressing memory cannot be retrieved completely (i.e., gets blurred) and is stored as a blurred memory after this competition. As a consequence, the blurred memory will be retrieved during future recalls. Presently, a body of evidence supports the WM hypothesis [e.g., Ref. (10–12); for review, see Ref. (13)]. The vast majority of studies have shown that dual taxation of WM blurs *autobiographical* memories [see Ref. (8, 13)], with a few exceptions, such as pictures (9, 14) and a film clip (15).

Most studies on the effects of recall + EM focused on changes in the subjective ratings of the experienced memory [e.g., Ref. (10, 16, 17)]. Therefore, the effects of EM in these studies could still, in part, be the effect of demand characteristics; inferences participants make based on what they think the researcher expects (11). Thus, it remains unclear whether changes in subjective ratings are the result of an experimental manipulation *per se* or of unconscious or conscious alterations in the participants' behavior to fit the hypothesis. Gunter and Bodner (11) showed that simultaneous recall + EM reduced subjective ratings, while making EM *after* memory recall did not produce these reductions. This seems to forestall the conclusion that demand characteristics fulfill a large role in the effects of EM, because if they did, both conditions should yield similar results. Nevertheless, objective

Abbreviations: EM, eye movements; EMDR, eye movement desensitization and reprocessing; WM, working memory.

memory measures could preclude the demand characteristics account even further.

To date, however, little attention has been devoted to objectively measure memory accessibility. Yet, WM theory predicts blurring of memories that are recalled under dual taxation conditions. This reduces its accessibility, because it is harder to access a blurred memory. Van den Hout et al. (18) attempted to objectively measure alterations in memory vividness with a reaction time (RT) task. In their experiment, participants studied two "neutral" pictures, though the pictures were not rated for emotional valence. One picture was followed by recall + EM and the other was followed by recall only. In the RT task, participants performed old/new recognition on cut-outs taken from both pictures and cut-outs from never studied pictures. The rationale for using cut-outs was that comparing a picture cut-out with a blurred memory of that same picture takes more time, than a non-blurred memory. Van den Hout et al. (18) showed that in the Recall + EM condition – but not in the recall only condition – a reduction in vividness ratings was accompanied by an increase in RTs: participants were slower in deciding whether they had seen the fragments before. Therefore, RTs seem suitable as an objective behavioral measure to assess the effects of memory blurring by EM. Notably, in a different paper (14), the question arose whether the allegedly neutral pictures from Van den Hout et al. (18) were truly neutral. As an annex, in the discussion of the later paper, the two pictures of Van den Hout et al. (18) were rated and it was observed that the pictures were hedonically positive. It is not self-evident that the effect of reduced accessibility of emotionally positive stimuli generalizes to negative materials.

While traumatic memories may seem to occur out of the blue, they are often activated by environmental cues (19). Therefore, the blurring of emotional memories needs to be placed in perspective. According to cognitive theories about posttraumatic stress disorder, traumatic memories are not contained in a vacuum, they can be activated by external cues. For instance, Brewin (20) argued that certain cues reminiscent of the traumatic experience can activate memory presentations that are otherwise inaccessible. Ehlers and Clark (21) make a comparable statement, namely, that involuntary intrusive visual memories are triggered by stimuli that are temporally associated with the trauma, but are not strongly semantically related to the event. Through an associative learning process these stimuli and trauma become connected, and as a consequence the stimulus becomes a warning signal: a stimulus that signals imminent danger (22).

Though it is apparent that traumatic memories are not isolated memories, it is currently unclear whether the effects of EM (i.e., reductions in subjective ratings and in memory accessibility) will be found when a reminder cue is presented. On the one hand, it is easier to remember episodic information in cued recall than in non-cued recall [e.g., Ref. (23)]. On the other hand, cues are frequently not uniquely encoded with one memory, which may make it difficult to recall a specific memory instantly. Furthermore, reduced subjective ratings do not necessarily have to co-occur with reduced accessibility, because declarative memory and memory for learning associations (i.e., conditioning) can be dissociated (24). To illustrate this point, patients with posttraumatic stress disorder may display trouble with intentional recall of aspects of the trauma memory, while cue-driven triggers lead to intrusive re-experiencing of that memory (21).

Inaccessibility of episodic memories has frequently been studied with the Think/No-Think paradigm (25). In this task, participants first learn cue-target word pairs. They then repeatedly recall the target for "think items" when seeing the cue, or stop target retrieval for "no-think items." For one-third of the items (baseline items), there is no recall or retrieval-stopping. Afterwards, memory for all pairs is assessed and generally a part of the cued no-think items – compared to baseline items – have become inaccessible [see Ref. (26) for a review]. Evidently, the accessibility of cued episodic memories can be affected.

The main aim of the current study was to replicate and extend the study of Van den Hout et al. (18) to negative memories. We tested whether recall + EM affect the accessibility of associative emotionally *negative* memory representations. Studies on the effects of dual taxation on memory typically use negative autobiographical memories. However, given that autobiographical memories are by their very nature hard to control and that positive effects have also been found with self-irrelevant memories for pictures shown in the laboratory [e.g., Ref. (18)], we decided to use memories of aversive pictures instead. We examined whether accessibility of emotional memories is affected when those memories are activated via *reminder cues*. We used these reminder cues as an experimental analog of the often cued nature of trauma intrusions. Additionally, we attempted to *objectively* measure memory blurring with a response latency task. To achieve our aim, we adapted the frequently used Eye Movements Task by incorporating elements from the think/no-think paradigm and reasoned that associative accessibility, measured by RT following a reminder cue, should be reduced for recall + EM compared to a recall only or to no-presentation control. Additionally, parallel to this RT reduction, we expect memory blurring in terms of reductions in self rated vividness and emotionality of the emotionally negative memory.

ETHICS STATEMENT

The research reported in this article involved healthy human participants, and did not utilize any invasive techniques, substance administration, or psychological manipulations. It was conducted according to the principles expressed in the Declaration of Helsinki. The sample size was set before data collection and written informed consent of each participant was obtained. In giving consent, participants indicated to have read and to have agreed with both the rules regarding participation and proper (laboratory) behavior, and the researchers' commitments and privacy policy. They were also informed that they would be able to stop participating in the experiment whenever they wanted to do so. After consent, participants were randomly allocated to conditions and all gathered data were analyzed anonymously. Afterwards participants were debriefed.

MATERIALS AND METHODS

PARTICIPANTS

Sixty-two undergraduates of Utrecht University ($M = 22.12$ years, $SD = 3.16$; 45 females, 17 males) participated for course credit or financial reimbursement. Two participants were excluded (one because of sudden illness, another because of EMDR knowledge prior to the experiment), resulting in a sample of 60 participants.

MATERIALS

Words

In this paradigm, participants studied word-image association pairs that were divided over recall + EM, recall only, and control. For these pairs, 12 neutral Dutch words and two filler words (bean, caterpillar, chip, clock, gate, hawk, iron, mill, nail, plum, reptile, spleen, stamp, and wind) with moderate levels of arousal were selected from Moors et al. (27) ($M_{\text{valence}} = 4.08$, SD = 0.15; $M_{\text{arousal}} = 3.59$, SD = 0.41; words were rated on a scale from 1 *very negative/passive* to 7 *very positive/active*). Filler were used as buffers at the beginning and end of lists to avoid primacy and recency effects. Importantly, the three experimental conditions were matched on ratings of valence and arousal, as well as on ratings of word length, word frequency, power, and age of acquisition. The latter two referred to the extent to which a word is submissive/dominant, and to the estimated age a word was first learned.

We used neutral words as a model of cued trauma recall. Frequently, objects or situations that are associated with trauma – because of their temporal proximity – are of neutral valence (e.g., a bank in case of a bank robbery). A second reason to use neutral words instead of negative words was to avoid inter-pair associations as much as possible (i.e., associations other than those between the word and image of a pair). Because negative materials stem from a small number of categories (e.g., death, disease), they are related to each other quickly. Since, the use of negative images was crucial, use of negative words would rapidly increase inter-pair associations. Moreover, we made sure cue words were not related to other cue words in the stimulus set with the association database from the University of Leuven: www.kuleuven.be/semlab.

Images

In a pilot study, participants ($N = 24$) rated 52 potentially neutral and 52 potentially negatively valenced images from IAPS (28) and Google Image. Pictures were rated with the Self-Assessment Manikin [SAM; (28)] on a nine-point rating scale, where nine represents a high score on each dimension, and one represents a low score. From the pilot data, 12 images (and two filler images) with the lowest valence and highest arousal ratings were selected ($M_{\text{valence}} = 2.29$, SD = 0.53; $M_{\text{arousal}} = 6.2$, SD = 0.85). Five IAPS images were selected (2053, 6313, 6821, 9433, and 9911) and seven Google Image Pictures depicting a bullfighter attacked by a bull; an anorexic woman looking in the mirror; masked soldiers carrying guns and explosives; the hanging of two men; elephants killed by poachers; and a man who set himself on fire. Images had a landscape orientation and were of the same size (500 × 375 pixels). For the final test, each image was divided into four equally sized cut-outs (250 × 187 pixels).

Visual analog scale

Participants rated the dependent variables vividness, emotionality, difficulty to retrieve the memory of the target scene, and degree of confidence in their decision ("choice confidence"; see end of Section "Response Latency Task") on a visual analog scale (VAS) from 0 (*not vivid/emotional/difficult/certain at all*) to 100 (*very vivid/emotional/difficult/certain*). Choice confidence was added as a novel outcome measure, because correct target image identification in forced choice can be independent of choice confidence. Decreases in confidence are an extremely robust finding of research on obsessive–compulsive disorder in our laboratory [e.g., Ref. (29)].

Response latency task

Four cut-outs were taken from each picture (48 cut-outs in total). Participants were asked to identify which cut-out had been paired earlier with the cue word presented on screen. They consecutively rated their choice confidence. The cue was displayed for 1000 ms followed by four cut-outs presented in four quadrants around the cue. The correct cut-out belonging to the target image had to be selected within 4000 ms by pressing the button on the numerical keypad that corresponded with the cut-out's location on screen. To avoid learning from novelty elimination, three other cut-outs displayed parts from images that had been used as targets for other cues. There was one pseudo-randomized order set, wherein the total serial position for each condition was identical, and no more than two cues from the same condition were displayed consecutively. Response latency was measured as dependent variable. Additionally, participants rated how confident they were their answer was correct (400 ms intertrial interval; ITI).

Post-experimental questions

Participants rated on paper-and-pencil VAS to what extent they were compliant with and had been able to follow the instructions, which was used as a manipulation check. For recall + EM and recall only they rated to what extent they made EM, were able to recall the cued target memory, and how vivid and detailed that memory was.

PROCEDURE

Learning phase

Initially, all cue-target pairs – consisting of a word and image – were presented in the middle of a black screen for 8000 ms followed by 400 ms ITI. The display time was taken from Depue, Banich, and Curran (30) and was doubled, because participants were instructed not only to associate cue and target but also to be able to recall the target image as complete and detailed as possible when seeing the cue. Based on a pilot, participants indicated that this display time was sufficient to comply with instructions. Next, participants saw the cue word for 1000 ms and were instructed to select the correct target image for each cue from four image options presented in four quadrants around the cue. Three images displayed scenes that were targets of other cues. Cue and image options disappeared after 4000 ms or after target selection. The maximum decision time was based on a pilot, in which all decisions made by participants were within 4000 ms. The correct target was highlighted by presenting a green rectangle around the correct target for 2000 ms followed by 400 ms ITI (31) regardless of the participant's answer. When participants correctly selected 11 out of 12 experimental targets, they proceeded to the learning test. They had up to six list repetitions to achieve this criterion. All participants reached this criterion within six repetitions.

Learning test

In the learning test (pre-test), participants were presented with a cue word and retrieved the accompanying target as vividly and detailed as possible, and pressed the spacebar when they did. They then rated the memory of the retrieved target on vividness, emotionality, and difficulty of retrieval. Next, the cue was presented a second time for 1000 ms, and the participant had to select the correct target from four scenes within 4000 ms. Contrary to the learning phase, no feedback was provided. After each decision, participants rated how confident they were their answer was correct (400 ms ITI). After participants completed the learning test for all cues, they proceeded to the EM phase.

Eye movement phase

Participants were instructed to retrieve and visualize the target as vividly and detailed as possible after a cue was presented. For one-third of the cues, participants were instructed to simultaneously follow a dot of 20 pixel that moved laterally with their eyes (1 Hz frequency and 461 pixel amplitude) for 4 intervals of 24 s separated by 5-s breaks ("Recall + EM"). For another third of the cues, the same procedure was used except that participants did not perform a secondary task, but simply looked at the center of the screen while thinking of the target ("Recall Only"). The final third of the cues were not presented in this phase and served as "natural decay" control condition. The duration of the experimental manipulations was identical to previous studies [see Ref. (13)]. In total, eight cues were presented in this phase and no more than two cues with the same instruction were given in a row. Word pairs were rotated through conditions over participants. After the 4 × 24 s of the eighth cue, participants continued with the final test phase.

Final test phase

Memory for all experimental items was assessed in the final test (post-test). Participants were presented with the cue and were instructed to retrieve the memory of the image associated with the target. They then rated vividness and emotionality of the memory of the retrieved target, and did this for all cues before continuing to latency response task. After the latency response task, participants filled-out the post-experimental questionnaire.

RESULTS

Data with more than three SD from the mean were corrected. (Results for data with and without outlier correction were comparable.) Moreover, in order to retain sufficient power, slight violations of sphericity were corrected with Greenhouse–Geisser ($0.70 \geq \varepsilon < 0.75$) or Huynh–Feldt corrections ($\varepsilon \geq 0.75$). In case of severe violations ($\varepsilon < 0.70$) a multivariate test statistic (Pillai–Bartlett trace; V) is reported. Analyses were performed only on pairs for which participants recalled the target on the final learning test. **Table 1** presents means and SD of the self-report ratings for the three conditions.

MANIPULATION CHECKS

An analysis of variance (ANOVA) revealed that there were no differences between conditions on difficulty of retrieval, $F(2, 118) = 1.56$, $p = 0.21$, $\eta_p^2 = 0.03$, indicating comparable levels of recall before entering the EM phase.

On the post-experimental questions, participants indicated that they frequently made EM during recall + EM ($M = 83.77$, SD = 14.58), and rarely during recall only ($M = 13.87$, SD = 18.68), $t(59) = 18.79$, $p < 0.001$, $d = 4.2$. They were better able to recall the memory of the image during recall only ($M = 80.63$, SD = 15.40) compared to recall + EM ($M = 64.78$, SD = 24.36), $t(59) = 4.91$, $p < 0.001$, $d = 0.78$. Additionally, the recalled image was more vivid and detailed during recall only ($M = 72.35$, SD = 18.50) compared to recall + EM ($M = 52.25$, SD = 24.15), $t(59) = 6.56$, $p < 0.001$, $d = 0.96$.

VIVIDNESS

A 2 (Pre, Post) × 3 (recall + EM, recall only, control) ANOVA showed no significant main or interaction effects for vividness ratings, Fs < 1.90, ps > 0.17, $\eta_p^2 < 0.04$.

EMOTIONALITY

A 2 (Pre, Post) × 3 (recall + EM, recall only, control) ANOVA did not reveal significant main or interaction effects, Fs < 2.23, ps > 0.13, $\eta_p^2 < 0.04$.

CONFIDENCE

Because confidence ratings related to complete images before the experimental manipulation and to partial images after the manipulation, the former were entered as covariates in an ANCOVA. Pre-manipulation confidence ratings for recall + EM, $F(1, 56) = 17.38$, $p < 0.001$, $\eta_p^2 = 0.24$, and for control, $F(1, 56) = 11.87$, $p = 0.001$, $\eta_p^2 = 0.18$, related significantly to post-manipulation confidence ratings. There was no relation between pre-manipulation recall only scores and post-manipulation ratings, $F < 1$. The main analysis of condition on post-manipulation ratings showed no effect when controlling for the pre-experimental confidence ratings, $F(1.672, 93.641) = 0.17$, $p = 0.80$, $\eta_p^2 = 0.003$ (Huynh–Feldt correction).

Table 1 | Means and SD (in parentheses) of difficulty, confidence, vividness, and emotionality ratings for the recall + EM, recall only, and control conditions.

	Difficulty	Confidence	Vividness		Emotionality	
			Pre	Post	Pre	Post
Recall + EM	29.85 (16.82)	89.90 (11.6)	72.30 (14.22)	73.90 (16.59)	55.16 (16.23)	53.99 (19.04)
Recall only	31.21 (15.68)	89.05 (10.88)	70.77 (14.25)	73.59 (14.74)	51.05 (20.13)	53.07 (17.46)
Control	33.78 (17.93)	88.90 (12.05)	70.74 (14.72)	71.27 (15.28)	50.43 (19.74)	53.16 (19.68)

RESPONSE LATENCIES

Before analyses, response latencies were log transformed because of natural skewness in scores. Similar to confidence ratings, response latencies related to complete images before the experimental manipulation and to partial images after the manipulation. Therefore, pre-manipulation response latencies were entered as covariates in an ANCOVA. Pre-manipulation response latencies for recall only, $F(1, 56) = 6.70$, $p = 0.012$, $\eta_p^2 = 0.11$, related significantly to post-manipulation response latencies. Other pre-manipulation response latencies did not, $Fs < 3.10$, $ps > 0.08$, $\eta_p^2 < 0.06$. The main analysis for post-manipulation response latencies, though, did not reach significance when controlling for pre response latencies, $F(2, 112) = 0.7$, $p = 0.5$, $\eta_p^2 = 0.01$. **Table 2** presents means and SD.

ACCURACY

Participants needed, on average, 1.77 (SD = 1.30) repetitions to achieve the learning criterion. Because analyses were performed only on pairs for which participants recalled the target on the final learning test, pre-manipulation scores for accuracy reached the ceiling (100% for all conditions). Therefore, for accuracy, an ANOVA was performed on post-manipulation scores only (see **Table 2**). Participants did not differ in their accuracy to select the correct target images for the different conditions, $F(2, 118) = 0.45$, $p = 0.64$, $\eta_p^2 = 0.007$.

DISCUSSION

The aim of this study was to test whether recall + EM affect the accessibility of associative memory representations when emotionally negative materials are used. In this extended replication of Van den Hout et al. (18), we found no blurring of the emotional memory representations for recall + EM compared to recall only or no intervention. This was reflected in the absence of any effects on subjective ratings of vividness and emotionality, and also in objective measures of memory accessibility, specifically latency responses. Participants reported they had complied with the instruction to make EM. They also reported that mental images were less vivid, less detailed, and more difficult to retrieve *during* the intervention. However, this seems trivial, because these effects did not persist at the post-test.

The data show no reductions in memory accessibility, but they do not necessarily falsify WM theory as an explanation for the effects of dual taxation. The absence of effects may be a consequence of our materials. Could the data have been different if self-relevant or less negative pictures would have been used? The vast majority of earlier studies on the effects of demanding secondary tasks have used personally relevant, autobiographical memories [e.g., Ref. (10, 11, 32)], while our study used novel emotional images. These images could have lacked the potential to elicit sufficient levels of arousal, which may be necessary in the dual-tasking procedure to reduce vividness (Littel et al., submitted). Van den Hout et al. (14) showed that only negative autobiographical memories – which are associated with transient levels of arousal – were reduced in their vividness ratings, while neutral memories were not. This suggests arousal is a prerequisite for (re-)encoding of memories after dual taxation. Although our materials were not negative autobiographical memories, they were, however, thoroughly piloted and showed sufficient arousal during the pilot and on pre-test measures. Moreover, other studies have used non-idiosyncratic materials and showed effects for recall + EM compared to recall only [e.g., Ref. (15)] and specifically showed that effects can be found for materials that are neither autobiographical nor self-relevant (9, 18). It therefore seems unlikely that intrinsic qualities of our novel images *per se* explain the absence of effects.

The tasks we used may also have limited the effects of dual taxation. This study used a latency response task that was based on a similar task in Van den Hout et al. (18). In their task, participants were instructed to react as fast and accurately as possible, and had to decide whether a cut-out was old or new. In our experiment, participants received comparable instructions. Yet, they did not make an old-new judgment, but a source judgment: they had to indicate which of the four displayed images was the cue's target. Though these tasks look similar, they probably draw on different types of recognition: old-new recognition and source recognition. Old-new recognition can generally be performed at lower levels of item differentiation than source decisions (33). As a consequence, slightly blurred recall + EM pairs may show effects for old-new decisions compared to recall only pairs, but not for source decisions. It is possible that successful source memory differentiation does occur when pairs from the recall + EM condition differ more in the level of memory blurring from the recall only or no-presentation control conditions. Theoretically, it may be possible to find differences between conditions when an old-new recognition task is used instead of a source recognition task.

A different explanation may also be found in the response latency task, specifically in the distractors that were used as targets in previous trials. During the final part of the experiment, participants had to select the correct target out of four cut-out images. Here, the use of distractors that have been used as targets in previous trials may cause response inhibition, and related response delays. Alternatively, it is also possible that the blurring effects were abolished, when participants specifically saw recall + EM images as distractors in earlier trials, and in later trials saw these same images as targets. As a consequence, the image could have been reinstated in full and any condition effects were abolished as well. This does not, however, explain why there were no effects on any of the subjective ratings, which preceded the response latency task. Though, it might be possible that the effects of recall + EM in our design were subtle and only detectable with RT, but that this effect was abolished by how our response latency task was designed. Furthermore, emotional interference may have played a role, because participants had to select one out of four highly unpleasant images, which may have caused response delays that are not due to simple blurring or retrieval delay. Indeed, it cannot be ruled out that there

Table 2 | Means and SD (in parentheses) of response latencies and accuracy for recall + EM, recall only, and control conditions.

	Response latencies	Accuracy
Recall + EM	1268.7 (310)	0.97 (0.06)
Recall only	1292.4 (383.8)	0.96 (0.07)
Control	1280.9 (324.6)	0.97 (0.06)

might be a floor effect in that the delay is beyond the critical point where retrieval differences can be found.

Though several plausible explanations for the lack of effects can be found in the response latency task, it still leaves unanswered why subjective ratings of the images did not change, because these ratings preceded the latency response task, and were recalled without seeing any of the targets from other pairs. Perhaps cued recall of the to-be-recalled material influenced the effectiveness of dual taxation. On the one hand, cued recall could facilitate episodic memory retrieval compared to non-cued recall (23), and thus should allow the participant to vividly retrieve the associated target image. This is reflected in relatively low pre-test scores for self-assessed difficulty of retrieval and high scores for vividness. Subsequent retrieval of a vividly cued image should therefore be blurred as a consequence of dual taxation. This, however, did not happen. On the other hand, even though participants quickly learned the associations – which hints at strong relationships between cue and target – these may simply not have been strong enough. We used neutral words referring to objects that people may encounter frequently in daily life and thus could be linked to various situations. Although the association between the cue and target is novel and recent, it is unlikely that the cue's path exclusively leads to the target. Therefore, after images were cued in a recall + EM trial, participants may not have thought of the target image all the time, but of other images, objects, or words. As a consequence, the target may not have been sufficiently blurred and reductions in self-reported vividness and emotionality may not have been experienced for recall + EM. Hence, generally cued recall may ameliorate memory, but not when a multipath cue needs to prompt one specific target for prolonged periods of time. Additionally, this might also explain why there were no latency response effects. If cues did not elicit specific and continuous target retrieval, then differential item blurring and successful source recognition could not have occurred.

Provided that cued recall was primarily responsible for the lack of effects, the question ensues whether dual taxation is able to affect associative memory networks. A review of earlier studies showed that WM taxation, specifically EM, is able to reduce subjective ratings of emotional memories when those memories were recalled immediately after the intervention (8). The current study showed that these memories were not changed subjectively or objectively when cued with a memory reminder. Perhaps this limitation signals a boundary condition for this paradigm and limits the robustness of the dual taxation paradigm. Until now, Van den Hout et al. (18) conducted the only study that found effects of the EM intervention on objective measures of memory accessibility, and it cannot be ruled out that this represents a chance finding. It should be noted that other studies using objective measures of memory valence or emotionality have shown effects after dual taxation, such as eye blink startle reflex diminution (34), reduced heart rate variability (35), and decreased electrodermal responses (36), but these objective measures primarily related to arousal levels and not memory accessibility *per se*.

If it does, however, signal a limitation of the dual taxation paradigm, then memory change under dual taxation conditions may require a specific form of recall. This would imply that a memory must be directly recalled as opposed to memory recall that is initially cued by reminders. The former has been frequently used in previous work [e.g., Ref. (14)]. Interestingly, this does not preclude the possibility of finding effects with cued recall. Cued recall *after* dual taxation may still lead to reductions in subjective ratings, but only if the memory is recalled directly *during* dual taxation. This does, however, seem to contradict predictions from current trauma theories (20, 21), which state that encountering cues associated with an emotional memory could instantly trigger vivid intrusions of that memory. In the current study, cues probably elicited retrieval of the target memory, but most likely only briefly.

The lack of effect of cued recall also has implications for associative network theories, in which connectivity between different representations is paramount. A central tenet of network theories is modifiability of the network's structure after activation [e.g., Ref. (37)]. It is possible that small networks (e.g., two nodes representing only stimulus characteristics, such as gate – car accident) are difficult to modify. Larger, more ecologically valid networks typically also contain elements regarding responses ("panic") or meanings ("I am helpless"), next to mere stimulus relations. Perhaps these former relations are an inherent changeable part of the associative network, and also a part that does not need to be targeted directly. It is possible that stimulus characteristics change during dual taxation, and affect response and meaning elements, which changes how a person feels or thinks about an event. As a consequence, change in subjective experiences may be difficult to accomplish in smaller, laboratory created networks because these lack elements of meaning.

In sum, we found that EM during recall did not blur emotional memory representations measured by subjective or objective measures of memory accessibility. Response inhibition and emotional interference do not seem able to explain all the effects. Cued recall, on the other hand may; it may not have been potent enough to elicit specific and continuous target retrieval for differential item blurring to occur. Although memory effects following EM were not observed, it is unlikely – given the substantial body of evidence – that reductions in self-reported ratings are a chance discovery. Changes in objective measures of memory accessibility therefore still need to pass the critical test of replication.

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Mental imagery and food consumption

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INTRODUCTION

One enigmatic capacity of human experience is the ability to travel back and forth in time by using mental simulations. By imagining shapes, forms, and scenes, humans can relive the past and visualize future events (1, 2). Historically, this memory-based mechanism has been discussed in scientific and non-scientific fields. As described by Marcel Proust in his epic work, In Search of Lost Time (3), the sensory experience of gustatory cues, in this case, a sponge-cake called Madeleine, seems to be powerful enough to trigger a cascade of vivid intrusions associated with a particular set of memories (4). Besides anecdotal references, visual mental images are of great interest in the domain of eating behavior because research has shown that (involuntary) mental simulations of intrusions and (voluntary) repetitive mental imagery influence eating behavior. Unraveling the basic mechanisms that underlie mental imagery in the food domain has the potential to provide new insights into the perception and consumption of food.

In this opinion article, we briefly report on the role of mental imagery simulations in eating behavior and its associated pathologies and illustrate how research on mental imaginary has contributed to the current understanding of the cognitive aspects of food intake regulation and satiation processes. Furthermore, we discuss whether guided mental imagery intervention strategies can be integrated into the successful self-regulation of eating behavior and provide a perspective for future research on mental imagery.

MENTAL SIMULATION OF FOOD CONSUMPTION AND EFFECTS ON JUDGMENTS AND BEHAVIOR

Many individuals in modern society live in environments that promote excessive weight gain because of the omnipresence of food (5). The exposure to food automatically prepares individuals for food intake and often evokes thoughts about food, a simulation of food intake, and a strong motivation to consume food (6). Indeed, even the exposure to words related to tempting food can activate a cascade of associations with food (7) and the simulation or reenactment of prior eating occasions (8). Although internal cues of hunger or craving are relevant to the formation of such intrusive thoughts to a large degree, it is clear that thoughts about food consumption are also triggered by consumption-related cues in the environment. Shop design and product presentation in marketing have tapped into these mechanisms by using sensory, textural, and emotional triggers to evoke intrusions, facilitate the simulation of consumption, and increase actual purchases and consumption (9, 10). Recently, research has shown that such marketing practices are not just a creative idea put forth by marketing managers but are supported by concrete evidence for the link between mental simulations and behavior. Elder and Krishna (11) presented participants with a picture of smooth vanilla yogurt in a bowl. They varied whether a spoon was on the right or left side of the bowl. In support of the hypothesis that participants simulate their eating of the yogurt prior to their actual intake in order to forecast the taste of the yogurt, the researchers found that right-handed participants indicated higher purchase intentions when the spoon was on the right side of the bowl compared with when it was on the left side. Hence, the characteristics of the presentation that facilitated the simulation of eating increased the motivation to eat the yogurt. The facilitation effect is not limited to visual perception. For instance, Mitchell and Kahn (12) reported that the ambient odor of a room had a considerable effect on the extent to which individuals thought about the presented products. When the odor was congruent with a product (e.g., chocolate), consumers were more likely to process information about the product. Similarly, Seo and Roidl (13) found that congruent odor enhanced visual attention to odor-congruent food items. In their study, 60 participants were presented with four odors (orange, lavender, coffee, and licorice) prior to and during the presentation of foods via photographic slides. Participants who received olfactory cues looked more frequently and for longer at the corresponding foods than participants in a control condition with no odor presentation. The presentation of food also has an effect on taste assessments. For example, subtle changes of the natural color of an orange juice drink (darker orange hue) decreases liking scores substantially (14). In accordance, manipulating expected brand pronunciation (incongruent brand labelling) was shown to reduce hedonic liking of yoghurts (15). Taken as a whole, the results of the above-mentioned studies correspond with the assumption that conditions that facilitate the simulation of the consumption of attractive food increase interest in the food (e.g., visual attention or processing of information about the food) and the desire for food consumption.

Researchers have recently referred to theories on grounded cognition (16, 17) to explain the effects of perceptions on thoughts and behavior (10). The basic idea of these theories is that the cognitive representation of concepts is grounded in related modal systems. Previous theories on cognition had supposed that cognitions were amodal and, for example, not based on modal representations of motor behavior. These theories had implied that individuals can think about eating in the same way whether or not they can move their mouth and tongue at the current moment. By contrast, the more recent approaches of grounded cognition suppose that thinking about an object is related to perception and motor behavior. This means that humans cannot think about food without simultaneously activating related perceptions and that they simultaneously simulate motor behavior that is related to the stimulus. Hence, the mode of thinking is supposed to be strongly related to the mode of perception and the mode of action. According to the grounded cognition approach, thinking about food or just reading food-related words should evoke mental simulations of eating (7). Recently, such assumptions have received support from neuroscience research. Researchers found that solely the perception of pictures of palatable food led to activations in brain areas associated with gustatory experiences (18) and elevated ghrelin levels (orexigenic hormone) in healthy volunteers (19). Like food cues, ghrelin is one major mediator of food anticipation (20) and recruits the same neuronal circuitry in the dorsomedial and ventromedial hypothalamus (21).

An example of a particularly strong influence of thoughts on behavior is food craving. Food craving is regarded as a strong motivational state that urges individuals to seek and consume a particular kind of food (22), often containing high amounts of sugar or fat (23). When individuals crave food, their thoughts about food are often so intrusive that they have trouble pursuing other goals or focusing on different thoughts. For craving, the causal direction of the influence is bidirectional in the sense that craving has an influence on thought and vice versa. However, it is important to take into account that the mental simulation of food consumption triggered by external cues as described above can result in craving.

REPEATED MENTAL SIMULATION AND MINDFULNESS

EFFECTS OF REPEATED MENTAL SIMULATION ON FOOD CONSUMPTION

An interesting aspect of mental simulations during food perception is that mental simulations do not necessarily lead to increased consumption, but rather, under certain circumstances, they can lead to decreased consumption. Interestingly, repeatedly thinking about food consumption can lead to habituation and a reduced motivation to consume a specific food, just like real consumption (24). Habituation to food is understood as a process that leads to a decrease in both the physiological and behavioral responses to an eating episode and a drop in enjoyment with repeated consumption (24). Several studies (25–27) have found evidence that habituation can take place when individuals repetitively judge food or imagine eating food. For instance, Morewedge et al. (26) asked participants to think either 3 or 30 times about eating M&M's. Later, participants were allowed to eat M&M's. Participants who thought about eating the candy 30 times ate less of the product than those who thought about it 3 times and those in a control condition (who imagined throwing coins into a laundry machine). Like other habituation effects, this effect was shown to be sensory-specific and was only present when the imagined food was congruent with the consumed food. The effect did not show when the imagined food (e.g., M&M's) was not the same as the consumed food (e.g., cheese cubes) [(26); Experiment 4]. Similar sensory-specific characteristics between imagined and consumed foods are therefore fundamental for food habituation to occur. In our recent study, we found that habituation after imagined eating needs mental resources as habituation during actual eating does (28). Several studies have indicated that habituation is based on a memory process that needs cognitive capacity to occur. Hence, when individuals are distracted during eating, for example, when they watch TV during eating (29, 30), they habituate less to food and eat more. We found that a depleting task had a similar effect on habituation after imagined food consumption. In our study, we used a mathematical counting task (31) to deplete participants prior to simulating the eating of 18 walnuts in one condition. We showed that participants in this depletion condition did not habituate to the mental simulation, and habituation was blocked, whereas they habituated in a condition without depletion.

EFFECTS OF MINDFULNESS ON FOOD CHOICE

As reported above, repeatedly imagining food consumption can reduce the desire to consume the food (26). But repetitive thoughts about food consumption are not the only way to reduce the desire to consume a particular kind of food. Also important is *how* individuals think about the food. While a single vivid image of the consumption increases the influence of impulsive responses on food choice, the influence of impulsive responses on food choice decreases when consumers think about the reasons for their food choice (32). Similarly, mindful attention to thoughts about food consumption can reduce choices for unhealthy food items that are impulsively preferred by consumers. For example, Papies and colleagues (6) instructed participants to regard their thoughts from a metacognitive perspective as temporary constructions that appear and disappear. When this mindful attention was applied to food consumption, it reduced impulsive tendencies to approach food (6) and also promoted choices of healthy food (33).

REPEATED MENTAL SIMULATION AND MINDFULNESS AS INTERVENTIONS

It is important to note that the effects of mindfulness are conceptually different from effects of repeated mental simulation. First, repeated mental simulation, but not mindfulness, needs repetition to show effects. Second, repeated mental simulation shows specific effects on a particular kind of food (26) but this is not the case for mindful attention (6). At present, it can be assumed that the habituation effects of repeated mental simulation reflect a memory process that leads to inhibition after some length of imagining exposure to food, whereas mindfulness might be more likely to block the tempting simulation of food consumption. Both processes are of interest for practice. Mindfulness could be used as a method for reducing unhealthy food intake. By contrast, repeatedly imagining food consumption might reduce food intake when consumption has already begun. For example, to increase habituation to a particular kind of food, individuals could think about consuming an unhealthy food that they usually prefer to eat (e.g., chocolate) repeatedly across consecutive days. However, while such long-term effects were demonstrated with exposure to real food (34), it is still a task for future research to study the long-term effects of imagined food consumption. But there is no doubt that the relevance of habituation processes is obvious if we consider recent research that has shown that overweight children habituate more slowly during consumption than non-overweight children (35). Against this background, research on repeated mental simulations could provide a promising starting point from which to advance interventions in food consumption.

CONCLUSION

Current research on food intake behavior regulation is driven by a vital need to understand the successful and unsuccessful self-regulation of food consumption. Integrating the cognitive mechanisms of mental imagery and mindfulness that guide eating behaviors may be one important milestone for enhancing current models of food intake regulation. As proposed by Redden (36), a general model should include reflective (memory recall inferences, metacognitions) and perceptual (adaptation, habituation) components of satiation. He argues that satiation is partially constructed in the moment on the basis of external cues that interact with each other in a specific eating situation. Research on mental imagery and mindfulness can help us understand eating behavior and to design individual-level interventions. It can also help us understand why some individuals are more successful self-regulators than others (37).

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An imagery-based road map to tackle maladaptive motivation in clinical disorders

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INTRODUCTION

There is now a widespread recognition of the importance of mental imagery in a range of clinical disorders (1). This provides the potential for a transdiagnostic route to integrate some aspects of these disorders and their treatment within a common framework. This opinion piece argues that we need to understand why imagery is such a central and recurring feature, if we are to progress theories of the origin and maintenance of disorders. This will aid us in identifying therapeutic techniques that are not simply targeting imagery as a symptom, but as a manifestation of an underlying problem.

As papers in this issue highlight, imagery is a central feature across many clinical disorders, but has been ascribed varying roles. For example, the involuntary occurrence of traumatic memories is a diagnostic criterion for PTSD (2), and it has been suggested that multisensory imagery of traumatic events normally serves a functional role in allowing the individual to reappraise the situation (3), but that this re-appraisal is disabled by extreme affective responses. In contrast to the disabling flashbacks associated with PTSD, depressed adults who experience suicidal ideation often report "flash forward" imagery related to suicidal acts (4), motivating them to self-harm. Socially anxious individuals who engage in visual imagery about giving a talk in public become more anxious and make more negative predictions about future performance than others who engage in more abstract, semantic processing of the past event (5). People with Obsessive Compulsive Disorder (OCD) frequently report imagery of past adverse events, and imagery seems to be associated with severity (6). The content of intrusive imagery has been related to psychotic symptoms (7), including visual images of the catastrophic fears associated with paranoia and persecution. Imagery has been argued (8) to play a role in the maintenance of psychosis through negative appraisals of imagined voices, misattribution of sensations to external sources, by the induction of negative mood states that trigger voices, and through maintenance of negative schemas. In addiction and substance dependence, Elaborated Intrusion (EI) Theory (9, 10) emphasizes the causal role that imagery plays in substance use, through its role in motivating an individual to pursue goals directed toward achieving the pleasurable outcomes associated with substance use.

In this opinion piece, we would like to put forward the proposition that the motivating role that imagery plays in behavior may be a key reason for its presence in this wide range of psychopathologies, and that understanding its motivating role can help us identify common features in disorders and their treatments. It has already been recognized that the link between imagery and affect gives imagery a causative role in affective disorders (11), with the emotional amplifier hypothesis suggesting that in bipolar and anxiety disorders, state-congruent imagery leads to further affective responses, in a vicious cycle. Within EI Theory, the affective consequences of imagery are also used to explain why a cycle of elaboration follows an initial intrusive thought. The intrusive thoughts themselves are seen as the product of associative processes relating to both environmental cues and cognitions. Previous work on EI Theory focused initially on desires, and then on motivation in general. Our suggestion here moves a step further, highlighting its potential relevance to dysfunctional motivational imagery in multiple disorders.

ELABORATED INTRUSION THEORY

Elaborated Intrusion Theory was initially developed to provide a cognitive account of processes involved in the maintenance of substance dependence, and to demonstrate that dependence for different substances shared a common functional basis, despite gross differences in their psychopharmacology. More provocatively, EI theory saw substance-related craving as just an extreme example of a continuum of desire, and argued that it recruited the normal cognitive processes involved in everyday desires. Since its publication ten years ago, the key premises of EI Theory and hypotheses drawn from it have been supported in a substantial body of research (10, 12–14).

According to EI Theory, environmental cues, physiological symptoms (i.e., withdrawal or deficit states), affect, and automatic or overlearned associations that operate outside of awareness do not constitute desires, because the individual is not aware of them. Instead, they generate cognitive activity that, depending upon the task context and other cognitive activity, can become sufficiently strong to become the focus of attention, and be subjectively experienced as an apparently spontaneous thought. When this thought is about a target that is strongly associated with pleasure or relief, it is highly salient, and generates a cascade of cognitive activity, which draws on further associations to elaborate the thought. Sensory imagery is often involved in the intrusion and is a key component of the elaboration, leading to anticipatory responses and augmenting its positive affective impact. However, the sensory focus also elicits an increased awareness of current deficit states, which is increasingly aversive as acquisition of the target is impeded. If the person is trying to withstand the temptation, they may also experience guilt about having the thought, or worry that it means they are losing control. While the affective consequences of the imagery lead to its continued elaboration and perpetuate the craving episode, its functional role is to motivate behavior toward satisfying the desire: it sets up a behavioral goal that competes with and can displace current goals.

TARGETING IMAGERY COMPONENTS

Conceptualizing desire in this way has allowed us to devise therapeutic and behavior change techniques that target the two key components of desire: the initial intrusion and its subsequent elaboration. As the intrusion follows automatic processing of triggers external and internal to the individual, the frequency of intrusions can be reduced by either reducing those triggers or impairing their automated processing. Many existing approaches can be seen to operate through their effect upon intrusions: medications that ameliorate withdrawal symptoms are an obvious way of reducing physiological cues; mood enhancement can target the contribution of negative affect; and attentional retraining can lower an individual's preconscious processing of environmental cues associated with substance use. Once an intrusion has occurred, training in acceptance and a non-judgmental response style can help in letting the thought fade away and be displaced in focal awareness by mindful meditation or other cognitive tasks, without its elaboration dominating thought. If the thought does remain in focal awareness, a variety of imagery-based attentional control tasks can be employed to compete for imagery resources, blocking the sensory imagery of the target that maintains the elaborative cycle, shortening the duration, and weakening the affective intensity of the craving episode (12).

There are clear parallels here with the ways in which imagery is being addressed within therapeutic developments in clinical psychology. For example, imagery rescripting (15) was initially developed to help people with PTSD whose high levels of shame or guilt prevented them mentally reliving experiences, by reframing the event from the perspective of a neutral observer, weakening the emotional response. Different resolutions for the event could then be reimagined, resolving the guilt. This allows different patterns of elaboration to follow any intrusive thoughts, replacing the negative emotions associated with the original elaborations. It has since been applied to anxiety (16), eating disorders (17), and psychosis (8). Imagery-based cognitive therapy can help individuals to make the imagery more realistic (18). Within EI Theory, rescripting can be seen as an alternate elaborative strategy to a concurrent task or a modification of affective responses using mindfulness.

IMAGERY SUPPORTS MOTIVATION AND GOALS

Desire does not only lead us to pursue illicit or unhealthy targets, of course: the strength of hockey players' cravings to play hockey is also determined by the vividness of the sensory imagery that they experience during the episode (19). Imagery-based desires are part of normal motivational processes, directing us toward long-term as well as short-term goals, by bridging the gap in time, and help us deal with challenges in goal acquisition. They support a wide range of behaviors beyond consumption, and EI Theory can be applied to enhance goals for positive behaviors, as well as helping people abstain from dysfunctional ones. In fact, a modification of motivational interviewing called Functional Imagery Training has been developed (20), where people are encouraged to form mental images of the incentives for change, the path toward that change, and their past successes in attaining similar goals. Providing a rich repertoire of vivid positive imagery associated with attainment of an otherwise abstract and general long-term goal allows that goal to compete strongly in the elaborative cycle with the pleasurable sensory images of conflicting short-term goals, which are often highly concrete and specific. By strengthening thoughts of succeeding in behavior change, the very cues that otherwise lead to failure can be recruited to enhance success, in a positive feedback loop, with small steps toward the goal increasing the likelihood of subsequent steps being taken.

Motivation and goal fulfillment in behavior change may seem a long way from the issue of imagery within clinical disorders, but it is worth considering whether the experience of vivid mental images within psychopathologies might not also be linked to disorders of goal formation (21). Holmes et al. (11) raise this possibility in relation to bipolar disorder, arguing that vivid, positive imagery can foster creativity during hypomania but leads to pursuit of unrealistic goals during mania. The goal follows the image, as in their example of someone whose vivid image of a red sports car might prompt them to visit a car showroom. We hypothesize that the relationship between images and goals is broader, so images strengthen pursuit of existing goals as well as stimulating goal formation, and those existing goals may be goals for immediate safety or comfort rather than longer term well-being. In anxiety disorders, imagery of negative and threatening consequences sustains goals of staying safe or avoiding harm. Perhaps this can be taken further, and the flashbacks within PTSD that have been suggested as supporting re-appraisal (3) can be interpreted as part of a general problem-solving process where the individual seeks to imagine ways that they could have behaved in the traumatic situation, which could be recruited in future situations. Similarly, suicidal imagery may motivate goal directed behaviors through increasing the cognitive availability of the actions as solutions to the individual's distress (22) or it may motivate more constructive ways of achieving the imagined consequences of the actions (4). The common feature across these interpretations of imagery is that the intrusion has been triggered because an unresolved and emotionally salient problem remains unsolved. Intrusive imagery is our cognitive mechanism's way of prioritizing an unsolved problem, just as other goals stay active and intrusion-prone until fulfilled (23, 24) – but if the problem cannot be resolved, the imagery becomes maladaptive, and by sustaining a dysfunctional or unachievable goal leads to an affective disorder. In depression, for example, negative self-related ruminations displace ideas of success and lead to a cycle of anhedonia and loss of agency, with the individual finding it near impossible to imagine any future goals.

ROAD MAP TO TACKLE MALADAPTIVE IMAGERY

We suggest that EI theory could provide a road map for effectively tackling imagery of maladaptive goals across clinical disorders: helping to identify risky situations for temptation and loss of control; reducing attention to intrusive thoughts through mindfulness or acceptance training; reducing the elaboration of dysfunctional desires through modality-specific interference [e.g., concurrent visuospatial tasks while recalling trauma memories (25)], or rescripting the content of the image (e.g., adjusting overly positive expectancies of substance use). Treatments targeting imagery should also consider the need to address the goals that those images support, identifying alternative, adaptive goals, and training alternative imagery to boost desire for those goals and rehearse pathways toward them, as in Functional Imagery Training (20).

This interpretation of imagery research within clinical psychology is speculative, and glosses over details and differences between the particular ways in which imagery may be critical to particular disorders. Further argument and empirical work are needed to explore the value of linking clinical conceptualizations of imagery to the rapidly developing work in cognitive psychology and behavior change. Imagery of course has a long history in clinical psychology, from systematic desensitization to covert practice, and has been extensively used to enhance sporting performance: the conceptualization of its role and application in the current paper needs to recognize and accommodate these phenomena, as well as expanding its explanatory power. Reappraising imagery as one part of a larger set of processes that act in consort to guide people in their everyday behavior raises the possibility of engaging clinically with each part of that mechanism, understanding why and how imagery is being distorted or populated by maladaptive content in different ways in a range of disorders. Understanding even part of the relationship would, we believe, justify the effort.

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A role for mental imagery in the experience and reduction of food cravings

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The term "craving" refers to a strong motivational state, which compels an individual to seek and ingest a particular substance (1). It usually refers to alcohol, tobacco, or drugs, but has become increasingly applied to food. Thus, food cravings refer to an intense desire or urge to eat a specific food (2). It is this specificity that distinguishes a craving from ordinary food choices and hunger (3). In Western societies, the most commonly craved foods are those high in fat, sugar, and salt, such as cake, chips, pizza, ice-cream, and in particular chocolate (4). Most people experience cravings for such palatable foods on occasion without any problem (5). However, food cravings can pose significant health risks for some people. Most notably, they can contribute to the development of obesity (6) and disordered eating (7), increasingly serious global health issues (8, 9). This has prompted a surge of investigations into the mechanisms that underlie the experience of food craving with a view to developing effective craving reduction techniques. The present paper focuses specifically on cravings for food, and the role of mental imagery in the experience and reduction of such cravings. For excellent reviews of the theoretical underpinnings of craving and addiction more broadly, we refer the reader to recent works by May and colleagues (10, 11). We take a more applied perspective here and critically evaluate the practical significance of imagery-based craving reduction interventions.

Over the past decade, a growing body of literature has highlighted a key role for mental imagery in the experience and reduction of food cravings. Experimental and survey data have shown that when people crave, they have vivid images of the desired food, including how delicious it looks and how good it tastes and smells (11–14). For example, when undergraduate students were asked to describe a previous food craving episode, 30% made explicit reference to mental imagery, using phrases such as "I could picture [the pizza] in my mind, picture eating it" (14). In addition, when presented with a list of descriptive statements, respondents strongly endorsed imagery-based descriptors as characteristic of their food cravings. Imagery descriptors in the visual ("I am visualizing the food"), gustatory ("I imagine the taste of the food"), and olfactory ("I imagine the smell of the food") modalities in particular were rated highly; in contrast, auditory descriptors ("I imagine the sound of myself having it") were not highly rated (12, 14). Furthermore, when asked to assign specific percentages to each of the five sensory modalities involved in an imagined food craving experience, the visual modality (39.7%) scored the highest, followed by the gustatory (30.6%) and olfactory (15.8%) modalities; by contrast, the tactile (9.5%) and auditory (4.4%) modalities were little used (14). These findings indicate that craving-related food images are predominantly visual, gustatory, and olfactory in nature.

Further evidence for the imaginal basis of food cravings comes from studies that have experimentally induced food cravings by instructing participants to imagine a food-related scenario (e.g., "Imagine you are eating your favorite food") (15). Moreover, the strength of participants' food cravings has been shown to correlate with the vividness of their appetitive images (16). In line with these empirical observations, a recent cognitive model of craving, the Elaborated Intrusion Theory of Desire (17), has placed vivid sensory images of the appetitive target at the very heart of the craving experience. According to this theory, sensory images are a key component of the cognitive elaboration that follows an initial intrusive thought about the craved substance.

More general cognitive psychological research has shown that the generation and maintenance of mental images (of whatever kind) can be disrupted by competing cognitive activities in the same sensory modality. For example, performing a visual task (e.g., watching a flickering pattern of black and white dots, termed dynamic visual noise) reduces the vividness of imagined objects or scenes, whereas engaging in a verbal task (e.g., counting aloud) reduces the vividness of imagined sounds (18). This occurs because of mutual competition between task performance and image maintenance for limited-capacity, modality-specific cognitive resources. Clinical applications of this dual-task methodology have shown that interference by a concurrent visual task can successfully reduce the vividness and emotional impact of distressing autobiographical images, characteristic of post-traumatic stress disorder (PTSD) (19–23).

Applications in the craving domain have similarly shown that competing cognitive tasks can disrupt desire-related mental images, and thereby can suppress cravings for alcohol, tobacco, and food. Notably, tasks that introduce competing information in the same sensory modality as the imagery associated with the craving, and thus compete for the same pool of limited-capacity resources, have proven the most effective. In particular, evidence from numerous laboratory studies has shown that engaging in a range of visual tasks can reduce food cravings. For example, imagining a series of non-food scenes (e.g., a rainbow) has been shown to reduce cravings for food in general (16) and for chocolate in particular (24). Other visual tasks, such as making hand or eye movements (25, 26), watching a dynamic visual noise array (25–29), constructing shapes from modeling clay (30), and playing a game of "Tetris" (31), have also been shown to reduce food cravings.

All these tasks are thought to have their craving reducing effect by reducing the vividness of visual craving-related images. Indeed, many of the previous studies not only assessed participants' level of craving but also the vividness of their craving imagery, and reported a corresponding reduction in both measures under concurrent visual interference (25–31). However, in the absence of evidence for a causal relationship, the craving reducing effect could also reflect a reduction in the opportunity for craving imagery. In all this, it is important to note that people need not be good visualizers in general to derive benefit from imagery-based craving reduction tasks (26), thus demonstrating applicability across the board.

Although most research, to date, has focused on craving reduction via the visual sensory modality, there is evidence for a limited-capacity system that processes odor memory and imagery (32, 33) and is susceptible to olfactory interference (34, 35). Thus, the logic would suggest that a concurrent olfactory task would also reduce food cravings. In support, a number of studies have demonstrated craving reducing effects using olfactory tasks. The earliest such study showed that imagining the smell of non-food odors (e.g., eucalyptus, fresh paint) can reduce food cravings (24). More recent studies have shown that simply sniffing a non-food odorant, such as jasmine scented oil or a random chemical compound (36, 37), can also reduce food cravings.

In addition, a handful of studies has shown craving reducing effects from competing verbal tasks, such as imagining everyday sounds (e.g., a siren) (24), or listening to a foreign language recording (28). This suggests that competing tasks may act to distract participants or divert their attention. However, the craving reductions from verbal tasks in the above studies were substantially smaller than those produced by visual or olfactory tasks. Thus, although any cognitive task might serve as a distractor, it is tasks that engage the same cognitive processes as those used to construct and maintain craving-related imagery that will be most effective in reducing cravings. Further, although the great majority of people report craving-related images in the visual and olfactory/gustatory modalities (12), a minority do experience auditory images, and thus competing verbal tasks should reduce cravings for them.

All of the craving reduction studies described above have been conducted in the laboratory. These have induced food cravings experimentally using one of several methods, namely by depriving volunteers of food (30), instructing them to imagine eating a favorite food (16, 26, 27, 29), showing them pictures of food (25, 36, 37), or exposing them to actual food (24, 38). Recently, three studies have extended this laboratory work to the field. In the first, Knauper and colleagues (39) showed that a 4-day intervention whereby participants imagined themselves engaging in a favorite activity whenever they experienced a food craving reduced the intensity of naturally occurring cravings. Subsequently, Kemps and Tiggemann (40) showed that a concurrent visual task not only reduced everyday food cravings but also actual food intake. Specifically, they found that dynamic visual noise delivered on a hand-held electronic device reduced the strength of participants' food cravings over a 2-week period, as well as the likelihood that they would eat in response to craving, and consequently the amount of calories they consumed. Most recently, Hsu and colleagues (41) showed that a 1-week evaluation of a mobile app that prompted participants to imagine a visual scene whenever they experienced a snack craving reduced snack consumption. These findings demonstrate the real-world applicability of imagery-based craving reduction techniques and in particular their utility for modifying craving-driven consumption.

One remaining limitation of the current research is that the majority of craving reduction studies in the food domain has been conducted with individuals of mostly normal weight. To date, only one study has demonstrated food craving reduction by an imagery-based technique in an overweight sample. Specifically, Kemps and colleagues (27) showed that dynamic visual noise was a more effective technique for reducing food cravings in overweight women on a prescribed weight-loss diet than was suppressing thoughts about food. This finding offers considerable scope for tackling unwanted food cravings, as experienced by individuals actively trying to lose weight (42), binge eaters (7), and some obese individuals (6).

Thus, converging evidence from numerous studies has shown that competing cognitive tasks that disrupt mental imagery can suppress food cravings. However, thus far research has shown only immediate craving reduction effects following the use of imagery-based techniques. This, of course, begs the question of the longevity of these effects. In the only study to date to investigate this question, Hamilton and colleagues (36) found that craving reduction effects from a guided imagery intervention were not sustained beyond the actual intervention. Craving levels after the intervention had reverted back to those observed at baseline. This suggests that competing cognitive tasks may disrupt craving imagery only temporarily, thereby providing momentary relief from the craving. Thus, imagery-based techniques may provide an effective "in-the-moment" tool for curbing food cravings, providing assistance in the "here and now." Nevertheless, the field studies (39–41) suggest that imagery-based craving reduction techniques can be used successfully over the longer-term. While these techniques do not produce lasting reductions in craving, they do effectively reduce cravings on any one occasion. Moreover, their effectiveness does not diminish with repeated use. Indeed, the field studies clearly demonstrated that imagery-based techniques maintained their craving reducing effect with repeated use over several days (39), a week (41), and even over a couple of weeks (40).

Nevertheless, it is unlikely that imagery-based craving reduction techniques would be used as a stand-alone treatment. Although these techniques reliably reduce the craving, with reported reductions across studies around 20–25%, they do not eliminate it altogether. However, imagery-based techniques could be a useful adjunct to other therapeutic interventions for the treatment of craving-driven problematic eating behavior, for example, within the broader context of Cognitive Behavior Therapy. The Australian OnTrack program (www.ontrack.org.au) is an example of such an integrated treatment in the domain of alcohol dependence. Unlike other therapeutic techniques, imagery-based techniques involve very little effort on the part of the user. Visual and olfactory tasks also lend themselves for everyday use as a self-help tool to resist unwanted food cravings. Computerized visual tasks, such as dynamic visual noise and "Tetris," could be easily incorporated as downloadable apps on smart phones and other hand-held devices. In fact, as noted above, Hsu and colleagues (41) recently designed an app to help users combat in-the-moment snack cravings (and consumption) by prompting them to imagine a visual scene. Additionally, commercially available non-food odorants can be purchased locally and carried around in people's pockets and handbags. In this way, imagery-based craving reduction techniques can be readily accessible in a discreet manner virtually anywhere and anytime when a food craving arises.

In conclusion, increasing evidence highlights a key role for mental images in the experience of food cravings. Interference with these images from modality-specific cognitive tasks can effectively suppress such cravings, thereby paving the way for clinical interventions that target craving-driven problematic eating behavior.

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Thinking back about a positive event: the impact of processing style on positive affect

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The manner in which individuals recall an autobiographical positive life event has affective consequences. Two studies addressed the processing styles during positive memory recall in a non-clinical sample. Participants retrieved a positive memory, which was self-generated (Study 1, $n = 70$) or experimenter-chosen (i.e., academic achievement, Study 2, $n = 159$), followed by the induction of one of three processing styles (between-subjects): in Study 1, a "concrete/imagery" vs. "abstract/verbal" processing style was compared. In Study 2, a "concrete/imagery," "abstract/verbal," and "comparative/verbal" processing style were compared. The processing of a personal memory in a concrete/imagery-based way led to a larger increase in positive affect compared to abstract/verbal processing in Study 1, as well as compared to comparative/verbal thinking in Study 2. Results of Study 2 further suggest that it is making unfavorable verbal comparisons that may hinder affective benefits to positive memories (rather than general abstract/verbal processing *per se*). The comparative/verbal thinking style failed to lead to improvements in positive affect, and with increasing levels of depressive symptoms it had a more negative impact on change in positive affect. We found no evidence that participant's tendency to have dampening thoughts in response to positive affect in daily life contributed to the affective impact of positive memory recall. The results support the potential for current trainings in boosting positive memories and mental imagery, and underline the search for parameters that determine at times deleterious outcomes of abstract/verbal memory processing in the face of positive information.

Keywords: memory, processing style, positive, recall, mental imagery, abstract/verbal processing

The regulation of positive affect and the processing of positive material are gaining attention in the context of mood disorders [e.g., Ref. (1–6)]. Depression, for instance, is not only characterized by increased negative affect but also by anhedonia, which refers to reduced positive affect or reduced pleasure in daily activities [(7), p. 160]. Besides targeting negative affect, therefore, promoting positive affect, targeting responses to positive stimuli may enhance interventions for depression [e.g., Ref. (1, 2, 8, 9)]. One specific type of positive stimuli is positive memories. In a review on blunted positivity in depression, Dunn (2) has mentioned the need for more research on positive memories. For instance, positive memories in formerly depressed individuals have decreased vividness compared to never-depressed controls (10). Further, Joormann et al. (11) showed that, whereas never-depressed individuals are able to repair their sad mood by retrieving positive memories, this strategy is unsuccessful in formerly and currently depressed individuals. This suggests that recollection of positive memories may lead to multiple affective outcomes. Therefore, knowledge of relevant thought patterns is crucial to understand the relationship between positive memory recall and affect.

For negative stimuli, the way a negative event is processed, for instance, concrete/imagery-based vs. abstract/verbally based processing, influences subsequent affective responding [e.g., Ref. (12–14)]. A concrete/imagery-based processing style involves a situation-specific sensory processing of the event, focused on the experience of the moment (e.g., focusing on the sights and sounds). Abstract/verbal processing of a certain situation is more analytical and involves verbal thinking about the meanings, causes, and consequences or implications of an event.

More recently, research on the impact of processing styles was broadened from the domain of negative affect or situations to positive stimuli and positive memories [e.g., Ref. (5, 15, 16)]. When processing hypothetical positive situations, for instance, concrete/imagery-based processing instructions improve mood [e.g., Ref. (5, 15, 17)]. Mental imagery, therefore, is also referred to as an "emotional amplifier" [e.g., Ref. (18)]. By contrast, participants in these experiments who were instructed to think verbally (and abstractly) about positive scenarios do not show mood improvement. Moreover, it is sometimes found that verbal thoughts even lead to mood deterioration in the face of positive information (5, 15).

With regard to positive memories, Bryant et al. (19) demonstrated that daily sessions of imagining positive memories increase the amount of time that individuals report to feel happy. However, this study did not include a non-imagery control for positive memories. Positive memories have also been investigated in clinical samples as a strategy to repair sad mood: Werner-Seidler and Moulds (16) demonstrated that concretely processing a joyful memory may indeed help to reduce sad feelings in (previously) depressed individuals (16). In contrast, an abstract thinking style focused on causes, meanings, and consequences as well as on making comparisons between a past happy memory and the current life did not improve sad mood in (previously) depressed persons [this was not entirely replicated when participants retrieved a self-defining memory (20)].

Interestingly, it has been proposed that not all types of abstract/verbal processing cause mood deterioration. For instance, Holmes et al. [(5); Experiment 2] showed that especially making active verbal comparisons could be responsible for mood deterioration after verbal processing instructions for positive scenarios. Thus, even in non-clinical samples, hypothetical "overly" positive situations (i.e., ones that incurred unfavorable comparisons) could be stressful in that, in your own life, events may not end up that positive. In addition to the detrimental effect of unfavorable comparisons on positive affect, we also suggest dampening as a potential moderator of the impact of abstract/verbal processing of positive events on positive affect. Interestingly, some individuals are characterized by a "*dampening response*" *style* to positive affect (21). Dampening is a particular cognitive response style or emotion regulation strategy, defined as "the tendency to respond to positive moods states with mental strategies to reduce the intensity and duration of the positive mood state" [(21), p. 509]. Examples of dampening thoughts in response to positive affect are: "I do not deserve this," "you know, these feelings won't last," or "thinking about those times that did not go well." Dampening can be measured by the Responses to Positive Affect questionnaire (RPA) (21, 22) and is positively associated with depressive symptoms [e.g., Ref. (23)]. Dampening can be regarded as a type of analytical thinking, in that it is characterized by a negative interpretation or evaluation of the positive situation.

In these studies, we wanted to investigate whether dampening also influences the impact of positive memory recall. From research within social psychology, it has been suggested that adopting an abstract/verbal processing mode for a positive memory (without an explicit focus on comparative thinking) can have enhancing effects (24). This may be because abstract processing can lead to positive elaborations or positive self-attributions (e.g., "I am a happy person," "I am clever") instead of interpreting the event as an isolated moment (24). However, it is plausible that if people characterized by a dampening response style think about the meaning of a positive memory, that they will less easily generate a positive meaning or may even reduce the positivity of the event. In this sense, dampening could be a potential moderator of the effect of an abstract/verbal thinking style on affect. This is akin to the idea that the impact of processing style on negative mood is conditional on individual differences in trait rumination [e.g., Ref. (25)].

In two studies, we investigated which thought processes determine the impact of positive memory recall on positive affect. In a first study, affective responding to concrete/imagery and abstract/verbal processing of a self-generated positive memory was investigated with a focus on dampening (and depressive symptoms) as moderator. In a second study, we also examined a comparative/verbal processing style.

STUDY 1

We compared the affective impact of a concrete/imagery processing style focused on the sensorial and situation-specific details with an abstract/verbal processing defined as thinking about the broader meaning, causes, and consequences of an event. In addition, we investigated the moderating role of dampening.

In line with research on positive scenarios and positive memories [e.g., Ref. (5, 16)], we predicted that the processing of a positive memory in a concrete/imagery-based way would lead to increased positive affect compared to a verbal/abstract condition. With regard to an abstract/verbal processing style, we further predicted that this (immediate) change in positive affect would be smaller with increasing levels of dampening thoughts in daily life (due to minimizing or downgrading the positivity). Moreover, we did not only examine positive affect immediately after the processing of the memory but we also examined the affective impact of the processing styles after a short delay. We did this for two main reasons. First, we wanted to examine whether the processing styles would elicit a differential affective pattern after a delay. Second, we wanted to investigate the possibility that individuals characterized by higher levels of a dampening response style may still profit from positive memory recall, but only immediately. That is, it is possible that dampeners reveal an adequate initial affective response, but that the experienced positive feelings will be countered by downgrading thoughts after a delay. We predicted that these dampening thoughts would especially occur in the abstract/verbal condition, leading to a more negative affective change with increasing levels of dampening.

The study is conducted in a non-clinical sample. Given that reduced responding to positive material has been linked to depression, we also took the level of depressive symptomatology into account. Based on previous findings showing that mood improved after positive memory recall in never-depressed individuals but not in depressed individuals (11, 20), we predicted that increasing levels of depressive symptoms would be associated with worse affective outcomes.

METHOD

PARTICIPANTS

Seventy psychology students from the KU Leuven (University of Leuven) participated; see **Table 1** for characteristics. Written informed consent was obtained at the beginning of the study. There was no compensation for participation.

MEASURES

Affect assessment

Positive and negative affect were assessed using two visual analog scales, on which participants had to indicate how they felt at the moment. On the first scale, scores ranged from *totally not in a positive mood* (0) to *in a very positive mood* (100). The second scale

Table 1 | Sample characteristics, memory characteristics (VAS), and affect (VAS) per condition (Study 1).

	Concrete/imagery condition $n = 36$		Abstract/verbal condition $n = 34$	
	Mean	**SD**	**Mean**	**SD**
Gender (freq female)	32		31	
Age	21.50	0.85	21.56	0.66
BDI-II	6.36	5.08	5.71	7.09
RPA-Dampening	10.81	2.65	11.50	3.39
Positivity of the event	8.52	1.33	8.56	1.06
Emotional (positive) intensity – past	8.41	1.29	8.44	1.43
Emotional (positive) intensity – retrieval	6.96	1.61	7.02	1.82
Positive affect				
At baseline	6.18	2.03	6.41	2.16
After the induction	7.39	1.64	6.76	2.33
End of experiment	6.75	1.89	6.29	2.37

BDI-II, Beck Depression Inventory-II; RPA-Dampening, the Dampening subscale of the Responses to Positive Affect questionnaire.

ranged from *totally not dejected, "down," sad, depressed* (0) to *very dejected, down, sad, depressed* (100)[1].

Responses to positive affect questionnaire

The RPA (21) consists of 17 items scored on a 1 (*almost never*) to 4 (*almost always*) scale. Participants are requested to indicate how often they respond in a certain way when feeling happy, excited, or enthused. The RPA has three subscales: dampening (e.g., "My streak of luck is going to end soon"), self-focused positive rumination (e.g., "I am achieving everything"), and emotion-focused positive rumination (e.g., "Think about how happy you feel"). We used the 16-item Dutch version for which adequate psychometric properties are reported (22). In the current study, we focus on the 7-item dampening subscale, which had a Cronbach's alpha of 0.72.

Beck depression inventory – second edition

The Beck depression inventory – second edition (BDI-II) (26) measures severity of depressive symptoms and consists of 21 four-choice statements. Participants are asked to indicate which of the four statements best describes how they felt during the past 2 weeks. The total BDI-II score is computed by summing the 21 scores (ranging from 0 to 3), which offers a total score ranging from 0 to 63, with higher scores indicating more depressive symptoms. We used the Dutch translation by Van der Does (27). Cronbach's alpha in the present sample was 0.89.

Ruminative response scale (RRS) and the autobiographical memory test – minimal instructions

The ruminative response scale (RRS) (28) assesses the tendency to ruminate when feeling sad, down, or depressed. In the Autobiographical Memory Test (AMT)[2] (29, 30), participants are given 1 min to write down a personal memory in response to 10 cue-words. The study was set up for a broader purpose than the one presented in the current paper. Consequently, the RRS and AMT are not reported in the Section "Results."

Memory assessment

Three visual analog scales ranging from 0 to 100 were presented to assess the characteristics of the chosen event: (1) participants indicated that how positive they considered the event on a scale ranging from *totally not positive* to *very positive (the most positive emotional event from your life)*; (2) they rated the positive emotional intensity of the event at the moment it originally occurred on a scale ranging from *totally not emotional* to *very emotional*; (3) participants rated the positive emotional intensity that the episode had at the moment of recollection, from *totally not emotional* to *very emotional.*

Manipulation checks

Before and after the induction, level of self-focus and the focus on words or images were assessed using two visual analog scales ranging from 0 to 100: (1) at this moment, my attention is *totally not focused on myself* to *very much focused on myself*; (2) at this moment the things going through my head are *mainly words* to *mainly images.*

PROCEDURE

The study was presented as a study on the emotional life of university students and was conducted in a group setting. Participants were randomly allocated to one of the two conditions (abstract/verbal or concrete/imagery) via the distribution of different booklets. After giving their informed consent, participants completed a first version of the AMT. Next, participants completed the visual analog scales for negative mood, positive mood, self-focus, and focus on words or images. Participants were instructed to select a specific positive event from their own life, that is a life circumstance in which they had felt very happy and in a very positive mood. They were asked to write down a brief description of the specific episode. Next, they rated the chosen event on several characteristics (i.e., positivity, emotional intensity). This was followed by the processing style induction. In both conditions (abstract/verbal and concrete/imagery), participants were first instructed to think in the condition-specific style about their memory. Further, the processing style manipulations involved

[1]The anchors of all visual analog scale were 0 and 100. Unfortunately, due to photocopying, the scales were 101 instead of 100 mm. The answers were processed in centimeters and thus ranged from 0 to 10.1.

[2]During the AMT (written format), five positive and five negative cue words are presented in an alternating order. We used the "Minimal Instructions" version of the AMT (30). In this version, participants are asked to retrieve memories, without emphasizing in the instructions that these should be specific. At the end, participants were requested to code their memories for specificity and imagery perspective (dichotomous: first or third-person perspective). The administration of imagery perspective during the baseline AMT allowed us to investigate the relation between dampening and the use of an observer perspective during "unmanipulated" memory retrieval. For each subject, the number of observer and field memories was calculated. RPA-Dampening was positively correlated with the number of observer memories, $r(68) = 0.37$, $p = 0.002$ and negatively correlated with the number of field memories, $r(68) = -0.32$, $p = 0.01$ ($n = 68$, two persons without perspective ratings). These correlations had comparable effect sizes after control for BDI-II. The correlations were independent of the valence of the cue word.

asking five condition-specific questions, on which participants were required to focus for a duration of 1 min per question.

In the *abstract/verbal condition*, participants were given the following instructions: *Try to understand the event you described and think about the possible causes of the event, the meanings and implications of the event for you and its consequences for you. Think in words about why the episode happened as it did, about the meanings and implications of the episode for you, and the consequences of the episode for you. Consider what caused the episode and judge what it says about you. Think about the episode in words and meanings, using verbal language of the sort that you use when you speak.* Then, they were asked to answer the following five questions: "W*hy did this event happen to you?; What was the meaning of this event in your life?; What were the consequences and implications of this event for you?; What did you think of yourself after the event?; What does this event say about your personality?.*" In the *concrete/imagery condition*, participants were given the following instructions: *Try to build up a detailed image of the event, as if you were reliving the event and as if a movie of the event was unfolding in your head. Spend a few moments imagining the event as if you were really there in the situation.* Then, they were asked to answer the following questions: "*What could you see around you?; What could you hear?; What could you feel, touch and experience in that situation?; What was happening around you?; What happened immediately after the event?.*" The instructions and questions were framed to parallel aspects of those used by Moberly and Watkins [(13), "concrete vs. abstract"] and Holmes and Mathews [(12), " imagery vs. verbal"] as the imagery instructions appear virtually identical.

Immediately after the induction, students again completed the visual analog scales for negative mood, positive mood, self-focus, and focus on words or images. The delayed assessment of negative and positive mood was conducted after the completion of a second AMT, RRS, RPA, and BDI-II.

RESULTS

DESCRIPTIVE STATISTICS AND GROUP COMPARISONS

There were no differences between the two experimental conditions for any of the background variables (**Table 1**): BDI-II, $t(68) = 0.45$, $p = 0.66$, $d = 0.11$; RPA-Dampening, $t(68) = 0.96$, $p = 0.34$, $d = 0.23$; positive affect pre-induction, $t(68) = 0.46$, $p = 0.65$, $d = 0.11$; Distribution of gender was not significantly different between the two conditions, $\chi^2(1) = 0.10$, $p = 0.75$.

MEMORY CHARACTERISTICS AND CONTENT

To exclude the possibility that condition-specific effects on affect were due to baseline differences in memory characteristics, baseline ratings of the positive memory were compared between the two conditions. There were no significant differences between conditions on the positiveness of the event, $t(68) = 0.13$, $p = 0.90$, $d = 0.03$; emotional (positive) intensity of the event when the event happened, $t(68) = 0.11$, $p = 0.91$, $d = 0.03$; and the emotional (positive) intensity of the event at the moment of retrieval, $t(68) = 0.15$, $p = 0.89$, $d = 0.03$. Means and standard deviations are depicted in **Table 1**.

With regard to the content of the memories, we categorized the memories. Forty-three participants retrieved a *social* memory, primarily related to situations with family, friends, and partners (e.g., a nice evening out with friends, a special chat, being informed about a newborn; 11 of them were related to a romantic relationship). Other memories referred to an *achievement*: a scholarly ($n = 22$) or other achievement ($n = 2$). One participant reported a memory related to the enjoyment of *nature*, and two memories could not be categorized into one of the previous categories.

MANIPULATION CHECKS

Self-focus

To check that self-focus did not differ as a function of condition, a repeated measures ANOVA was conducted with time (before vs. after the processing style induction) as a within-subjects factor, condition (concrete/imagery vs. abstract/verbal) as a between-subjects factor, and self-focus as the dependent variable. The interaction between time and condition was not significant, $F(1, 68) = 1.38$, $p = 0.24, \eta_p^2 = 0.02$. The main effect of time was significant, $F(1, 68) = 6.47$, $p = 0.01, \eta_p^2 = 0.09$, $d = 0.31$, reflecting an increase in self-focus following the induction.

Processing style – imagery/verbal

A repeated measures ANOVA was conducted with time (before vs. after the processing style induction) as a within-subjects factor, condition (concrete/imagery vs. abstract/verbal) as a between-subjects factor, and focus on words vs. focus on images as the dependent variable. There was a main effect of time, $F(1, 68) = 17.71$, $p < 0.001, \eta_p^2 = 0.21$. Critically, the interaction between time and condition was significant, $F(1, 68) = 13.35$, $p < 0.001$, $\eta_p^2 = 0.16$, which is evidence for successful inductions. There was an increase (i.e., more use of images) in the concrete/imagery condition, $t(35) = 5.97$, $p < 0.001$, $d = 0.99$, but no change on the verbal/imagery scale in the abstract/verbal condition, $t(33) = 0.37$, $p = 0.72$, $d = 0.06$.

Processing style – concrete/abstract

Participants' answers were coded on the level of abstract thinking (focus on causes, meanings, and implications) and concrete thinking (focus on concrete objects, sensory details, feelings, and sensations). Each answer was rated on a scale ranging from 1 (*not at all*) to 4 (*very much*). A mean concrete and abstract score was calculated for each participant. Distribution of these ratings did not allow parametrical test due to skewed distributions. A non-parametric median test indicated that the induction was successful. The median level of abstractness was significantly higher in the abstract/verbal condition (*Median* = 3.80) than in the concrete/imagery condition (*Median* = 1.00), $\chi^2(1) = 62.28$, $p < 0.001$. Further, the median level of concreteness in the concrete/imagery condition (*Median* = 3.20) was significantly higher than in the abstract/verbal condition (*Median* = 1.10), $\chi^2(1) = 48.10$, $p < 0.001$.

THE IMPACT OF PROCESSING STYLE, DEPRESSIVE SYMPTOMS, AND DAMPENING ON POSITIVE AFFECT

To test if processing style (condition) influenced positive affect, and to test if RPA-Dampening or BDI-II acted as moderators of the association between processing style and positive affect, a hierarchical multiple regression analysis was conducted with change in positive affect from pre- to post-induction (positive affect after the induction minus positive affect at baseline) as dependent variable. Centered scores were used for RPA-Dampening and BDI-II. In the first step, condition, RPA-Dampening, and BDI-II were entered. In the second step, the interaction between condition and RPA-Dampening, and the interaction between condition and BDI-II were entered. Results are depicted in **Table 2**.

Both models were significant, $ps < 0.003$. The interaction terms were both non-significant ($ps > 0.45$). To facilitate interpretation of the main effects, the first model without interaction terms was examined ($R^2 = 0.23$). Importantly, there was a main effect of condition, $B = 0.73$, $p = 0.03$. The change in positive affect was higher in the concrete/imagery than in the abstract/verbal condition.

To investigate the direction of affective change within each condition, two paired-samples *t*-tests were conducted. Within the concrete/imagery condition, as predicted, positive affect increased significantly over time, $t(35) = 4.77$, $p < 0.001$, $d = 0.79$. Positive affect did not significantly change after abstract/verbal processing, $t(33) = 1.52$, $p = 0.14$, $d = 0.26$. RPA-Dampening was a non-significant predictor, $B = -0.10$, $p = 0.08$. There was a main effect of BDI-II, $B = 0.10$, $p < 0.001$, such that, somewhat unexpected, higher levels of depressive symptoms were associated with higher values of affective change. So the change in positive affect from pre- to post-induction was higher in the concrete/imagery than in the abstract/verbal condition.

To investigate whether there would also be a delayed effect of processing style, the hierarchical regression analysis was repeated with the change in positive affect from post-induction to the end of the experiment as dependent variable ($n = 69$, one missing value for the last affect rating), see **Table 2**. Both models were significant, $ps < 0.02$. In the first step, $R^2 = 0.15$, there was only a main effect of BDI-II, $B = -0.08$, $p = 0.001$, which was in the opposite direction than the main effect of BDI-II in the previous analysis (i.e., the immediate change in positive affect). The change in positive affect did not significantly differ between conditions. To investigate the direction of affective change during the delay, a paired-samples *t*-test was conducted. Positive affect decreased significantly during the delay, $t(68) = 3.77$, $p < 0.001$, $d = 0.45$, meaning that, the increased level of positive affect in the concrete/imagery condition was not fully maintained after a delay. However, positive affect at the end of the experiment was still significantly higher than at baseline in the concrete/imagery condition, $t(34) = 2.20$, $p = 0.04$, $d = 0.37$. Although positive affect slightly decreased during the delay, there was no difference between positive affect at baseline and at the end of the experiment in the abstract/verbal condition, $t(33) = 0.65$, $p = 0.52$, $d = 0.11$.

The inclusion of the interaction terms in step two added marginally significantly to the explained variance, $\Delta R^2 = 0.07$, $p = 0.059$. Importantly, this second step consisted of a non-significant interaction between BDI-II and condition, whereas the interaction between condition and RPA-Dampening was significant, $B = 0.23$, $p = 0.02$. The interaction with RPA-Dampening revealed a significant positive relation between change in positive affect and RPA-Dampening in the concrete/imagery condition, $B = 0.21$, $\beta = 0.53$, $p = 0.01$, and not in the abstract/verbal condition, $p = 0.72$. This means that the higher trait dampening in the concrete condition, the smaller the decrease in positive affect during the delay.

DISCUSSION

The affective impact of memory recall is not only determined by the valence of the event but also by how it is processed. The current study aimed to investigate the impact of concrete/imagery vs. abstract/verbal processing of recall of a positive memory on positive affect in a non-clinical sample. In addition, the role of

Table 2 | Hierarchical regression analyses: prediction of affective change (Study 1).

	DV: PA2PA1			DV: PA3PA2		
	B	**SE*B***	**β**	***B***	**SE*B***	**β**
Step 1						
Condition	**0.73***	**0.33**	**0.48**	−0.03	0.27	−0.03
RPA-Damp	−0.10	0.06	−0.20	0.07	0.05	0.17
BDI-II	**0.10*****	**0.03**	**0.39**	**−0.08****	**0.02**	**−0.40**
Step 2						
Condition	**0.73***	**0.33**	**0.48**	−0.02	0.26	−0.02
RPA-Damp	−0.13	0.07	−0.27	−0.02	0.06	−0.05
BDI-II	**0.08***	**0.04**	**0.33**	**−0.07***	**0.03**	**−0.35**
Condition × RPA-Damp	0.09	0.12	0.17	**0.23***	**0.09**	**0.58**
Condition × BDI-II	0.04	0.06	0.18	−0.02	0.05	−0.12

PA2PA1 as criterion: $R^2 = 0.23$ for Step 1, $\Delta R^2 = 0.02$ for Step 2 ($p = 0.47$); PA3PA2 as criterion: $R^2 = 0.15$ for Step 1, $\Delta R^2 = 0.07$ for Step 2 ($p = 0.06$).

DV, dependent variable. PA2PA1, positive affect after the induction minus positive affect at baseline; PA3PA2, positive affect at the end of the study minus positive affect after the induction; BDI-II, Beck Depression Inventory-II; RPA-Damp, Dampening scale of the Responses to Positive Affect questionnaire (RPA). Centered scores were used. Condition, abstract condition coded as 0 and concrete condition coded as 1. Significant predictors are indicated in bold. β's indicate the regression coefficients when predictors (except condition) and the dependent variable were standardized.

**$p < 0.05$.*

***$p < 0.01$.*

****$p < 0.001$.*

dampening and depressive symptoms as potential moderators was investigated. As predicted, we found that positive memory recall in a concrete/imagery way increased positive affect. This is in line with earlier studies on imagining standardized positive scenarios [e.g., Ref. (5, 15)] and with positive memory recall to repair sad mood (16). Abstract/verbal processing did not influence positive affect in our study. This is, as a general outcome here for positive autobiographical memories, less "negative" than an actual mood deterioration (reduction in positive affect) found after verbally/abstractly processing hypothetical positive situations (5, 15). This suggests that abstract/verbal processing of a positive information may not always lead to a mood deterioration [see also Ref. (5, 20, 24)], though it does not appear to boost positive mood.

The affective impact of abstract/verbal processing was in our sample not related to people's tendency to dampen positive affect in daily life. This suggests that, the extent to which people use dampening thoughts in response to positivity (as measured via the RPA) may not influence the immediate affective impact of positive memory recall. However, the affective response to positive memory recall was higher for people with higher levels of depressive symptoms. To clarify this main effect of BDI-II, we present a group approach. In the "high BDI-II group" (=BDI-II above median), positive affect significantly increased from baseline to post-induction ($p < 0.001$, $d = 0.81$), but there was no significant change in affect in the "low-BDI-II group" ($p = 0.13$, $d = 0.26$). This means that "dysphoric" participants were more responsive to positive memory recall. This was not expected based on research that revealed a reduced responding to non-autobiographical positive pictures in people with depressive disorder [e.g., Ref. (3)] and a worsening of sad mood after positive memory recall (11). An explanation could be that "dysphoric" participants retrieved a more positive memory. However, positiveness of the event was unrelated to BDI-II, $r = 0.01$. The counterintuitive main effect of depressive symptoms might also be caused by a lower baseline state affect in dysphoric participants, and so there was more room for affective improvement. Baseline positive affect was indeed lower in the "high BDI-II group" compared to the "low BDI-II group," $p = 0.048$. The main effect of BDI-II that we observed, however, is in line with the so-called *mood-brightening effect* observed in naturalistic settings: several studies have shown that in depressed individuals and in individuals with elevated depressive symptomatology, positive events are followed by a greater decrease in negative affect (31) and a greater increase in positive affect (32) than in controls. Further research is needed to sort out the nature of this effect.

We were also interested in the delayed affective responding to memory recall. Overall, following a short delay, positive affect decreased, but still remained slightly higher than at baseline for the imagery/concrete condition. We make two notes. First, the affective change was worse for people with increasing levels of depressive symptoms. Again, to clarify this by a group approach, after the delay, the "high BDI-II" group experienced a drop in positive affect, $p < 0.001$, $d = 0.79$, while this was not the case for the "low-BDI-II group," $p = 0.38$, $d = 0.15$. This means that the increased immediate responding in people with more depressive symptoms had the downside of a greater drop after a short interval. Depressed individuals fear or suppress positive affect (33), possibly because they want to prevent that they will experience such a drop in positive affect or that they will even feel worse afterwards. Second, on top of the main effect of BDI-II, concrete/imagery processing had a positive impact on the delayed affective response in participants with increasing levels of a dampening response style. The results suggest that after concrete memory recall, positive affect is better maintained in individuals who dampen more, which points to the importance of processing positive events in a concrete manner for "vulnerable" individuals (in this case, high trait dampeners). One possible explanation for this result is that the "dampeners" were distracted from their habitual "abstract" (dampening) responses.

Some remarks can be made about this study. First, there were no restrictions on the content of the chosen memory. Consequently, participants retrieved different types of memories, for example social or interpersonal (e.g., a nice chat with friends) or achievements (e.g., good exam results). It is plausible that meanings and consequences for social memories are generally different than for scholarly achievements. Second, there was no assessment of the temporal distance of the memory. Given that age can influence phenomenal characteristics of past events (34), it would be better to check for potential differences between conditions on memory age. Third, and critical to the next study, it has been suggested that making (unfavorable) comparisons between positive scenarios and the (less fortunate) self (5) or between a past happy event and the (less positive) current life/self might be a crucial process that undermines the benefits in positive information recall [e.g., Ref. (16)]. Therefore, an interesting next step entails the comparison of three processing styles in their affective outcome on positive memories: (1) a concrete/imagery style focused on the sensorial and situation-specific details, vs. (2) abstract/verbal processing defined as thinking about the broader meaning, causes, and consequences, vs. (3) an abstract/verbal thinking style focused on making comparisons between the current self/life and the past self/life ("comparative/verbal"). The comparison with a comparative/verbal thinking style would show whether it is a non-concrete/verbal processing style that is unbeneficial or whether it is specifically making (unfavorable) comparisons that is afforded by this processing style, which undermines positive memory recall [cf. (5)].

STUDY 2

A second study was designed with three objectives: (1) to address limitations of the first study, (2) to examine a third way in which a positive memory could be processed by making verbal comparisons, and (3) to examine mental imagery perspective.

Concerning the first objective, the content variability of the memories in Study 1 was addressed by using the same memory for all participants. Passing an entrance exam is a necessary condition to study medicine or dentistry in Flanders. As a consequence, students of medicine and dentistry share this achievement. This guided retrieval also aided to control the time period of the memory (i.e., restricted to July, August, and September).

With regard to the second objective, a concrete/imagery-based processing style was generally better than an abstract/verbal processing style in Study 1. However, an abstract/verbal processing style did not significantly deteriorate affect, which was the case in some other studies with positive hypothetical scenarios [e.g., Ref. (5)]. It is hypothesized that it is especially making unfavorable comparisons with positive events that is detrimental [e.g., Ref. (5), cf. (35)]. Extending this to positive memories, past events might act as a point of comparison to evaluate one's present life (16, 36). Therefore, pleasant events could contrast with someone's less satisfactory current life, emphasizing negative aspects of the current situation or self-deterioration. Joormann and Siemer (37) and Joormann et al. (11) suggested that for depressed individuals a positive memory may highlight that one is not that positive anymore. Although the memory itself is positive, it comes to underline the discrepancy between positive times in one's past and the sad mood or the less favorable situation now [see also Ref. (16)].

We included a third processing style in which individuals compare their current self (current life) with the person they were (the life they had) at the time the positive memory was investigated (comparative/verbal). It has been suggested that especially for depressed individuals a positive memory highlights the discrepancy between the happy past moment and a sad current life, or negative current self [e.g., Ref. (11)]. We predicted that after adopting such a comparative/verbal thinking style, change in positive affect would be less beneficial, especially with increasing levels of depressive symptoms. We had no specific predictions with regard to the delayed responding. For the concrete/imagery and abstract/verbal styles, predictions are the same as in Study 1.

A third objective was to investigate the effect of processing style on imagery perspective. Episodic memory is defined by including sensory perceptual details (38, 39). That is, when remembering a specific event, people typically generate mental images. These mental images can be experienced from an observer perspective, in which people observe themselves from the outside, or from a field perspective, in which people experience the event again through their own eyes (40). What was our reasoning behind this third, perspective-related study objective? For example, research showed that hypothetical situations, which are described at an abstract level (e.g., the broader goal of the action), are more likely to be imagined from an observer perspective than concretely described actions (41). Similar results are found if participants think about the broader meaning of a personal past event (graduation) vs. if they focus on the experience (concrete details) (42). In addition, some studies indicate that an observer perspective entails a negative evaluative component. That is, seeing oneself from the outside facilitates a negative evaluation of the self and the imagined situation, or facilitates unfavorable comparisons between the self and a positive situation (43–46) and could contribute to a negative response in the face of recalling a positive event. Bringing this together, we might expect less field (and more observer) perspective after abstract/verbal processing (as compared to concrete processing). And, observer imagery in the abstract/verbal condition could be more pronounced with increasing levels of dampening (as dampening could be regarded as negatively evaluating something positive). We also expected less field (and more observer) perspective after comparative/verbal thinking [cf. Ref. (43)].

METHOD

PARTICIPANTS

Participants were students of medicine and dentistry from the KU Leuven (University of Leuven). They were invited through an online university platform to participate in an online study. Participants who completed all measures were included ($n = 159$). Most participants were students of medicine ($n = 123$), 35 participants studied dentistry, and 1 participant combined both studies (see **Table 3** for characteristics). Twenty randomly selected participants received a gift voucher in exchange for participation. The study was approved by the Ethical Committee of the Faculty of Psychology and Educational Sciences, KU Leuven (University of

Table 3 | Sample characteristics, memory characteristics, and affect (Study 2).

	Concrete/imagery condition $n = 53$		Abstract/verbal condition $n = 53$		Comparative/verbal condition $n = 53$	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Gender (freq female)	35		31		38	
Age	21.15	2.46	20.38	1.44	20.83	4.82
DASS-Depression	4.09	3.43	4.57	3.75	3.83	5.57
RPA-Dampening	12.47	3.16	13.38	4.28	12.47	3.78
Number of sittings	2.02	1.22	1.96	1.02	2.08	1.02
Positivity of the event	7.77	0.99	8.08	0.81	7.57	1.01
Important/meaningful memory	7.66	1.87	7.77	1.75	7.34	1.69
Concentration	8.04	1.27	8.13	0.88	7.91	1.29
Positive affect						
Baseline	5.92	1.58	6.11	1.38	6.51	1.01
After the induction	6.62	1.68	6.64	1.27	6.51	1.49
End of survey	5.92	1.65	5.96	1.49	6.17	1.67
Post-induction imagery perspective						
Field	4.96	1.66	4.70	1.62	4.77	1.55
Observer	3.66	1.78	3.96	1.61	3.72	1.81

DASS-Depression, The Depression subscale of the Depression Anxiety and Stress Scale; RPA-Dampening, The Dampening subscale of the Responses to Positive Affect questionnaire. Number of sittings, how many times participants attended the entrance exam.

Leuven). Informed consent was obtained online before the start of the study.

MEASURES

Affect assessment

Administration of positive and negative affect was as in Study 1. However, this time, participants responded using a 9-point Likert scale (cf. internet-based nature of Study 2).

Responses to positive affect questionnaire – dampening subscale

See Study 1 (21). The 7-item Dampening subscale was administered, with a Cronbach's alpha of 0.78.

Depression anxiety stress scale – depression subscale

The Depression anxiety stress scale – depression subscale (DASS-D) (47) assesses the severity of depressive symptoms for the past 7 days. Item scores range from 0 (*did not apply to me at all*) to 3 (*applied to me very much or most of the time*). The basic DASS-D contains 14 items; we used the short version of the DASS-D with 7 items. The Dutch version by de Beurs et al. (48) was used. Cronbach's alpha in the present sample was 0.84. We did not use the 21-item BDI-II as in Study 1 to limit the time of the online assessment.

Memory characteristics

Several Likert scales were used to assess baseline characteristics of the event or memory, and to assess memory characteristics after the induction. At baseline, participants were asked how *positive* they found the moment when they were informed that they passed the entrance exam (cf. Study 1, but, again not rated on a visual analog scale but using a 9-point Likert scale). Participants additionally rated to what extent the memory was an important and meaningful memory for them personally, using a scale ranging from *totally not important and meaningful* to *very much important and meaningful*. Post-induction, students rated to what extent passing the entrance exam was characteristic for the person they are now (this scale will not be discussed in the current paper). Age of the event was assessed by determining the moment (month and year) the event took place. Finally, we assessed imagery perspective. For that, participants were first asked to make an image of the moment they were informed that they passed the entrance exam. Next, they completed two 7-point scales: the first scale ranged from (1) *totally not first person* to (7) *completely first person*; the second scale ranged from (1) *totally not third person* to (7) *completely third person* [similar scales were used in Ref. (49)].

Concentration

Because of the online format, participants were asked to what extent they were able to complete the online tasks with concentration (without being distracted) on a 9-point scale ranging from *totally not* (1) to *very good* (9). Although participants are randomized to condition, we wanted to check whether individuals from the three conditions would differ on how focused they were while completing the questions.

PROCEDURE

After completing the online informed consent, participants filled out a first measure of affect and self-focus (on a 9-point Likert scale). Next, they were asked to rate the positivity of a specific event, namely "the moment you were informed that you passed the entrance exam." This was followed by a rating of how important and meaningful the memory is. Next, participants were randomized to one of the three conditions. Randomization to condition was conducted automatically via the survey software Qualtrics. Processing style was manipulated using a general condition-specific instruction followed by seven condition-specific questions. Participants had to type their answer to each question in full sentences. The induction was based on, and adapted from previous research (5, 12, 13, 15, 16, 20, 50). Unlike in Study 1, there was no time restriction per question used in the online assessment.

In the *concrete/imagery condition*, participants were prompted to focus on the moment, to replay the event in their mind as a movie, and to form a sensory mental image. Comparable to Study 1, the condition-specific questions were what they could hear, see, and what they felt when receiving their exam result, and what they did immediately after. In addition, we prompted for more details by asking how the moment unfolded, how they received the exam result (e.g., via e-mail, phone), where they were, and how bystanders behaved.

In the *abstract/verbal condition*, participants were asked to verbally generate meanings about the situation. Comparable to Study 1, they were asked what the consequences and implications were, how they thought about themselves, what the meaning was of the event for their life, and what the performance said about their capabilities. Instead of asking why the event happened to them, they were asked more specifically how they explained that they passed (succeeded in) the exam. Two extra questions assessed *why* they felt the way they did, and whether the result (performance) was as expected.

In the *comparative/verbal condition*, again, participants were asked to use verbal language. They were asked how the person they are now differs from the person they were at that moment, and how their life is different now. They were also asked how they expected their life would unfold at the time of the memory vs. how it has turned out. One question focused on a social comparison (how their performance compared to that of other students who participated in the same exam).

After the processing induction, all participants completed a second measure of affect and self-focus, followed by the assessment of how characteristic the memory is and imagery perspective. Next, we asked for demographics (such as gender and study level) and details about the entrance exam (such as time). The Dampening subscale of the RPA and the Depression scale of the DASS were completed and the study ended with a final measure of affect and an assessment of their concentration during the online study.

RESULTS

DESCRIPTIVE STATISTICS AND GROUP COMPARISONS

Five one-way ANOVAs showed that the conditions did not significantly differ on age, depression score (DASS-D), level of dampening (RPA-Dampening), concentration, or baseline positive affect, $0.08 < ps < 0.60$. There were also no gender differences, $\chi^2(2) = 2.06$, $p = 0.36$ (for descriptive, see **Table 3**).

MEMORY CHARACTERISTICS

To exclude that the effects on affect were due to baseline memory differences, several one-way ANOVAs were conducted. Conditions did not differ on the mean number of times participants sat the entrance exam, $F(2, 156) = 0.14$, $p = 0.87$, $\eta_p^2 = 0.002$ or the level of importance/meaningfulness of the memory, $F(2, 156) = 0.86$, $p = 0.43$, $\eta_p^2 = 0.01$. As expected, the mean positivity rate was high and no one rated the entrance exam as totally not positive. However, conditions significantly differed on how positive they perceived passing the entrance exam, $F(2, 156) = 3.93$, $p = 0.02$, $\eta_p^2 = 0.05$. Notice that this difference cannot be driven by the processing induction as that was afterward. *Post hoc* t-tests revealed that positivity was significantly higher in the abstract/verbal compared to the comparative/verbal condition, $t(104) = 2.87$, $p = 0.005$, $d = 0.56$. Therefore, we controlled for positivity in the following regression analyses. The entrance exam took place during the year of the current research to a maximum of 4 years previously, with the exception of one participant for whom it was 6 years ago. Conditions did not differ for the age of the event, $F(2, 156) = 1.16$, $p = 0.32$, $\eta_p^2 = 0.02$. Means and SDs are reported in **Table 3**.

MANIPULATION CHECKS

Self-focus

To verify if self-focus did not differ as a function of condition, a repeated measures ANOVA was conducted with time (before vs. after the processing style induction) as a within-subjects factor, condition (concrete/imagery, abstract/verbal, comparative/verbal) as a between-subjects factor, and self-focus as the dependent variable. The interaction between time and condition was not significant, $F(2, 156) = 0.38$, $p = 0.69$, $\eta_p^2 = 0.005$. The main effect of time was significant, $F(1, 156) = 49.05$, $p < 0.001$, $\eta_p^2 = 0.24$, $d = 0.56$. Comparable to Study 1, self-focus increased after the processing style inductions.

Processing style

To analyze responses to the questions, 21 participants per condition were randomly selected. This group ($n = 63$) was comparable to the others in terms of baseline memory characteristics and DASS-D, $ps > 0.10$, but despite the random selection, they scored lower on RPA-Dampening, $p = 0.01$. The written induction was coded in terms of level of *concreteness* (to what extent does the answer focus on sensorial information or on the concrete unfolding of the situation), *abstractness* (to what extent does the answer tell you something about meanings, causes (why they passed the exam), consequences, or why they felt the way they did), and the level of *comparative thinking* (to what extent is the answer about the person at the time of the event and the comparison with then vs. now or vs. others, the expectations then vs. how it is now, and the time in between).

We used a scale ranging from 1 (*not at all*) to 5 (*very much*). Distribution of the ratings did not allow significance tests (limited range on the scores within each condition), therefore descriptives are reported. As expected, comparative thinking was high in the comparative condition ($M = 4.05$, range 3–5), whereas there was almost no comparative thinking in the other two conditions (range 1–2). Ratings for concrete thinking were high in the concrete/imagery condition ($M = 4.86$, range 4–5), but less pronounced in the other two conditions (range 1–3). Abstract thinking was high in the abstract/verbal condition ($M = 4.67$, range 4–5), low in the concrete/imagery condition ($M = 1.38$), and somewhat represented in the comparative condition ($M = 2.90$, range 1–4). In each condition, 11 of the 21 texts were randomly selected and recoded by a second researcher. For each scale, an intraclass correlation coefficient between the score of rater 1 and rater 2 was calculated. The correlation coefficients are 0.94 for concrete thinking, 0.85 for abstract thinking, and 0.95 for comparative, suggesting a good interrater reliability.

THE IMPACT OF PROCESSING STYLE AND DEPRESSIVE SYMPTOMS ON POSITIVE AFFECT

To test the impact of processing style on positive affect and to test the hypothesis that there would be an interaction of condition and depressive symptoms, we conducted a hierarchical multiple regression analysis with the change in positive affect from pre- to post-induction (positive affect after the induction minus positive affect at baseline) as the criterion variable. Because of the increased number of predictors in the second study, regression analyses were separately conducted for DASS-D and RPA-Dampening. In Step 1, positivity of the event was entered as a control variable (due to baseline differences between conditions). In Step 2, DASS-D scores, and two dummy variables to specify condition were included. The abstract/verbal condition functioned as the reference group. Finally, in Step 3, the interaction terms – which specify the interaction between condition and depressive symptoms – were entered. For DASS-D, and the positivity of the event, we used centered scores. **Table 4** summarizes the hierarchical regression analysis. For all three steps, the model was significant, $p < 0.001$. In the first step, positivity of the event was a significant predictor of change in positive affect. Next, in Step 2, the level of depressive symptoms was not a significant predictor. There was a significant main effect of condition, in such that the change in positive affect was higher in the abstract/verbal compared to the comparative/verbal condition, but the abstract/verbal and concrete/imagery condition did not significantly differ.

To know in what direction affect changed from pre- to post-induction within each condition, we conducted three paired-samples t-tests. Means and SDs are depicted in **Table 3**. As predicted, in the concrete/imagery condition, positive affect significantly increased, $t(52) = 5.45$, $p < 0.001$, $d = 0.75$ ($M = 0.70$, $SD = 0.93$). In the abstract/verbal condition (for which the mean change did not significantly differ from the concrete/imagery condition), positive affect also significantly increased, $t(52) = 3.73$, $p < 0.001$, $d = 0.51$ ($M = 0.53$, $SD = 1.03$). In the comparative condition, positive affect remained unchanged after the induction, $t(52) = 0$, $d = 0$ ($M = 0$, $SD = 1.09$).

In the comparative/verbal condition, affective change was dependent on depressive symptoms. That is, importantly and as hypothesized, the main effect of condition was qualified by an interaction effect in the third step. The slope representing the relationship between DASS-D and affective change significantly differed between the abstract/verbal condition and the comparative/verbal condition. To interpret this interaction, we present the slope for the relation between DASS-D and affective change within

Table 4 | Hierarchical regression analysis: prediction of affective change after processing of the positive memory (Study 2).

	B	SE *B*	β
Step 1			
Positivity	**0.29*****	**0.09**	**0.27**
Step 2			
Positivity	**0.25****	**0.09**	**0.23**
Dummy 1	0.24	0.20	0.23
Dummy 2	**−0.41***	**0.20**	**−0.39**
DASS-D	−0.01	0.02	−0.04
Step 3			
Positivity	**0.26****	**0.09**	**0.23**
Dummy 1	0.26	0.19	0.25
Dummy 2	**−0.42***	**0.20**	**−0.39**
DASS-D	0.03	0.04	0.10
Dummy 1 × DASS	−0.001	0.06	−0.004
Dummy 2 × DASS	**−0.12***	**0.05**	**−0.40**

$R^2 = 0.07$ for Step 1, $\Delta R^2 = 0.06$ for Step 2 ($p = 0.01$), $\Delta R^2 = 0.03$ for Step 3 ($p = 0.046$).

PA2PA1, change in positive affect from pre- to post-induction (positive affect after the induction minus positive affect at baseline); Positivity, self-reported positivity of the event; DASS-D, Depression subscale of the Depression Anxiety Stress Scales. Centered scores were used. Dummy 1, concrete/imagery condition coded as 1, the other two conditions as 0; Dummy 2, comparative/verbal condition coded as 1, the other two conditions as 0. Significant predictors are indicated in bold. β indicates the regression coefficients when predictors (except condition) and the dependent variable were standardized.

**p < 0.05.*

***p < 0.01.*

****p < 0.001.*

each condition. As expected, in the comparative condition, higher DASS-D scores were associated with a lower value of the change score, $B = -0.09$, $\beta = -0.30$ $p = 0.02$, whereas the slope did not significantly differ from zero in the concrete/imagery condition, $B = 0.03$, $\beta = 0.09$, $p = 0.51$, and in the abstract/verbal condition (see **Table 4**).

THE IMPACT OF PROCESSING STYLE AND DAMPENING ON POSITIVE AFFECT

The same hierarchical regression analysis as described above was conducted, however, with DASS-D score changed by RPA-Dampening. This regression analysis did, again, reveal the same main effect of condition. However, there was no main effect of RPA-Dampening, and the two interaction terms did not significantly add to the explained variance of change in positive affect ($\Delta R^2 < 0.001$).

THE DELAYED AFFECTIVE IMPACT OF PROCESSING STYLE

The regression analyses were repeated with, as the criterion, the change in positive affect from post-induction to the end of the survey. The models with DASS-D as well as the models with RPA-Dampening were non-significant ($ps > 0.14$).

From post-induction to the end of the survey, positive affect significantly decreased in the concrete/imagery and the abstract/verbal condition ($ps < 0.001$), but not in the comparative condition ($p = 0.08$), such that in all three conditions, positive affect at the end of the survey did not differ from baseline affect, $ps > 0.10$.

THE IMPACT OF PROCESSING STYLE ON IMAGERY PERSPECTIVE

Using two one-way ANOVAs, the effect of processing style (condition) on field perspective and observer perspective was examined (see **Table 3**). Conditions did not differentially influence imagery perspective, $ps > 0.63$. To inspect associations with RPA-Dampening and DASS-D, correlations were calculated within each condition. RPA-Dampening was not significantly associated with imagery perspective. With regard to the DASS-D, depressive symptoms were negatively associated with field perspective ratings in the comparative condition, $r(53) = -0.28$, $p = 0.04$, but not in the other two conditions, $rs < -0.14$, $ps > 0.33$. However, the correlation in the comparative condition did not significantly differ from the correlations in the other two conditions ($ps > 0.41$).

DISCUSSION

The aim of this study was to investigate the effect of processing style manipulation of retrieval of a positive memory on positive affect (immediate and delayed) and on mental imagery perspective. Based on previous investigations, we compared three thinking styles: concrete/imagery, abstract/verbal, and comparative/verbal. We also investigated the role of self-reported dampening during daily life and current depressive symptoms as potential moderators. All participants thought back about the same achievement – an exam.

As expected, positive affect increased after concrete/imagery processing of the positive memory, replicating our Study 1, and extending results in previous related papers. However, unlike Study 1, here the abstract/verbal condition did also lead to an increase in positive affect, showing that generally abstract/verbal thinking might not be maladaptive under certain conditions. This would at least be without a focus on the comparative thinking element [cf. (5)] and for a positive content. A necessary condition to gain positive mood while generally abstract/verbal might be that the positive memory receives a strong meaning in someone's life: this was reflected in the generation of positive meanings in the abstract/verbal condition (e.g., "*it meant a lot for me,*" "*it teaches me that with dedication you can excel in life,*" "*it showed that I have more capacities than I thought*").

In analogy with our results, an abstract processing style in combination with a lab-induced success experience yielded the same affective outcomes as a concrete processing style (51). This was the case for low as well as high dysphorics. Non-deleterious effects of abstract processing have also been shown in social psychology. Marigold et al. (24) hypothesized that people with low self-esteem (who tend to dampen the positivity of a partner's compliment) would profit from an abstract processing of a partner's compliment [see also Ref. (52)]. Indeed, people with low self-esteem who were prompted to verbally describe the meaning of a past compliment felt happier compared to participants who were asked to describe the isolated, concrete details of the moment they received a past compliment (24).

Unexpectedly, the immediate affective response as well as the delayed responding was independent of self-reported dampening responses during daily life, partially replicating results from Study 1. The fact that the affective response in the concrete/imagery and abstract/verbal processing conditions was independent of depressive symptoms suggests that people with higher levels of depressive symptoms are, at least under certain circumstances, able to profit from positive memory recall [e.g., when thinking back about important achievements without making (unfavorable) comparisons].

As expected, making comparisons between the current self/situation with the past self/situation in the memory was less helpful and did not increase positive mood over time. Importantly, in line with the prediction, the affective impact of making such comparisons was worse with increasing levels of depressive symptoms. It is unlikely that this is driven by a ceiling effect for individuals with higher levels of depressive symptoms, given that they started with lower positive affect at baseline. Plausibly, a general discrepancy between the current negative self or life situation and the past positive situation drives this effect. In this reasoning, we assume that especially in individuals with depressive symptoms a discrepancy between the past happy situations and the current life may exist, driving unfavorable comparisons. This discrepancy is less easily triggered while using a more concrete/imagery or abstract/verbal thinking style without explicit comparisons. The "risky" side of comparing oneself (or one's current life circumstances) with a positive event was also present in Holmes et al. (5) for hypothetical events. Our study now reveals that this also pertains to real personal positive events from the past. An implication is that if working with positive stimuli, we should take care not to get stuck in unbeneficial comparative thinking.

Importantly, passing an entrance exam is particularly related to expectations and predictions about the future university years. Therefore, making comparisons between now and then might easily prompt unachieved expectancies with regard to one's academic performances. Indeed, if we control for how satisfied participants are with how their studies unfold, the association between depressive symptoms and affect change in the comparative condition becomes marginally significant ($\beta = -0.23$, $p = 0.085$), although the interaction between condition and depressive symptoms remains significant. This suggests that the effect may also be driven by the current state of the life domain from the memory.

The three thinking styles did not differentially influence imagery perspective of the recalled event. However, in another between-subjects investigation, students who thought abstractly about their graduation were more likely to recall the memory from an observer perspective relative to students who adopted a concrete processing style (42). The induction was comparable but not identical, though, speculatively, the differential imagery measure between studies (dichotomous vs. continuous) might be a candidate explanation for the mixed results.

GENERAL DISCUSSION

In two studies, we investigated the impact of processing style during positive memory recall on positive affect. We also considered the role of dampening and depressive symptoms as potential moderators.

A focus on the sensory experience of the positive event (concrete/imagery processing) improved positive affect for a positive memory that was self-generated (Study 1) and experimenter-chosen (i.e., an academic achievement, Study 2). This parallels evidence with standardized positive hypothetical scenarios [e.g., Ref. (5, 15)] and extends research on the concrete recall of a positive memory to repair sad mood in (previously) depressed individuals (16) to increasing positive affect in the absence of a negative mood induction in a non-clinical sample.

Results also support the development of training procedures to help make depressed individuals more specific and concrete in the retrieval of their memories [e.g., Ref. (53)] and boost their positive mental imagery of hypothetical and future events [e.g., Ref. (9, 54–56)]. It is likely that the combination of the concrete/imagery processing style with a positive content drives the increase in positive affect [for a control with a neutral or negative content, see Ref. (57, 58)].

Considering abstract/verbal processing of a memory (i.e., thinking about the broader meaning, causes, and consequences of the event), in neither of the two studies did abstract/verbal processing cause significant mood deterioration; however, it failed to lead to a beneficial effect in the controlled lab environment in Study 1. This affective outcome is thus less detrimental than contrast effects (i.e., mood deterioration) with positive memories observed in a depressed sample (11) and with hypothetical positive events in non-clinical samples (5, 15, 43). Speculatively, the different outcome for abstract/verbal processing in Study 1 and Study 2 might be driven by the content of the memory or the control over the study environment. Another possibility is that the abstract instructions in the second study were adjusted to the memory and included positive connotations (e.g., what do you think about your *performance*). This might have stimulated to derive a positive meaning. Indeed, Marigold et al. (24) confirmed that such subtle positive framework avoids self-evaluative concerns in individuals with low self-esteem.

We also examined delayed responses to memory recall. Delayed responses were characterized by a decrease in positive affect in both studies. In general, the pattern indicated that people ended at their baseline level of positive affect (note that in the imagery/concrete condition of Study 1 positive affect did not entirely drop to baseline after the delay). In both studies, the delay phase included the assessment of questionnaires (such as a depressive symptom scale), which might have been mood triggering. Ideally, positive imagery protects against later mood triggers. In previous investigations, an elaborated imagery training protected against future negative mood (5) and positive affect was maintained during a 10 min neutral filler (17).

With regard to dampening as a suggested moderator, unexpectedly, the immediate as well as the delayed impact of abstract/verbal processing was not worse for people characterized by dampening responses. This means that although people have a stronger dampening cognitive style in response to positive affect, they do not appear more vulnerable to the effects of abstract/verbal thinking about a positive memory. We should note, however, that high levels of dampening might be not sufficiently resembled in the present samples. We also note that we investigated "trait" dampening responses to positive affect. For future research, it would be interesting to include a state measure of dampening [cf. LeMoult et al. (59) for state rumination].

In the second study, we compared two less concrete/imagery-based processing styles (abstract/verbal vs. comparative/verbal). As hypothesized, comparative/verbal thinking yielded different responding than abstract/verbal thinking. This suggests that verbal processing itself is not necessarily a problem, but rather it is the combination with making (unfavorable) comparisons, which makes it less adaptive. Importantly, comparative thinking was especially detrimental for individuals with higher levels of depressive symptoms. Overall, this suggests that, at least with this type of achievement memory, comparative thinking (presumably *unfavorable* comparisons) turns out to be the unbeneficial factor and not the abstractness of thinking as such. Interestingly, given that abstract/verbal processing did not increase positive affect in Study 1, but did in Study 2, it is unclear whether the difference between abstract and comparative-based thinking in Study 2 was solely driven by the negative ingredients of comparative thinking or also by positive aspects of the abstract/verbal induction. It will be important to replicate this study and investigate it with different types of memories.

The interpretation of the results and comparison of the two studies have some final limitations. First, we are aware that the comparison of the two studies is limited due to method differences. For example, two different measures of depressive symptoms were used and the numerical anchors of the affect scales differed. Second, both studies were limited to student samples and we did not collect diagnostic information on depressive status. Therefore, we should remain cautious when interpreting our results in the context of clinically depressed patients or persons at risk for (relapse/recurrence of) clinical depression. Third, in both studies, we did not include a neutral control condition, therefore we cannot conclude whether the differences between conditions are driven by the active positive effect of a concrete/imagery-based processing style. Fourth, both studies were not conducted in an individual setting. Although similar manipulations were conducted in a group context (50) or via internet (24), it is recommended to repeat the study in an individual setting.

Overall, the present studies support the potential of trainings in positive mental imagery with autobiographical material. In addition, the studies stress taking care of thought patterns when working with (autobiographical) positive stimuli in therapy and underline the need for research into parameters that determine the outcome of abstract/verbal processing.

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Involuntary cognitions in everyday life: exploration of type, quality, content, and function

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Psychological research into spontaneous or intrusive cognitions has typically focused on cognitions in one predefined domain, such as obsessional thoughts in OCD, intrusive memories in posttraumatic stress disorder and depression, or involuntary autobiographical memories and daydreaming in everyday life. Such studies have resulted in a wealth of knowledge about these specific cognitions. However, by focusing on a predefined type of cognition, other subtypes of cognition that may co-occur can be missed. In this exploratory study, we aimed to assess involuntary cognitions in everyday life without a pre-determined focus on any specific subtype of cognition. Seventy unselected undergraduate student participants were administered a questionnaire that assessed the presence of any involuntary cognitions in the past month, their quality, type, content, and potential function. In addition, participants provided self-descriptions and completed measures of psychopathology. Content analyses showed that involuntary cognitions were common, predominantly visual in nature, emotional, often about social relationships, and often related to a hypothetical function of emotional processing. About two-thirds of the cognitions that participants reported were memories. Non-memories included daydreams, imaginary worst case scenarios, imaginary future events, hypothetical reconstructions, and ruminations. Memories and non-memories were strikingly similar in their subjective experience of content and emotionality. Negative (but not positive) self-descriptions were associated with negative involuntary cognitions and psychopathology, suggesting a link between involuntary cognitions and the self. Overall, the findings suggest that people experience a wide variety of subtypes of involuntary cognitions in everyday life. Moreover, the specific subtype of involuntary cognition appears to be less important than its valence or content, at least to the subjective experience of the individual.

Keywords: intrusions, mental imagery, intrusive cognitions, involuntary memory, psychopathology

INTRODUCTION

The field of psychology is characterized by a historical interest in the ways of the mind that appear to operate beyond voluntary control. For example, Sigmund Freud inspired an interest in subconscious processes that operate outside of our volition. Within the domain of psychopathology there has been a marked interest in involuntary phenomena such as psychotic hallucinations, obsessions, and traumatic flashbacks. In cognitive psychology, a growing body of research has investigated the occurrence of involuntary memories experienced in everyday life by individuals in the general population. These interests in involuntary processes across the clinical and cognitive psychology literatures have resulted in numerous scientific publications on specific forms of involuntary cognitions; i.e., thoughts, memories, or images that come into awareness in the absence of an intention of conjuring them. In this study, we aimed to explore involuntary cognitions in everyday life using a bottom-up approach that is free from the restrictions of any theoretical framework or an *a priori* restrictive focus on any one subtype of involuntary cognition.

Several theorists and researchers have sought to describe and explore features of different forms of involuntary cognitions. Some studies sought to compare involuntary cognitions between clinical and non-clinical populations, whereas others assessed their occurrence in everyday life. Below we describe the main observations that have emerged from this literature. Throughout this literature, many different terms have been used to describe the type of cognition that was studied (e.g., obsessions, intrusive thoughts, and involuntary memories), although a definition of the adopted terms is not always provided. When reviewing the literature, we will describe the research findings using the original terminology adopted by the authors, and provide their definitions where available. In our own writing, we use the term "cognition" as an umbrella term for memories, thoughts, and images. "Memories" refer to representations in autobiographical or semantic memory, "thoughts" refer to verbal thoughts, and "images" refer to mental images from sensory modalities, most commonly visual. Thoughts and images may or may not be part of a memory representation.

INVOLUNTARY AUTOBIOGRAPHICAL MEMORIES

Involuntary negative autobiographical memories (often referred to in the literature as "intrusive memories" owing to the fact that they are distressing and intrude into consciousness unbidden) represent another type of involuntary cognition that has been investigated across a range of clinical disorders (1). Involuntary memories of negative events have been characterized and studied most extensively in posttraumatic stress disorder (PTSD), a clinical condition in which the reliving of one's traumatic experience via the experience of recurrent and distressing memories is a key diagnostic criterion. Beyond PTSD, a growing evidence-base has documented the presence of involuntary negative memories, as well as other mental images, in a range of disorders, including panic disorder with agoraphobia (2), social phobia (3), bipolar disorder (4), grief (5), and depression (6). However, although involuntary memories of negative events are reported by clinical samples, it is noteworthy that such memories are also reported by healthy individuals. For example, Newby and Moulds (6) found that there was no significant difference between the proportions of currently depressed, formerly depressed, and never-depressed individuals who had experienced an involuntary memory of a negative event in the previous week. Interestingly, the phenomenological experience of involuntary negative autobiographical memories (e.g., here and now quality, reliving) was strikingly similar across the three groups; however, currently depressed participants reported that their memories were more vivid, distressing, caused greater interference, and were associated with more sadness, helplessness, and anger.

Turning to studies on this topic outside of the clinical literature, Brewin et al. (7) assessed intrusive thoughts and intrusive autobiographical memories in a non-clinical sample. They defined intrusive thoughts as "spontaneous, repetitive thoughts" that interrupted ongoing activities and were hard to control, including images, impulses, or ideas. Intrusive memories were defined as memories of a specific event that interrupted daily activities and were hard to control. Participants were asked to report five intrusive memories and five intrusive thoughts and to rate their frequency in the past 2 weeks, as well as their level of (un)pleasantness. After controlling for the order of recall (i.e., memories first or thoughts first), the only difference that emerged was that thoughts tended to intrude more often than memories.

Studies conducted outside of the laboratory have also investigated involuntary autobiographical memories in everyday life. For example, in an elaborate diary study, Berntsen (8) asked 14 participants to record 50 involuntary memories with a maximum of 2 memories per day. Participants answered a series of questions about each memory. In addition to the diary, participants were asked to estimate how many involuntary memories they experienced on an average day. Participants reported that they experienced more than two involuntary memories per day, with five or six involuntary memories per day being the most typical estimate (range 3–20). Almost all memories were cued by triggers that shared salient features with the memory, with activities, objects, and people being the most common triggers. The valence of the memories was often congruent with participants' mood state at the time of recall [see also Ref. (9)]. Most of the memories were of unusual events, such as traveling abroad, parties, and romantic encounters, and memories were more often rated as positive rather than negative [see also Ref. (10)]. Participants reported an increase in positive mood as a result of recalling positive memories, and an increase in negative mood from recalling negative memories.

In another study, using Galton's "memory walk" as well as a word-cue task, Berntsen and Hall (11) found that involuntary autobiographical memories, compared to voluntary memories, were more often of specific events as opposed to general events, and evoked more intense physical and emotional reactions. Using diary monitoring, Schlagman and Kvavilashvili (12) found that participants experienced an average of 17 involuntary autobiographical memories over a period of 1 week.

INVOLUNTARY SEMANTIC "MEMORIES"

In other studies, researchers have examined instances in which semantic information comes to mind spontaneously. Kvavilashvili and Mandler (13) referred to these instances as "involuntary semantic memories," and defined them as information without context and not related to the self, such as words, images, or songs. In a study with 205 psychology students, Kvavilashvili and Mandler (13; Study 3) administered a questionnaire that asked participants whether they had experienced involuntary semantic memories or "mind-popping." Of the participants, 84% indicated that they had at any time in their life experienced involuntary semantic memories. On average, participants estimated that these memories occurred between 1–2 and 3–4 times per week. The most frequent type of memory was a familiar tune popping into mind (indicated by 80% of participants).

In a subsequent study (13; Study 4), the authors compared involuntary semantic memories to involuntary autobiographical memories obtained from 50 psychology students. Participants were asked to record their involuntary autobiographical memories in a diary for 1 week, and their involuntary semantic "memories" in a diary during another week (in counterbalanced order). Overall, 205 involuntary autobiographical memories and 74 involuntary semantic memories were reported, which was a statistically significant difference in frequency. Similar to the earlier study, involuntary semantic memories were of words (61%), songs (27%), and images (12%). The authors did not report on the content of the autobiographical memories. Both memory types were associated with relatively low levels of cognitive demand or concentration. Eighty percent of the involuntary autobiographical memories were associated with identifiable triggers, whereas this was only the case for 37% of the involuntary semantic memories, which was a statistically significant difference.

INVOLUNTARY THOUGHTS AND IMAGES

In an early paper on this topic, Rachman and De Silva (14) reported the findings of two studies in which they assessed obsessions in a non-clinical and a clinical sample of "obsessional patients"; i.e., individuals who sought clinical help for their obsessions. Obsessions were defined as "repetitive, unwanted, intrusive thoughts of internal origin" (p. 233). In the first study, 99 out of 124 non-clinical participants reported experiencing obsessional thoughts, which they generally found easy to dismiss. Participants varied in the extent to which they rated their obsessions as tolerable. In the second study, information about obsessions was obtained from clinical and non-clinical participants. Blind raters with clinical experience were presented with the obsessions and asked to judge whether each one was reported by a clinical or non-clinical participant. The raters were fairly accurate in identifying the obsessions from the non-clinical participants as belonging to the non-clinical group. However, for the obsessions reported by clinical participants, raters did not do well in identifying these obsessions as belonging to the clinical group. This indicated that the content was quite similar in both groups. The obsessions reported by participants in the clinical group were experienced as longer, more frequent, more intense, and less acceptable and dismissible than the obsessions reported by participants in the non-clinical group. A later study by Salkovskis and Harrison (15) replicated these results and further reported that participants' discomfort with experiencing the obsessions was not related to obsession type (i.e., "thoughts" or "impulses"), but by the ease with which they could be dismissed.

Clark and De Silva (16) asked non-clinical participants to rate a list of six depressive and six anxious cognitions (i.e., thoughts and images) on several dimensions. On average, participants reported that these cognitions occurred between twice a month and once a week. Anxious cognitions were rated as more emotionally intense than depressive cognitions, and the perceived controllability of both anxious and depressive cognitions predicted their frequency. In turn, frequency and emotional intensity (and disapproval for anxious cognitions only) predicted participants' ratings of controllability.

Beyond studies of involuntary memories and involuntary thoughts, researchers have investigated other intrusive cognitive phenomena and processes, including mind wandering (17, 18) and involuntary images of future events ["flashforwards"; (19)].

PRESENT STUDY: INVOLUNTARY COGNITIONS

Taken together, the studies outlined above provide valuable insights into an array of specific subtypes of involuntary cognitions that have been indexed across studies in the clinical and non-clinical literatures. Although investigating different types of involuntary cognition, a common feature of these studies is that the researchers identified *a priori* the subtype of involuntary cognition that was to be assessed. This may be an important limitation of the literature, because it may well be that people experience a range of different types of involuntary cognition. Focusing on one or two pre-determined subtypes of involuntary cognitions precludes the collection of data on other subtypes, and limits examinations of their relative importance in everyday life. That is, when wanting to determine the content of a fruit basket, one can decide to examine only cherries, or apples, or bananas. However, by doing so, the full content of the basket will never be known. In light of the abovementioned limitations, in this study we adopted a bottom-up approach as a means by which to take a first step into exploring the full scope of involuntary cognitions in everyday life as they are experienced by an unselected sample of individuals.

Given that involuntary cognitions are accepted as a transdiagnostic occurrence across many disorders [e.g., Ref. (20)] we also explored the link between different types of involuntary cognitions that would emerge from our procedure and psychopathology. The link between involuntary cognitions and psychopathology has been described in the Self-Memory System Model [SMS; (21)]. According to this model, the content of involuntary images should be related to psychopathology through the individual's self-images. In order to explore this link, self-descriptions were also obtained.

MATERIALS AND METHODS

PARTICIPANTS

Seventy participants (58 females) were recruited from the student population of the Radboud University Nijmegen. Of these, 68 were undergraduate students, one was a graduate student, and one recently dropped out of their course. Participants received a €10 gift voucher for their participation, and ranged in age from 18 to 37 ($M = 21.71$, $SD = 3.65$).

INVOLUNTARY COGNITIONS QUESTIONNAIRE

This self-report questionnaire was developed for the purpose of this study and the structure was based on earlier intrusive memory interviews (22–24). First, participants read an introduction about involuntary cognitions, which read:

> Many people have the experience that in some moments a certain image, a certain thought, or a certain memory comes to mind, without them deliberately thinking about this. These can be positive as well as negative experiences. Someone who is in love, for example, sees the face of his or her loved one in their mind time and time again. Someone who just experienced a car accident can keep seeing images of this experience in their mind. It is also possible that someone frequently sees a certain image in mind without exactly knowing where this is coming from. For example, someone can see an image of themselves completely alone, or trapped, or covered in germs. What is important here is that it is about images, thoughts, or memories that come in your mind spontaneously without you deliberately thinking about it.

Participants were then asked whether they had experienced any such spontaneous images, thoughts, or memories within the last month. If they had, participants were then asked to provide a detailed description of each image/thought/memory, which included its content (e.g., location, people, event, and time), personal meaning, whether it was a memory of an actual event that they had experienced (yes/no), which (if any) emotions were associated with the involuntary cognition (fear, anger, sadness, disgust, happiness, or other), and how strongly they experienced any such emotions (1 = *not at all*, 7 = *very strongly*). After completing these questions, participants were asked whether they had experienced another spontaneous image, thought, or memory within the past month. If so, the questions were repeated for this involuntary cognition. Participants were queried about a maximum of three involuntary cognitions.

CODING SCHEME

The descriptions of the involuntary cognitions on the involuntary cognitions questionnaire (ICQ) were coded independently by two raters (Julie Krans and June de Bree) on the characteristics of quality, type, content, and exploratory, possible function. Disagreements were resolved based on consensus after discussion.

Quality

For quality, involuntary cognitions were classified according to their dominant quality (i.e., visual, verbal, emotional, or bodily sensation). These categories were based on earlier studies on the qualities of intrusive memories (22–24). Inter-rater agreement for quality was $K = 0.472$.

Type

For type, participants' response to the question about whether the involuntary cognition was a memory was used to identify spontaneous cognitions as either memories or non-memories. We initially intended to code non-memory cognitions according to existing categories (25), but this resulted in a high number of unclassifiable cognitions. Accordingly, we classified non-memory involuntary cognitions into the following categories, on the basis of the coders' ratings (i.e., Julie Krans and June de Bree; $K = 0.666$): daydream, worst case scenario, future event, hypothetical reconstruction (descriptions that fill gaps in the information that the participant has about a certain event), or rumination (recurring and extended verbal dwellings on a certain topic).

Content

The content of the involuntary cognitions were coded into categories based on the classification systems developed to study self-defining memories (25, 26), on the basis that these categories were a good fit for the involuntary cognitions reported by participants ($K = 0.714$). These categories were as follows: relationships (emphasis is on a particular interpersonal relationship), life-threatening events (plausible or actual death or threatened physical well-being of oneself or someone else), recreation/exploration (recreation, play or exploration or obstruction of these), achievement/mastery (the effortful striving toward or achievement of own, in-group, or significant others' physical, material, social, or spiritual goals), guilt/shame (issues of wrong or right, moral, and ethical decisions), and not classifiable (not belonging to any of these categories).

Function

The function categories were the most explorative of all categories. Although the literature of function of autobiographical memory is rather substantive [e.g., Ref. (27)], to our knowledge, no empirical research has been published on functions of involuntary recall. According to a functional analysis of involuntary memories (28), the theoretical literature has suggested several possible "functions." Therefore, we borrowed from the autobiographical memory literature and the trauma literature to develop our "function" categories.

Emotional processing. First, according to the Self-Memory System of autobiographical memory (21), involuntary memories persist when there is a discrepancy between an individual's current state and desired state. The content of the involuntary memory provides information about the nature of this discrepancy. In that sense, involuntary memories "signal" that something is wrong and action needs to be taken to reduce a certain unwanted discrepancy in the psychological self. The dual representation theory of PTSD (29) suggests that in trauma, involuntary memories provide the information that is necessary to emotionally process the traumatic event. That is, a traumatic event often induces a discrepancy in the self (not dissimilar to the discrepancy put forward by the Self-Memory System), which can be dealt with by integrating all available information about the event with other knowledge in autobiographical memory. The theory proposes that highly emotional sensory information is by definition stored in involuntary memories, hence these memories provide the necessary information to successfully emotionally process the event. Taken together, these two models appear to converge on the idea that involuntary memories contain information that aids in the emotional processing of an emotional experience. Here, this category included involuntary cognitions that emphasized an event that still required closure, such as loss or holding a continuing grudge against someone about a wrong-doing in the past.

Maintaining social relations. In the autobiographical memory literature it has been suggested that recalling (and sharing) autobiographical memories about significant others is involved in the maintenance of social relationships (30). It is possible that involuntary memories or other cognitions about significant others may be helpful for the same reason. That is, recurring involuntary cognitions about friends, family, or other social relations may stimulate the social relation by keeping the memory active. Therefore, involuntary cognitions that emphasized a specific relationship with a significant other were assigned to this category.

Mood repair. In the emotional memory and depression literature, it has been found that individuals can improve a sad mood state by recalling positive autobiographical memories [e.g., Ref. (31–33)]. Positive images especially are expected to have an effect on mood (34). Hence, it is possible that spontaneous occurrences of positive images can have the same effect. Accordingly, involuntary cognitions that emphasized positive events or feelings were assigned to this category.

Preparation. Thinking about or imagining future events has been implicated in the preparation for and likelihood of actual behavior in the future (34, 35). Similarly, involuntary cognitions about upcoming events may provide an opportunity for preparation and increase likelihood of future actions. Involuntary cognitions that predominantly emphasized upcoming events were assigned to this category.

Warning signal. This may be the most concrete proposed function of involuntary memories, at least in the trauma literature. According to the warning signal hypothesis [e.g., Ref. (22)], involuntary memories of negative events come to mind in situations that resemble the physical characteristics of this earlier negative experience. In this way, the involuntary cognition functions as a "warning signal" for potential danger in the present situation. Involuntary cognitions of negative events that were triggered by (a subjective sense of) similarity with the current situation were assigned to this category. We note one difference between Ehlers et al. (22) warning signal hypothesis and our conceptualization of this function in the current study: the involuntary cognitions reported by participants in this study were not restricted to actual memories of a traumatic event.

SELF-DESCRIPTIONS

Self-descriptions were assessed with the Twenty-Statements Test [TST; (36, 37)]. The TST assesses individual self-descriptions as conceptualized in the SMS model by asking participants to complete 20 sentences starting with "I am…" (37). These descriptions were subsequently coded as positive (e.g., "I am smart"), negative ("I am ugly"), and neutral ("I am curious") self-descriptions ($K = 0.785$).

PSYCHOPATHOLOGY

The Dutch version of the Symptom Checklist 90 [SCL-90; (38)] is a 90-item self-report questionnaire that assesses perceived current physical and mental complaints aimed to reflect a general level of psychopathology. It is one of the most widely used screening questionnaires in Dutch mental health facilities. The total score is an indicator of general physical/mental dysfunction or "psychoneuroticism." In addition, the following subscales can be identified: Somatization, Obsessive compulsive, Interpersonal sensitivity, Depression, Anxiety, Hostility, Phobic anxiety, Paranoid ideation, Psychoticism, and additional items. In a Dutch sample of individuals who contacted a mental health facility for the first time the internal consistency was $\alpha = 0.97$ (39).

PROCEDURE

Participants were tested individually in a testing cubicle in the lab of the Behavioral Science Institute. They completed a demographics questionnaire, the ICQ, followed by several measures that are not relevant to the present study (assessing depression, anxiety, goals, and self-esteem) and the SCL-90. For more information on all measures that were included in the study please contact the corresponding author. Afterwards participants were debriefed, thanked, and paid. The entire session was usually completed within about 45 min. All questionnaires and tasks were completed on a PC using Inquisit version 2.0 (40).

RESULTS

FREQUENCY

In total 62 involuntary cognitions were reported. Of the 70 participants, 23 (32.86%) reported not having experienced any involuntary cognitions in the past month. A further 34 participants (48.57%) reported 1 involuntary cognition, whereas 11 (15.71%) and 2 (2.86%) participants reported 2 and 3 involuntary cognitions, respectively. Thus, the majority of all participants, which is 67.14% of the present sample, recalled having experienced at least one involuntary cognition in the past month.

ASSOCIATED EMOTIONS AND EMOTIONAL INTENSITY

For two participants no emotion data were recorded due to a technical error. On the ICQ participants were presented with the options "fear," "anger," "sadness," "disgust," "happiness," or "other." For 13 involuntary cognitions, the "other" category was endorsed after which participants were asked to label the associated emotion. The "other" category emotions were labeled by the participants as "distress," "love," "doubt," "shame," and "relaxed." The large majority of involuntary cognitions were associated with either happiness (20; 32.26%) or sadness (15; 24.19%). These two categories far outweighed all other categories. **Table 1** presents the frequency with which each emotion was endorsed and the mean intensity score for each emotion.

Table 1 | Frequencies of endorsed emotions for all involuntary cognitions in descending order and the mean emotional intensity per emotion.

Emotion	Frequency	Intensity	
		M	SD
Happiness	20	6.05	0.74
Sadness	15	5.67	0.90
Fear	6	4.83	0.98
Distress	6	5.00	0.84
Anger	3	5.33	0.58
Disgust	3	6.33	0.58
Love	3	6.00	0.00
Doubt	2	5.50	0.71
Shame	1	6.00	n.a.
Relaxation	1	6.00	n.a.

Overall, the reported involuntary cognitions were highly emotional, with average intensity ratings across emotions from 4.83 to 6.33 on a 1–7 scale. Due to low numbers of involuntary cognitions that were associated with emotions other than happy or sad, no statistical analyses were performed to test for differences in emotional intensity.

QUALITY

The large majority of involuntary cognitions (82.26%, $n = 51$) were predominantly visual in nature. A further 8.06% ($n = 5$) were predominantly verbal in nature, four (6.45%) were predominantly an emotional experience, one was a bodily sensation, and one could not be coded into any of these categories.

TYPE

For more than half of the involuntary cognitions (61.29%, $n = 38$), participants indicated that the content was a memory of a specific event that had occurred in their lives. Thus, the remaining 24 involuntary cognitions were not memories. These non-memories were classified into the Type categories. **Table 2** presents the frequency for each category, as well as an example.

CONTENT

Half of all involuntary cognitions were about relationships. The next most frequent content concerned life-threatening events ($n = 15$; 24.19%), followed by recreation/exploration ($n = 8$; 12.90%), achievement/mastery ($n = 4$; 6.45%), and guilt/shame involuntary cognitions ($n = 2$; 3.23%). Two involuntary cognitions were marked as not classifiable, as they did not fit into any of these categories. **Table 3** presents an example of an involuntary cognition for each of the categories.

FUNCTION

Of all involuntary cognitions, 22 (35.48%) were assigned to the category emotional processing, 15 (24.19%) to maintaining social relations, 12 (19.35%) to warning signals, 8 to mood repair (12.90%), and 5 (8.06%) to preparation. **Table 4** provides examples for each category.

Table 2 | The type of non-memory involuntary cognitions with their frequency and an example for each.

Type	Frequency
Daydream	7
Example: *I sometimes see a person with whom I might be in love, we are in a room and he looks at me and I have the feeling that he honestly thinks that he loves me. Besides us no one else is in the room. I have several feelings with it, on the one hand it's very beautiful to me, and on the other hand it's not, because in theory I shouldn't have feelings for him. Still I think it's beautiful, when the image appears*	
Worst case scenario	5
Example: *Last Friday I was at my parents' house and there was no one else at home, only our 2 dogs were there. I was brushing/grooming one of them and the TV was on at the same time, where a movie was playing. Suddenly the image came to mind that my brother would not make it through the job application, that his world collapsed, including my parents' and therefore of the entire family. There was a lot of pressure, because in times of this economic crisis as a [occupation] he would not get a new chance soon. After I had let the image come over me, a worried and jaded feeling came over me, also because it could come true. There was indeed a chance that he would not make it. Of course you take this into account, but still*	
Future event	5
Example: *The location is [city name] and I'm there with my future friends. It's about the art academy where I'm going in [month] it is an image instead of a memory. This means a lot to me because I really want it. I have positive thought with it. I'm happy but also a little insecure of whether I will be able to do it*	
Hypothetical reconstruction	4
Example: *On the occasion of break-in at home. Backyard, 2 burglars, walking through the backyard to the backdoor, seeing exactly how they would have done it. It happens at night. Does not really mean anything to me, I try to ignore it. It evokes feelings of fear, doubt whether they will come back again and if it really happened this way. Desire to see the movie in real life so that I really know how it happened*	
Rumination	3
Example: *When I'm alone then often memories come up of my relation that ended 2 weeks ago. I mostly have this when I'm alone, then I start wallowing in my head and then memories come up. Or when I hear a specific music track that is associated with a memory or that I encounter things that remind me of the 4.5 year relationship. So my ex is involved in this. And it takes place mostly at night when I'm alone in my room and don't have distraction from other people. It evokes mixed feelings, feelings of loss but also negative feelings about everything that went wrong and how much it has hurt me. I often am furious but I can also burst into tears because it has become such a mess. And I often have to tell myself: Come on, you deserve better. But that is often easier said than done*	

SELF-DESCRIPTIONS

The number of positive self-descriptions was significantly correlated with psychopathology, $r = -0.31$, $p = 0.009$, but was not associated with any of the other measures. The number of negative self-descriptions was significantly correlated with psychopathology, $r = 0.43$, $p < 0.001$, the number of negative involuntary cognitions, $r = 0.32$, $p = 0.008$, the number of sad involuntary cognitions, $r = 0.36$, $p = 0.002$, the level of sadness of these involuntary cognitions, $r = 0.38$, $p = 0.001$, the number of involuntary cognitions with guilt/shame content, $r = 0.29$, $p = 0.016$, and the number of involuntary cognitions that were assigned to the emotional processing function category, $r = 0.38$, $p = 0.001$.

PSYCHOPATHOLOGY

SCL-90 scores were significantly correlated with the level of distress associated with cognitions that participants reported as distressing, $r = 0.25$, $p = 0.037$, number of cognitions that were associated with disgust, $r = 0.29$, $p = 0.016$, and the levels of disgust associated with those cognitions, $r = 0.29$, $p = 0.015$, number of cognitions in the form of bodily sensations, $r = 0.322$, $p = 0.007$, and the number of worst case scenario non-memory involuntary cognitions, $r = 0.25$, $p = 0.037$, and, as mentioned, the number of positive, $r = -0.31$, $p = 0.009$, and negative self-descriptions, $r = 0.43$, $p < 0.001$. **Table 5** shows the Pearson correlations between each of the SCL-90 subscales (columns), and involuntary cognitions characteristics and self-descriptions (rows). Only variables with at least one significant correlation with the SCL-90 subscales are included.

COMPARISONS BETWEEN INVOLUNTARY MEMORIES VS. INVOLUNTARY NON-MEMORIES

The finding that nearly half of the reported involuntary cognitions were not memories was of great interest to us, particularly in light of the surprising lack of empirical research into non-memory involuntary cognitions. The relative proportions of memories and non-memories therefore prompted us to consider the extent to

Table 3 | Examples of each of the Content categories.

Content category	Example
Relationships ($n = 31$)	*There is not really a location. It is about my father whom I haven't seen for about 14 years due to circumstances. I visualize him and me in a living room where we catch up on the last 14 years. The time when it plays is also unclear. The image means quite a lot to me. I would like to speak to him again and stuff, but it doesn't work the way I want it to. The thoughts I have with this are tricky, because I don't know what he is like now and how I will respond to that in turn. It evokes (again) feelings of being incomplete*
Life-threatening event ($n = 15$)	*A car came by very closely and I already saw myself lying under the car. I was alone. I felt very nervous afterwards*
Recreation/exploration ($n = 8$)	*A holiday in America with a friend who was an au pair there for a year. We are cycling in the sun, on our way to the supermarket for groceries. This is sometime during the course of a weekday, on which my friend had to work as usual. This image makes me happy, I think back to this holiday as very successful, a beautiful experience. It was also a unique experience. In relation to the weather in the Netherlands I think back to it and then I feel a little nostalgic. Especially the weather is important in this memory. Also the feeling of being happy, not to have to do things, just holiday and relaxation*
Achievement/mastery ($n = 4$)	*I think a lot about a job interview that I have in the near future. It is set in a room at the [name university]. The feelings it evokes I can perhaps best describe as 'healthy stress'. I think about it a lot because I really want to be admitted, but that also causes mild tensions*
Guilt/shame ($n = 2$)	*Last week when I was lying in bed a shameful event came up spontaneously that was not nice at all at that moment. The same shameful feeling arose and I wanted mostly to cringe*

Table 4 | Examples for each of the function categories.

Category	Example
Emotional processing ($n = 22$)	*Location: the apartment where I used to live with my boyfriend at the time. What happens: my sister and my boyfriend are making love. When does it happen: when I was out working. It is something that I hadn't wanted to know. That it happened is already bad enough, but I hadn't wanted to know. Sometimes I don't care at all, sometimes I feel so betrayed, then I see myself again at Easter giving my boyfriend and sister an Easter egg and hearing myself say: "For the two people I love the most." That my boyfriend cheated on me is not even the problem, but that my sister could so easily betray me I really cannot understand*
Maintaining social relations ($n = 15$)	*A good friend – that I like very much by the way – who has been a regular fellow passenger on the train. She often sat across from me and sometimes I see her in my mind, even though in reality no one is sitting across from me. A visualized memory of those travels, which do me good*
Warning signal ($n = 12$)	Memory*: I once had my toe stuck between something which made the nail almost fall off. The doctor then removed the nail and it looked horrible for a while. Every time I'm wearing thongs on the bicycle/walk behind a grocery cart I'm afraid that my toe will get stuck between. There is no special location/people present/event. Just the startle moment and the image of the bloody toe. It always frightens me and I'm scared it will happen again, it's not that I'm afraid of the pain, but the way it looked just gives me the creeps. Then I don't feel comfortable at all for a moment* Non-memory*: Someone is holding something valuable in their hand and I see in my mind how the objects falls down on the floor. Sometimes it's just a bottle of wine held by my friend and I feel like I need to be vigilant and be ready to catch the bottle*
Mood repair ($n = 8$)	*In [city] at the quay during the [event]. Together with a colleague a meeting with a group of guys. It happened last year. We chat some and then party on for a long time all together. Evokes feelings of joy because it was a lot of fun and hoping to run into them again this year.*
Preparation ($n = 5$)	*It's more thoughts than experiences. Because I study in [country] but am from [other country], I think about my parents a lot lately and thoughts of them come to mind. Partly I wonder what they are doing now and partly I think about what it would be like if they wouldn't be there anymore, because they are near their 70s already. Then I do wonder whether I will be able to say that I have spent enough time with them. This is not necessarily negative for me. I'm thinking about them a lot and actively take on things, which makes me feel that we ARE spending an intensive amount of time together because I realize that the time together can end*

Table 5 | Pearson correlations between the SCL-90 subscales, and characteristics of the involuntary cognitions and self-descriptions.

	SOM	OBS	INT	DEP	ANX	HOS	PHO	PAR	PSY	ADD
Emotion										
Distress	n.s.	n.s.	n.s.	n.s.	0.275*	0.240*	n.s.	n.s.	n.s.	n.s.
Disgust	n.s.	0.294*	0.308*	n.s.	n.s.	0.426***	0.330**	n.s.	n.s.	0.256*
Love	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.289*	n.s.
Intensity										
Happiness	n.s.	n.s.	n.s.	n.s.	−0.258*	n.s.	n.s.	n.s.	n.s.	n.s.
Distress	0.242*	n.s.	n.s.	0.259*	0.316**	0.244*	n.s.	0.249*	n.s.	n.s.
Disgust	n.s.	0.301*	0.310*	n.s.	n.s.	0.409**	0.320**	n.s.	0.251*	0.255*
Love	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.289*	n.s.
Quality										
Bodily sensation	0.349**	0.307*	0.282*	n.s.	0.385*	0.275*	0.532***	n.s.	n.s.	0.241*
Type										
Worst case scenario	0.290*	n.s.	n.s.	n.s.	0.370**	0.340**	n.s.	n.s.	n.s.	n.s.
Rumination	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.316**	0.341**
Content										
Life-threatening event	n.s.	0.246**	n.s.	n.s.	0.316**	n.s.	n.s.	n.s.	n.s.	n.s.
Function										
Warning signal	n.s.	n.s.	n.s.	n.s.	0.318**	n.s.	n.s.	n.s.	n.s.	n.s.
Self-descriptions										
Positive	n.s.	−0.362**	−0.358**	−0.236*	n.s.	−0.275*	−0.248*	n.s.	n.s.	n.s.
Negative	n.s.	0.427***	0.380**	0.436***	n.s.	0.350**	0.291*	0.357**	0.295*	0.269*

*SOM, somatization; OBS, obsessive compulsive; INT, interpersonal sensitivity; DEP, depression; ANX, anxiety; HOS, hostility; PHO, phobic anxiety; PAR, paranoid ideation; PSY, psychoticism; ADD, additional items. *p < 0.05, **p < 0.01, ***p < 0.001.*

which these two types of involuntary cognitions might overlap or differ in terms of their features, as well as the way in which they are subjectively experienced.

Chi-square analyses were conducted to compare memories and non-memories on valence (positive and negative), associated emotions, quality, content, and function. A t-test was conducted to compare the levels of emotion (i.e., emotional intensity) of the emotions associated with the involuntary cognitions. Memories vs. non-memories were equally often positive or negative, and there was no difference in the associated emotions or the emotionality (i.e., rated level of emotion) of the two types of cognitions, all $ps > 0.05$.

There was a significant difference in the content of the involuntary cognitions between memories and non-memories, $\chi^2(5) = 15.71$, $p = 0.008$, and a difference in the function, $\chi^2(4) = 10.51$, $p = 0.033$. The difference in quality approached significance, $\chi^2(4) = 9.19$, $p = 0.057$. In regards to content, approximately half of all memory and non-memory involuntary cognitions were about relationships. After that, memories were most often about life-threatening events whereas non-memories were equally often about life-threatening events and achievement/mastery. That is, life-threatening events were twice as likely to be the content of memories as non-memories. Finally, none of the non-memories were about recreation/exploration, whereas about 21% of memories have this content.

In terms of possible function, memory involuntary cognitions were most often coded as having the possible function of emotional processing and social relations. Further, this function was assigned to memory involuntary cognitions twice as often as was the function of mood recovery or warning signals. Similarly, the function of emotional processing was most often assigned to non-memory involuntary cognitions. In contrast to memories, non-memories had the possible function of social relations, preparation, and warning signals equally often. Relatively speaking, the functions of emotional processing followed by social relations were assigned to memories and non-memories equally often. Memories tended to be associated with the possible function of mood repair relatively more often than non-memories. Non-memories tended to be associated with the possible functions of preparation and warning signal relatively more often than memories. In fact, none of the memories were coded as having the function of preparation.

The large majority of memories were predominantly visual in nature, whereas only about two-thirds of the non-memories were. This is perhaps not surprising because autobiographical memories by definition have a strong visual component whereas non-memories could also exist of purely verbal thoughts (e.g., ruminations).

DISCUSSION

The aim of this study was to explore the occurrence of involuntary cognitions in everyday life using a bottom-up approach. We use the term "involuntary cognitions" to refer to memories, thoughts, and mental images that pop up into mind spontaneously, without conscious effort to retrieve or produce them. To assess involuntary cognitions in everyday life, a PC administered structured interview was presented to an unselected group of 70 university students, most of them female. The interview queried participants about involuntary memories, thoughts, and images from the past month. By adopting a bottom-up approach, the exploratory analysis was more or less free of guidance from any specific theoretical framework, and was not limited to one specific type of cognition.

In this sample, 67.14% of participants reported at least one involuntary cognition in the past month. In terms of qualities or characteristics, all cognitions were considered to have at least some emotional impact, and the predominant emotions were "happy" and "sad." In regard to sensory modality, 82.26% of the reported involuntary cognitions were rated as being predominantly visual in nature, which is in line with earlier research showing that the visual modality is often dominant in mental imagery [e.g., Ref. (24)]. Of all reported involuntary cognitions, only 61.29% were (autobiographical) memories, as indicated by the participants. This left us with 38.71% of "non-memories," which were further categorized using available coding schemes and relevant descriptive literature (see Materials and Methods). The non-memories mainly consisted of daydreams, imagery of worst case scenarios, future events, hypothetical reconstructions of past events that were not solved for the individual (i.e., "missing pieces" in a coherent narrative), and verbal ruminations. These types of cognitions occurred more or less in equal numbers.

In terms of content, the three main categories that were observed were social relations (e.g., an image of a friend sitting across from you in the train), life-threatening events (e.g., a bloody accident), and recreation/exploration (e.g., relaxing on top of a hill with a great view). Possible or hypothetical functions were identified based on available literature (see Materials and Methods). Our examination led us to conclude that around 33% of the involuntary cognitions reported could be functional for emotional processing, 25% for maintaining social relationships, 20% as warning signals, 10% in mood repair, and another 10% in preparing for future events. Analyses that compared memories and non-memories revealed surprisingly few differences. Memories and non-memories were comparable in terms of valence, emotions, and emotional intensity. This may suggest that for the individual, the distinction between memories and non-memories may not in fact be important, as both types of involuntary cognitions represent fairly similar experiences, at least in terms of the characteristics that were measured in this study. Further, for the life-threatening events category, intrusive cognitions were twice as likely to be memories as opposed to non-memories, and there were no non-memories of the recreation/exploration categories. These findings may be methodological artifacts, because the inherent nature of the categories "life-threatening events" and "exploration/recreation" have a strong associations with personal past experiences.

For both memories and non-memories, the most prevalent potential function was emotional processing. Mood repair was more often associated with memories than non-memories, in line with previous evidence of the effectiveness of positive memory recall as a means by which to counter a sad mood state [e.g., Ref. (33)]. Prevalent potential functions for non-memories were warning signals and preparation for future events. For the potential function of preparation this is not surprising, as the cognition is about an event that has not happened yet and could therefore not be a memory [although it is likely that the information represented in the future oriented cognition heavily draws on information from past experiences; (41)]. This potential function of a "warning signal" was identified from the literature on psychological trauma, in which it has been proposed that involuntary autobiographical memories of negative events may occur in situations in which cues are present that could signal or predict a repeat of the past experience (22). In our study, we identified memories that could be interpreted as serving the function of a warning signal. For example, one participant had experienced her foot getting stuck in the wheel when cycling, which resulted in a bloody toe. She experienced an involuntary memory of this toe whenever the risk of a repeat of this accident was present (e.g., walking close behind a grocery trolley). The finding in our sample that it was not only memories served that function of a warning signal may suggest that non-memories may function as warning signals for negative experiences even if the individual has not experienced a similar experience him/herself before.

In addition to involuntary cognitions, self-descriptions and psychopathology were assessed using the Twenty-Statement Test (37), and the SCL-90 (38), respectively. Correlational analyses showed that whereas positive self-descriptions (e.g., "I am smart") were negatively associated with psychopathology, they were not related to any characteristics of the involuntary cognitions. Negative self-descriptions (e.g., "I am ugly"), in contrast, were not only associated with levels of psychopathology, but also with the number of negative, mostly sadness-related involuntary cognitions, levels of sadness associated with the cognitions, the number of guilt/shame cognitions, and the hypothetical function of emotional processing. This latter relationship may indicate that emotional processing of one or more negative experiences could be a main goal for individuals with a negative self-image. This would be in line with the theoretical proposition that mental images are associated with an individual's goals, which in turn are related to their self-image, according to the Self-Memory System (42). Higher scores on the SCL-90, indicating higher levels of psychopathology, were related to more distressing involuntary cognitions, and specifically higher numbers of disgust-related involuntary cognitions, greater levels of disgust, more involuntary cognitions involving bodily sensations, and more non-memories classified as worst case scenarios. Further, the SCL-90 subscales revealed many significant correlations with characteristics of involuntary cognitions and self-descriptions, supportive of a theoretical link between psychopathology, involuntary cognitions, and the self (21). Some general observations were that most correlations were positive (except for the correlation with intensity of happiness associated with happy involuntary cognitions), suggesting that the experience of involuntary cognitions is mostly associated with poorer mental health, and not with positive mental well-being. Further, some variables showed significant relations across multiple subscales of the SCL-90, such as intrusive bodily sensations, involuntary cognitions associated with distress or disgust, and the intensity of the associated distress or disgust, lower numbers of positive self-descriptions and higher number of negative self-descriptions. Although it is tempting to engage in theoretical interpretation of these correlations as some appear very intuitive (e.g., a correlation between involuntary cognitions about life-threatening events and the subscales Obsessive compulsive and Anxiety; and the function of warning signal and the

Anxiety subscale) we should be extremely careful with any such interpretations as our findings await replication.

Because an unselected sample was recruited, it is possible and even likely that some participants suffered from psychological symptoms (whether subclinical, or consistent with a clinical diagnosis – e.g., obsessive compulsive disorder, panic disorder) at the time of testing, which may in part explain these findings. Further, the majority of participants in our sample were female and therefore the results may be more representative of females than males. Future research with samples of individuals who have been screened for the presence of psychopathological conditions will test this possibility.

This study has several limitations. First, the advantages of using a bottom-up approach also come with methodological disadvantages. The coding schemes that were used were based on existing literature where possible, but were not available or suitable for all our study goals. Therefore, we constructed several classifications on face value (e.g., "hypothetical reconstructions"). Overall inter-rater reliabilities for existing classifications varied from minimal (e.g., for quality coding) to moderate (e.g., type) to high (e.g., for content and self-descriptions). Therefore, the findings presented here are very preliminary and replication will be important. Notwithstanding these shortcomings, this approach allowed us to explore the phenomenon of involuntary cognitions in a way which resulted, in our opinion, in an intriguing pattern of findings. Further, the literature that was reviewed in the Section "Introduction" included different types of involuntary cognitions that have been identified in the cognitive and clinical literature. That is, involuntary autobiographical memories, involuntary semantic cognitions, and involuntary thoughts and images all come to mind unbidden, and in the case of cognitions of negative content or valence, are unwanted. However, our data showed that other mental phenomena, such as rumination and forms of mind wandering (e.g., daydreams) were sometimes similarly experienced as involuntary and spontaneous by our participants, even though in the literature rumination and daydreaming are typically not categorized as "intrusive" or "involuntary" cognitions (although their onset may be spontaneous). Thus, it may be warranted to broaden our view of the types of cognitions that can potentially be experienced as involuntary to include rumination and forms of mind wandering. Second, the structured interview assessed only three "main" involuntary cognitions that occurred during the month preceding the study. This is likely to be a gross underestimation of the number of involuntary cognitions that occur daily [c.f., (13, 17)], and frequency of occurrence of involuntary cognitions was not assessed which, although not the goal of this study, may be considered a limitation as cognitions with a high frequency of occurrence may also differ from low frequency cognitions. In addition, we did not assess triggers, which could have provided further information about the content and function of the involuntary cognitions.

Relatedly, the involuntary cognitions that were reported all had some emotional impact (with means ranging from $M = 4.83$ to $M = 6.33$ on a scale from 1 to 7), which is likely at least partly due to a retrospective bias, such that more significant or emotional cognitions will be remembered whereas less significant or emotional cognitions, which are perhaps also more frequent, may be forgotten. Nevertheless, emotional cognitions may be more informative for some purposes as these are more likely to translate to behavior [e.g., actually preparing for a future event, avoiding a negative consequence, etc., (34)]. Third, all cognitions that were reported were classified on all factors of interest (quality, type, content, and function), resulting in overlapping categories. For example, a cognition with a function of maintaining social relations most likely overlaps with cognitions with a content of social relations, and cognitions for mood repair and cognitions about recreation/exploration likely overlap because of their positive valence. In light of this, the findings therefore need to be interpreted with caution. Finally, although the findings of this study show that there are many different types of involuntary cognitions, each with its own specific quality and characteristics and potential function, the nature of this study prevents us from drawing firm conclusions about the relations between these characteristics. Prospective and experimental studies are needed to test their empirical significance.

To summarize, we present several interesting findings that provide food for thought for both clinical and cognitive psychologists who are interested in involuntary cognitions. The main goal of this study was to explore the quality, type, content, and function of involuntary cognitions in everyday life, without limiting focus to a specific subtype (e.g., autobiographical memories, positive or negative cognitions). One of the main findings was that involuntary memories differ very little from other involuntary cognitions on important markers such as valence and emotionality. This raises the question as to whether the distinction between memories and non-memories is actually an important one in the experience of the individual. Interestingly, specific relationships emerged between psychopathology and negative self-descriptions, as well as the characteristics of cognitions. In our view, these are exciting preliminary findings that we hope may spark future research into involuntary cognitions and their specific impact on the individual's experience and behavior.

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Intrusive mental imagery in psychological disorders: is the self the key to understanding maintenance?

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Introduction

Intrusive mental imagery is a transdiagnostic process (1) present in many psychological disorders including trauma-related disorders; anxiety, mood, and eating disorders; as well as severe mental health problems, such as bipolar disorder and psychosis. In this article, we summarize some of the current literature on intrusive images and then argue that one critical way in which they maintain disorders is through their representation and relationship with patients' sense of self. We conclude by briefly discussing the treatment implications of this position.

Characteristics of Intrusive Images

Intrusive images are vivid and, although the visual elements are predominant, they often include other sensory modalities. Cutaneous sensations (e.g., the clothes being tight) and organic elements (e.g., a sense of heaviness), for example, are characteristic in bulimia nervosa (2). Images experienced by patients with vomit phobia can include physical sensations (e.g., being sick), auditory elements (e.g., others' disgusted reactions), smells (e.g., bleach), and tastes (e.g., recently consumed food) (3).

Intrusive images are often recurrent [e.g., Ref. (2, 4–6)] and can be triggered by specific stimuli (both situational and internal). Social situations (and their anticipation or recall) cue self-images in social anxiety disorder (4, 7), whereas binge eating and weight/shape concerns may activate images in bulimia nervosa (2, 8). Worry or anxiety about appearance can trigger images for individuals with body dysmorphic concerns (9), and in vomit phobia stomach sensations such as nausea or external stimuli such as seeing another person looking unwell act as cueing situations (3).

Image content varies according to the disorder. Sometimes, there is a close correspondence between imagery and patients' verbal cognitions. For example, persecutory delusions may be accompanied by persecutory images, such as being put in an oven (10) or pharmacy staff tampering with medication to poison the patient (11). In some cases, images link to catastrophic fears – physical or mental catastrophes in agoraphobia (e.g., passing out while crossing the road) (12, 13), making a fool of oneself in social anxiety disorder (4, 14), being contaminated in obsessive–compulsive disorder [OCD; (15–17)], vomiting in vomit phobia scenarios (3), or having a serious illness and dying in health anxiety (5, 18). In other cases, images relate specifically to the physical body. Patients with body dysmorphic disorder experience exaggerated pictures of and sensations such as tingling in the body parts of concern (6). Patients with bulimia nervosa experience images of the self being overweight and unattractive and sensations such as feeling bloated (2, 8). The correspondences between fears and intrusions, however, are not always so immediate or so closely linked.

Individuals with depression and bipolar disorder, for example, often report images related to interpersonal problems, including isolation and victimization (19–22).

The perspective from which patients experience intrusions varies across disorders. Patients with disorders like bulimia nervosa (2), social anxiety disorder (23), and body dysmorphic disorder (6) tend to see themselves from an observer perspective. By comparison, patients with disorders like OCD (15–17) are more likely to experience images from a field perspective. Perspective is potentially important because it may influence the images' emotional and behavioral impact. The field perspective may be associated with more intense emotions [see Ref. (24, 25)], whereas the observer perspective may exert a greater influence on individuals' future behavior (26).

Origin of Intrusive Images

Intrusive images are often related to memories of past adverse experiences. In disorders like post-traumatic stress disorder [PTSD; (27–29)], agoraphobia (12), health anxiety (18), bipolar disorder (30), OCD (17), and psychosis (10), intrusions are frequently associated with traumatic experiences, such as being physically or sexually assaulted/abused. In other cases, intrusions originate from less severe experiences, such as arguing with significant others or being teased, criticized, bullied, and humiliated [e.g., body dysmorphic disorder (6), depression (21), social anxiety disorder (4), agoraphobia (12), bipolar disorder (31), OCD (17), bulimia nervosa (8)]. Memories related to feeling bad about one's self-image and self-consciousness about one's appearance are also associated with intrusive images; characteristic examples are body dysmorphic disorder (6), bulimia nervosa (2), and social anxiety disorder (4).

Not all intrusive images arise directly from an adverse experience or correspond exactly to what happened during this experience. Some patients experience images that are partly or entirely products of their imagination. In PTSD, for example, intrusive images may be composites formed from fragments of several events (e.g., repeated traumas) or worst-case scenarios about what could have happened during a traumatic event (32, 33). In depression, images may be flash-forwards to imagined future suicide attempts (34, 35).

Role of Images in Disorder Onset and Maintenance

Evidence suggests that intrusive images play a role in both the onset and the maintenance of psychological disorders. Many patients suffering from health anxiety (5), agoraphobia (12), body dysmorphic disorder (6), and social anxiety disorder (4) report that their symptoms either appeared or intensified after the intrusion-related adverse experience. When it comes to maintenance, imagery may play a significant role through its impact on emotions. Intrusive images are frequently associated with negative emotions, such as fear, helplessness, anger, guilt, anxiety, shame, and disgust [e.g., Ref. (11, 17, 19, 22)]. Their emotional impact is also associated with specific behavioral responses that themselves contribute to disorder maintenance. In OCD, intrusive images elicit anxiety, which often triggers rituals such as washing or checking (15, 17, 36). In bulimia nervosa, images and negative emotions elicited after a binging episode may lead to self-induced vomiting (8). In bipolar disorder, images may amplify positive and negative emotions, thus contributing to the patients' unstable mood (37, 38). In health anxiety, images may trigger behaviors such as reassurance seeking and body/health checking (5). In PTSD, they may contribute to a sense of impending threat and the use of maladaptive coping strategies (e.g., avoidance) (39). In social anxiety disorder, images often trigger safety behaviors such as internal monitoring that have a detrimental effect on social performance (7, 40–42). They may also be involved in the "post-mortem" of social interactions that patients with this disorder conduct [see Ref. (43)]. In generalized anxiety disorder (GAD), images may play a rather different role. Persistent verbal worry, which is a characteristic of GAD and helps maintain it, may be an attempt to avoid the emotional impact of imagery (44). This may explain the brevity and low frequency of images reported by patients with GAD (45).

Relevance of Images for the Self

Intrusive images often represent the self and incorporate meanings about the self that are derived from the original memory (e.g., "*I am unlovable/powerless/a failure*" or "*I deserve to be punished*") [e.g., Ref. (10, 12, 17, 18)]. We believe that the relationship between images, memory, and the self has not been sufficiently explored in the literature and that its analysis would pay dividends both in understanding how self-images contribute to the maintenance of psychological disorders and how best to target them in treatment. The concept of a self-defining memory is a useful starting point. Self-defining memories are vivid, emotional, highly accessible memories that are related to individuals' most important concerns and conflicts and contain knowledge about their progress in goal attainment (46, 47). As described earlier, many intrusive images are linked to memories and represent critical meanings about the self. Sometimes, these self-images confirm beliefs about the self (e.g., "*I am foolish*" in social anxiety disorder). At other times, as in the case of PTSD, they may be linked to a self-defining memory which has transformed the self in some important way (e.g., "*I am no longer the person I was*").

The majority of work on intrusive self-images to date has recognized that there may be associated memories and has highlighted the link to beliefs, emotions, and behavior. However, it has not investigated the role of patients' broader sense of self in these links and the mechanisms that are set in motion when intrusive self-images are activated and that may produce specific emotional and behavioral responses. Our position is that intrusive self-images can only be fully understood by examining the links between self and memory and the self-memory system (SMS) model (48–51) offers one way to do this. According to the SMS model, self-images and goals are part of the working self, the representation of the self that is active at any one time. Working selves are activated when individuals face a shift in environmental demands that requires adaptive responding. They modulate individuals' cognitive, affective, and behavioral responses to this shift. The aim of the working self – and that of the SMS in general – is to help individuals adapt to their current circumstances while maintaining a stable, coherent sense of self over time (48).

When a traumatic event occurs, the goals of the active working self may not match the situation and therefore cannot guide its processing (50, 51). Moreover, the achievement of these goals is thwarted and this threatens the stability of the self. Consequently, the trauma is either not encoded or is encoded but not integrated with the individual's autobiographical knowledge base (50). The trauma thus remains highly accessible and associated with the working self that was active when it occurred [see Ref. (52)]. In an attempt to preserve the coherence of individuals' long-term sense of self, the working self may attempt to inhibit or distort the intrusive memories (e.g., through maladaptive beliefs). In addition, trauma-related images may become associated with goals which try to avoid the state of the world that these images represent (e.g., panic attack, public humiliation) by increasing the discrepancy between them and individuals' actual state (48, 49).

We have used the SMS model to investigate the impact of self-defining memories on the self (53). We confirmed the hypothesis that these memories and associated images influence the working self and may produce specific emotional and behavioral responses. Specifically, we found that participants reported different aspects of the self (e.g., goals, emotion-related self-cognitions, state self-esteem) after recalling self-defining memories, depending on the valence of the memory (positive or negative) and the extent to which they had derived meaning from it (53). Based on these findings and on the research evidence reviewed in this article, we have proposed that the intrusive images experienced by patients are part of working selves related to adverse events (53). When patients encounter situations that remind them of these events, they do not simply experience the activation of related images: they experience the activation of an entire working self consisting of the images, negative self-beliefs, and goals that aim to distance them from the failure- or threat-related standard represented by the intrusive image(s). This may explain why patients report negative emotions and engage in maladaptive behaviors when intrusions come to mind. For obsessive–compulsive patients, washing or checking rituals (15, 17) may be a way of coping with the intrusion-related anxiety and of distancing themselves from the feared scenarios represented in the intrusions (e.g., contamination). For bulimic patients, self-induced vomiting (8) may be a way of coping with the anxiety triggered by the images of the overweight self and of ensuring that these images do not become reality.

Relationship Between Intrusions and the Self: Directions for Future Research and Implications for Therapy

Research on the impact of intrusions on the working self is still in its infancy. We believe that this area of research may advance our understanding of the maintaining role of intrusive images in psychological disorders and – crucially – may illuminate the mechanism of change behind therapeutic techniques, such as imagery rescripting, that specifically target self-images and associated meanings. Understandably, to date, clinicians have focused primarily on the symptom outcomes of imagery interventions. We know, for example, that imagery rescripting effectively alleviates symptoms in several disorders, including PTSD (54, 55), acute stress disorder (56), depression (57), and social phobia (58–60). Because this technique helps patients modify the beliefs associated with their intrusions, it is reasonable to assume that it changes their sense of self. To date, this change and its possible relation to patients' symptomatic relief have not been studied in depth. We recommend that future clinical research relies on cognitive and social psychological evidence and theories on the self to investigate the impact of self-defining memory recall and intrusion activation on patients' sense of self, as well as the way in which therapeutic interventions modify this impact. We also recommend that clinicians working with patients who experience intrusions explore and focus not only on self-beliefs but also on the whole sense of self. We believe that, by focusing more on the self, we may be able to not only help patients recover but to also reduce the chances of relapse by teaching them to exert greater control over the activation of negative working selves associated with adverse experiences.

Author Contributions

SÇ reviewed the literature and drafted the manuscript. LS contributed to and edited the manuscript. Both authors gave their approval for the final version of the article to be published.

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Memory distortion for traumatic events: the role of mental imagery

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Trauma memories – like all memories – are malleable and prone to distortion. Indeed, there is growing evidence – from both field and lab-based studies – to suggest that the memory distortion follows a particular pattern. People tend to remember more trauma than they experienced, and those who do, tend to exhibit more of the "re-experiencing" symptoms associated with post-traumatic stress disorder (PTSD). Our own research suggests that the likely mechanism underlying that distortion is a failure in people's source monitoring. After a traumatic experience, intentional remembering (effortful retrieval) and unintentional remembering (intrusive mental imagery) can introduce new details that, over time, assimilate into a person's memory for the event. We believe that understanding the role these factors play in distorting people's memories for traumatic experiences is both theoretically and practically important, particularly given their potential role in influencing people's recovery.

MEMORY DISTORTION FOR TRAUMATIC EVENTS: THE ROLE OF MENTAL IMAGERY

People's memories for traumatic events are – like their memories for more mundane events – easily distorted. Importantly, memory distortion for traumatic events appears to follow a particular pattern: people tend to remember more trauma than they experienced, a phenomenon referred to as "memory amplification." Unfortunately, memory amplification carries real consequences: the more amplification people demonstrate, the more likely they are to report the "re-experiencing" symptoms associated with PTSD, such as intrusive thoughts and images [e.g., (1, 2)]. Our research program focuses on the mechanism by which memory amplification occurs. Specifically, we suspect people confuse the information generated *after* a traumatic event – both intentionally, for example, via conversation with others, and unintentionally, for example, via intrusive imagery – with what really occurred during the event. Put another way, we suspect the mechanism underlying memory amplification is a failure in people's *source monitoring* that ultimately results in memory distortion (3, 4). In this review, we provide an overview of the source monitoring framework [SMF; (3, 4)], the evidence for traumatic memory distortion, and the role that we propose source monitoring errors, particularly imagery-based errors, play in promoting traumatic memory distortion.

First, let us briefly outline the tenets of the SMF (3, 4). Put simply, the SMF states that memory distortion occurs because we do not store our memories with a label specifying the origins of each individual detail. Generally this approach is an appropriate use of our capacity-limited cognitive resources and we employ simple heuristics to judge the origins of a particular detail or entire memory. However, sometimes those heuristics fail us. For example, event details that have been repeatedly or vividly imagined can come to mind more easily over time, and – if there is no trace of the effort that went into imagining those details – people can easily mistake the accompanying sense of familiarity for the familiarity that we know accompanies genuine recollection (5). A significant body of research has investigated the factors that make source monitoring more or less difficult, and thus source monitoring errors more or less likely to occur (3, 4). Many of those factors are an issue for traumatic experiences.

For example, traumatic events are highly likely to be rehearsed extensively in an intentional manner: victims will often make a statement to police, be exposed to media footage, and engage in conversations with other friends, family, doctors, or therapists (6). Each rehearsal opportunity comes with the potential for the inadvertent suggestion of misleading details [e.g., (3, 4, 7, 8)]. In addition, traumatic experiences are also frequently rehearsed in unintentional ways via intrusive images, thoughts, and memories; the "re-experiencing symptoms" typically associated with PTSD [e.g., (9)]. Sometimes, those thoughts and images will reflect genuinely experienced aspects of the event; sometimes, however, they may be memory traces of similar events witnessed in the news or entertainment media. In either case, people may inadvertently generate additional imagery relating to those traces that fits with the experienced event. Critically, over time, those non-experienced thoughts and images may become just as familiar as those that were experienced, increasing the likelihood of source monitoring errors (3, 4).

Several lines of converging evidence now document that people are susceptible to memory distortion for experiences of trauma, regardless of whether that trauma is a single event (such as a motor vehicle accident) or a sustained stressful experience that might involve multiple trauma types (such as military deployment). One line of research examines the impact of an external source of suggestion, such as suggestive questioning, on peoples' memories for surprising, traumatic, and public events [e.g., (7, 8, 10–17)]. For example, Nourkova et al. (11) convinced people that they had witnessed a non-existent wounded animal in the film footage of the Moscow apartment bombings [(10–14); September, 1999]. Similarly, Crombag et al. (8) led participants to believe they had seen the moment an El Al Boeing 747 crashed into an apartment building, killing 43 people. Although there was no film of the crash, there was considerable media coverage of the aftermath. Indeed, participants often elaborated on the original suggestion (e.g., the plane was already burning when it crashed). Importantly, and in line with the SMF, Crombag et al. opined that traumatic events might be *more* susceptible to memory distortion than benign events because they typically provide more avenues for mental imagery, which can make source monitoring more difficult, and thus source monitoring errors more likely to occur (3, 4).

A second line of research with real victims of personal trauma examines how they remember their traumatic experience over time. These studies demonstrate that such victims often come to report being exposed to traumatic events they did not initially report experiencing (9, 18–25). For example, Southwick et al. (1) asked Desert Storm veterans at 1 month and 2 years after their return from service, whether certain events occurred during that service (e.g., sniper fire). They found 88% of veterans changed their response to at least one event; 61% changed more than one. Importantly, the majority of those changes were from "no, that did not happen to me" to "yes, that happened to me," what has been termed "memory amplification." How can we explain the change? One possibility is that the veterans were also exposed to external sources of suggestion during the intervening period. Additionally, the intrusive re-experiencing symptoms that typically accompany trauma exposure may have stimulated the production of other thoughts and images related to war-time experiences. In support of this possibility, Southwick et al. reported that the more severe the veteran's re-experiencing symptoms, the more likely they were to exhibit memory amplification [see also Ref. (19, 21, 23)].

Our research provides a third line of evidence for the existence of traumatic memory distortion and the role mental imagery plays in that distortion. In our research, we have systematically examined the influence of source monitoring errors using a laboratory-based trauma analog. In one study, we showed participants a series of film clips depicting a fatal car accident (2). Each clip was separated by 2 s of blank screen, which allowed us to remove some scenes from the film. The next day participants returned to the laboratory for a surprise recognition memory test – comprised of scenes they had seen the day before ("old"), scenes we had removed from the original film ("missing"), and scenes depicting other road settings ("new"). The participants' job was to identify whether each clip was old or new and how confident they were in that decision. Importantly, we divided the missing clips into *cruxes* (scenes critical to the film's meaning; e.g., a child screaming for her parents) – which were also rated as the most traumatic scenes – and *non-cruxes* (more peripheral scenes; e.g., the arrival of a rescue helicopter). We found that participants were very good at recognizing what they had and had not seen. However, they also falsely claimed to have seen 26% of the missing clips, or an additional 13.5 s of the event. Moreover, participants were more likely to falsely remember seeing the cruxes, the more traumatic scenes, compared to the non-cruxes.

Drawing on the SMF, we proposed that there are at least two, possibly related, routes to the pattern of memory distortion we observed, both of which rely on mental imagery (3, 4). First, we argued that it is possible participants recognized that there were gaps in the film and intentionally generated imagery – that echoed the content of the missing clips – to fill those gaps (4). Second, we argued that it is also possible participants did not notice the gaps in the film and instead their intrusive thoughts and images about the film happened to echo the content of the missing clips [e.g., (19)]. Of course, these two routes are not mutually exclusive: both rely on source monitoring failures, both may involve conscious and unconscious elements, and therefore both are likely to play a role in distorting participants' memories for the film. Nevertheless, we argued that if source monitoring errors were responsible for the memory distortion we observed, we should be able to manipulate the likelihood of those errors by encouraging different approaches to source monitoring.

Therefore, in a subsequent study, using the same film, we first drew attention to the gaps at encoding and then attempted to induce different approaches to source monitoring (26). Specifically, some participants saw visual static – just like the "snow" on an untuned television – for the duration of the missing clips. This static clearly identified that the film was missing particular scenes. We compared the memory performance of those participants to the performance of participants who simply saw our original film, which did not highlight the missing scenes (2). Here, we found that highlighting the missing scenes had no impact on the pattern of memory distortion we observed.

However, we included two further conditions – where participants also saw visual static highlighting the missing scenes – to test the impact of different source monitoring strategies. First, we warned some participants before encoding that we had removed some scenes. The purpose of this warning was to encourage a more systematic source monitoring approach – a slower, more deliberate and controlled, style – when these participants came to evaluate what they had and had not seen at test. Indeed, basic memory research demonstrates the effectiveness of similar advanced warnings [e.g., (27, 28)]. Our results suggested the warning worked: warned participants exhibited less memory distortion than unwarned participants. Second, we also included a condition where participants saw a brief written description of the missing scenes overlaying the visual static. The purpose of this label was to specify the missing content so that participants could imagine what occurred between the depicted scenes. Related research has shown that the more detail people are given about a scenario, the easier it is for them to imagine that scenario (4, 29). Thus, we expected that if participants did generate mental imagery that fitted with the label, then the missing scenes would feel more familiar at test and participants would rely on a more heuristic – more rapid, non-deliberative, less controlled – source monitoring approach (4). Here too, the data supported our predictions: people exhibited more memory distortion when they saw a label specifying the missing content. Taken together then, our research provides indirect evidence that mental imagery plays a role in traumatic memory distortion.

Of course, there are significant methodological limitations to keep in mind when evaluating all laboratory-based research on traumatic memory. Although laboratory research can provide critical insights as a result of tightly controlled experimental designs, it is frequently a poor analog for an event that meets the criteria described in the Diagnostic and Statistical Manual of Mental Disorder's (5th Ed.) Criterion A (30). For example, the stress and trauma-induction procedures researchers employ cannot ethically or morally reach the levels people experience in a real-world trauma. Moreover, participants are typically "witnesses" to an experience rather than the "victim" of the experience, the duration of the events is limited and delays are often truncated to meet experimental demands.

Nevertheless, we believe that developing a better understanding of source monitoring errors and the role of mental imagery in traumatic memory distortion should be a research priority. How people exposed to trauma remember and misremember aspects of their experiences in ways that influence their recovery is both theoretically and practically important. For example, the touted correlation between the likelihood a person will develop PTSD and the severity of their experienced trauma is largely based on observed correlations between self-reported current symptoms and retrospective reports about the severity of the trauma [e.g., (1, 19)]. That relationship – likely distorted and exacerbated by a person's current memory for the event – could well be masking other, better predictors of PTSD. Thus, to determine the true psychological impact of trauma, and therefore the best ways to treat maladaptive reactions to that trauma, we must know to what extent memory (in)accuracy plays a role. Hence, we will continue to investigate the extent, causes, and triggering conditions of errors in memory for traumatic experiences.

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Involuntary autobiographical memory chains: implications for autobiographical memory organization

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Sometimes when we unintentionally or intentionally retrieve a memory of a past episode, we experience one or more additional memories, which spring to mind quickly and uncontrollably. For example, one might involuntarily remember seeing mummies in the British Museum, and this memory could in turn trigger a memory of seeing the Egyptian collection at the natural history museum in New York City. Known as an involuntary autobiographical memory chaining (1, 2), this memory phenomenon is probably common in everyday life when we are engaged in controlled, voluntary recall of the past, and when memories just come to mind unintentionally [Ref. (1–3); see also (4–6), for reviews of involuntary remembering]. Involuntary memory chaining has not been researched as much as singly experienced involuntary memories (i.e., the case where an involuntary memory does not result in additional involuntary retrievals), so comparatively little is known about them. However, studies that have focused on involuntary memory chains have turned up findings with interesting implications for theories of autobiographical memory organization (7, 8). In this article, I review how these findings have helped develop a theory of autobiographical memory organization that posits that episodic memories are organized as conceptual classes of events.

I have argued that involuntary memory chains are the products of spreading activation in the autobiographical memory system (2, 6). Thus, when a memory is activated in the autobiographical memory system (e.g., as a result of voluntary or involuntary retrieval), this activation spreads to other memories in its associative network. Normally, these types of activations do not come into consciousness because they are either too weak or irrelevant to one's current cognitive activity. However, when activations are strong enough, or relevant, they come into consciousness where they are experienced as chained involuntary memories.

Although we have no firm evidence that involuntary memory chains are spreading activations, there are a number of reasons why we should see this as a good, tentative explanation. For one, there is good reason to believe that like semantic memories, memories in the autobiographical memory system are networked (or connected) and therefore capable of activating one another. Thus, like semantic memory, once memories are activated in autobiographical memory, there is an obligatory spread of activations to neighboring, related memories within a network. Evidence that such an architecture exists in autobiographical memory can be found in priming studies [e.g., Ref. (3, 9, 10)]. For example, Mace (3) and Mace and Clevinger (8) have shown that activating autobiographical memories in voluntary recall task primes the subsequent recall of related memories at some future point.

Additionally, there is good reason to doubt that involuntary memory chains are driven by some sort of alternative retrieval process other than spreading activation. For example, the most obvious alternative explanation is that a single retrieval cue simply triggers more than one memory, and since both memories cannot come to mind at once, they are experienced in sequence as a chain of memories. If this view were true, then memories in involuntary memories chains should almost always be related to the retrieval cue that trigger the first memory, however, just the opposite is true [see Discussion in Ref. (2)].

Viewing involuntary memory chains as an automatic retrieval process akin to spreading activation has led us to assert that the products of involuntary memory chains (i.e., the memories found in a chain) are reflective of the underlying organization of autobiographical memory (7, 8). Thus, examining their output should prove elucidating to the study of autobiographical memory organization.

To date, the output of involuntary memory chains has been observed in two types of settings, in the laboratory, where participants reported involuntary memory chains, resulting from voluntary retrievals, and in naturalistic settings, where participants reported involuntary memory chains, resulting from involuntary retrievals (i.e., involuntary memories experienced in everyday life). In both laboratory and naturalistic measures, involuntary memory chains have consistently exhibited two types of associative forms: general-event associated memories or conceptually associated memories.

In general-event associations, memories in a chain come from the same general (or extended) event period [i.e., a general memory such as the night at the opera, a trip to London; or a summary memory, repeated events such as Sunday walks in the park, see Ref. (11, 12)]. These memories appear to be connected by the larger general or summary event, and therefore, are typically temporally proximate (e.g., spanning the same day, evening, week, month, etc.). In contrast, conceptual associations are associated by their overlapping content. For example, they commonly involve the same people, objects, activities, or other common themes (such as work or school). Conceptually associated memories can span any time period, and therefore, temporality does not appear to be their main organizing principle.

Analyses of the relative proportions of conceptually associated and general-event associated involuntary memory chains have highlighted the importance and dominance of conceptually associations. In both laboratory and naturalistic measures, conceptually associated memories have significantly outnumbered general-event associated memories, with conceptual associations usually exceeding 80% (1, 2, 7, 8). Other analyses and measures have also revealed conceptual association dominance [see Ref. (7, 8)], and while these analyses alone could make a strong case for the idea that episodic memories are contained mostly in conceptual associative networks, retention interval analyses of conceptually and general-event associated memories have made a more cogent case.

In Mace et al. (8), involuntary memory chains were divided into three retention intervals, chains with memories up to a year old, 1–9 years old, and over 9 years. Analyses of conceptually and general-event associations showed the two categories were equal when memories were up to a year old (53% conceptual, 47% general event), but their relative proportions changed dramatically when memories were over a year old (1–9 years, 77%, conceptual, 23%, general event; over 9 years, 85%, conceptual, 15%, general event). These data make a stronger case for a basic conceptual organization than the simpler data presented above because they show that conceptual associations do not just simply outnumber general-event associations because there are more of the former type of experiences, but because the basic architecture fundamentally favors forming and maintaining conceptual consolidations.

For example, let us consider this proposition with memories of being at a wedding. When one remembers an episode from a wedding they had recently attended (e.g., within the last few weeks or months), this memory has a 50% chance of triggering others episodes from that same event, and a 50% chance of triggering memories of having attended other weddings. However, when one recalls that same episode some time later (e.g., 2 years later), it now has an 80% chance of triggering memories of other weddings. According to the conceptual organization account, this happens because memories of the wedding initially consolidate together (as a general-event network of the wedding), as well as with memories of other weddings (joining the existing conceptual network for wedding memories). However, as time passes, some or all of the episodes from that memory are forgotten, leaving the connections to other wedding memories. Thus, events always consolidate into their conceptual class (e.g., all wedding memories), and it is these connections (or associations) that endure over time, not the temporal ones (i.e., memories from a particular wedding). In this account, general-event memories are lost quickly because they have a limited, short-term relevance. So, in the short-term it may be equally important to remember episodes from a wedding, or those of other weddings, while in the long term, it is more important to remember that one has been to various weddings.

In sum, then, these various finings showing the dominance of conceptual associations have led us to assert that autobiographical memories are organized primarily, or fundamentally, along conceptual lines. While temporal associations are clearly a part of autobiographical memories organization [see Ref. (3, 8)], they are not retained over time as conceptual associations are. It is important to emphasize that we are not claiming that autobiographical memories are a collection of abstract or categories association as in semantic memory. Instead, our use of the term conceptual refers to, for lack of a better term, experiential type concepts, such as people, places, locations, activities, and so forth. Thus, events coalescence according to their many and varied experiential similarities [see data in Ref. (8)].

In closing, the study of involuntary memory chains has been informative to the study of autobiographical memory organization. While I have presented some interpretations of the findings, clearly there are more, and more work is certainly needed to fully flesh them out. I have also argued (here and elsewhere) that involuntary memory chains are spreading activations that are normally unconscious, but for some reason they become conscious. This idea is interesting in its own right, and research that could elucidate why such activations sometimes surface into consciousness is likely to be informative to understanding involuntary retrievals and other areas of cognitive science and mental experience.

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Mental imagery affects subsequent automatic defense responses

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Automatic defense responses promote survival and appropriate action under threat. They have also been associated with the development of threat-related psychiatric syndromes. Targeting such automatic responses during threat may be useful in populations with frequent threat exposure. Here, two experiments explored whether mental imagery as a pre-trauma manipulation could influence fear bradycardia (a core characteristic of freezing) during subsequent analog trauma (affective picture viewing). Image-based interventions have proven successful in the treatment of threat-related disorders and are easily applicable. In Experiment 1, 43 healthy participants were randomly assigned to an imagery script condition. Participants executed a passive viewing task with blocks of neutral, pleasant, and unpleasant pictures after listening to an auditory script that was either related (with a positive or a negative outcome) or unrelated to the unpleasant pictures from the passive viewing task. Heart rate was assessed during script listening and during passive viewing. Imagining negative related scripts resulted in greater bradycardia (neutral-unpleasant contrast) than imagining positive scripts, especially unrelated. This effect was replicated in Experiment 2 ($n = 51$), again in the neutral-unpleasant contrast. An extra no-script condition showed that bradycardia was not induced by the negative-related script, but rather that a positive script attenuated bradycardia. These preliminary results might indicate reduced vigilance after unrelated positive events. Future research should replicate these findings using a larger sample. Either way, the findings show that highly automatic defense behavior can be influenced by relatively simple mental imagery manipulations.

Keywords: imagery, freezing, bradycardia, heart rate, rescripting, immobility, passive viewing paradigm, memory

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Introduction

Like animals, humans freeze, fight, or flight under threat. Fight-flight reactions, characterized by heart rate acceleration (tachycardia), increased muscle tonus and action, are well known and well studied in general as well as in relation with emotional disorders. For example, panic is associated with uncoordinated behavior (an uncoordinated fight-flight response) during imminent and inescapable threat (1, 2). Moreover, the relevance of flight behavior in the etiology of threat-related disorders is generally acknowledged, which is reflected in the use of exposure as a major component in the treatment of anxiety disorders.

Although freezing behavior is well studied in animal literature, interest in human immobility responses has grown since the last decade only. Like fight-flight, freezing is part of the defensive system, although it is physically – and proposed functionally – different. Freezing is characterized by heart rate deceleration (bradycardia), increased muscle tonus, and immobility (3). It is associated with optimal perceptual and attentional processing and prepares for rapid action, thereby increasing survival chances (4–6).

Like other defense behaviors (see, for example, avoidance), immobility responses may also become dysfunctional. For example, in humans, retrospective self-reports of peri-trauma immobility suggest an association between peri-trauma immobility responses and the development of psychiatric symptoms, such as posttraumatic stress disorder [PTSD; e.g., Ref. (7)]. Trauma-analog experiments with healthy participants – using observational quasi-experimental designs (8) and experimental manipulation designs (9) – also found that self-reported immobility and immobility manipulations during an aversive film resulted in increased intrusive memories of the film. Moreover, retrospective reports of peri-trauma immobility were related to decreased treatment effect in PTSD patients (10). Clearly, more research is needed in this relatively under-explored area. Findings are relevant, but most studies used retrospective self-report indicators of immobility responses, thereby relying on memory, which is known to be affected by factors like forgetting, over-reporting, and erroneous attribution of symptoms. The use of objective indicators of freezing could solve some of these problems.

In the past decade, freezing responses have also been elicited in a laboratory setting using objective markers of freezing (heart rate reductions and decreases in body sway). Freezing indeed occurred when participants were viewing highly unpleasant stimuli, such as pictures of corpses and threatening animals (11, 12), angry faces (13), or unpleasant films (14). The passive viewing task is considered a good analog for post-encounter threat responses, as participants are confronted with threatening stimuli while not being able to escape the situation [albeit by instructions and social compliance (15)]. Cognitive factors may contribute to perceived uncontrollability of feeling trapped (16). As findings have been quite consistent not only across different stimuli but also across different research groups, the paradigm seems solid for provoking freezing-like responses.

In conclusion, as peri-trauma immobility may play a role in the development and treatment of emotional disorders, a next step would be to examine whether these automatic immobility responses could be influenced. Apart from providing tools for interventions, this would also enlighten some of the mechanisms associated with automatic defense responses. This study, therefore, examined whether automatic immobility responses (freezing) can be influenced in an analog setup.

Mental imagery refers to the experience of perception without concurrent sensory input (17). It is highly relevant with respect to PTSD, with vivid intrusive images as a key component. Moreover, mental imagery is used successfully in the main treatment strategies for PTSD. For example, in imaginal exposure (18), patients have to relive (i.e., vividly imagine) the traumatic event repeatedly, until anxiety responses habituate. Another strategy, imagery rescripting, also uses the trauma images as a basis for change. Here, patients have to mentally imagine the event, after which they are asked to intervene and alter the ending in a way that they would prefer [e.g., Ref. (19, 20)]. Here too, it is of great importance that the patients are depicting the unfolding of the event as vivid as possible, meaning that they have to create vivid mental images. Except for healthy effects of expressing inhibited responses the effects of imagery rescripting are considered to result from changing the meaning of the original event (21), or changing the UCS-UCR representation in memory (22). Although, clearly, this mechanism takes place after the event has happened, possibly, creating a different stage before the event will happen will also proactively change the meaning of the event.

The success of these two treatments may lay in the fact that the original event becomes very real by activating mental images, and as a consequence, basic alterations can be made in the memory of that event and its associated emotional responses. Brain areas activated during mental imagery greatly overlap with those activated during processing of real sensory information (23). Images were also more confused with reality than verbal thoughts (24). Mental imagery has been shown to be strongly related to emotional processing (25, 26). Mental imagery has even been shown to affect subjective feelings associated with a specific event (27) and influence future behavior (28–30). Indeed, mental imagery also affects physiological responses, such as heart rate and skin conductance (31, 32). It proved to promote fear potentiated startle as well (33).

In sum, mental imagery is widely used in the treatment of PTSD. It has shown to strongly elicit emotional responses including changes in heart rate. However, it has not been established whether it can also change physiological reactions to a later event. It is possible that negative imagery activates the defense motivational system, thereby changing automatic responses to subsequent threat. It may change the meaning of or set a stage for a subsequent event (34, 35). This study, therefore, examined whether manipulations of mental imagery before picture viewing could alter automatic autonomic responses during subsequent picture viewing. It was hypothesized that imagining a script that was related to unpleasant pictures that would later be shown, would affect automatic threat responses during picture viewing. We expected increased bradycardia during subsequent unpleasant picture viewing if the script had a negative outcome (negative related script; NR), but not when the script had a positive outcome (positive related script; PR). A positive unrelated (PU) script was used as an extra control condition in order to distinguish mood induction and changes in attribution as explanatory factors. That is, the PR script could activate a general positive mood or approach system, thereby hindering defense responses, such as bradycardia (i.e., similar effects in PR and PU conditions). Alternatively, the PR script could change the meaning of or set the context for the subsequent negative event (pictures; i.e., different effects in PR and PU conditions). For instance, participants in the PR condition would perceive the unpleasant pictures as negative but "controllable," whereas those in the NR condition would perceive them as "uncontrollable" and those in the PU condition would be unprepared. Such distinct effects were found previously after administration of PU and PR post-"trauma" imagery interventions (34). Possibly, similar changes in meaning can also be achieved "proactively" by PR imagery by providing an alternative context before the actual event takes place. We measured changes in self-report anxiety and controlled for them in case of significant condition differences, in order to check whether the effects of the scripts would be the result of changes in mood or rather changes in attribution.

Experiment 1

Method Experiment 1

Participants

A total of 43 students (two males) from Leiden University took part in the study. Participants received course credits or cash money for their participation. Age ranged from 18 to 26 years, with a mean age of 19.7 years (SD = 1.8). Participants were randomly assigned to the script conditions: PU ($n = 13$), PR ($n = 13$), and NR ($n = 17$). As a result of technical problems with the polar band system, heart rate assessments failed for 1 participant, leaving 16 participants in the NR condition. Written informed consent was obtained from all participants.

Material/Measures

Heart rate

Heart rate was recorded with a Polar s810 Heart rate Monitor. The polar band was placed at the height of the sternum. The signal was converted to beats per minute (BPM) and heart rate variability. The raw heart rate data were processed and checked with use of the Polar Precision Performance SW v.4. The Polar s810 proved valid to measure R–R intervals (36).

Subjective anxiety

Participants rated subjective anxiety/distress on a scale from 0 (not at all) to 10 (extremely).

Scripts

Three different scripts with a similar setups and similar phrases were created for this study. The PU script was not related to any of the pictures that were presented in the passive viewing task. It described how the participant takes a walk through a sunny town, thinking about where to have a coffee and hearing Summer-sounds. He/she sits down to have a drink, while people nod friendly. The PR and NR scripts were both related to the unpleasant pictures; these scripts describe the "story" of an injured victim of physical violence while the pictures showed injured and mutilated people resembling that victim. The PR script had a positive outcome. It described how the participant walks through town when hearing a loud scream. The participant runs toward the sound and finds a seriously injured person, while another person is running away. The participant responds quickly and immediately calls 911, staying with the victim until the parametrics arrive. The victim survives the attack because of this adequate action, and his family is very grateful. The NR script was similar to the PR script except that the outcome was negative. That is, after hearing the scream and running toward the event, the participant is scared and stiffens. When the participant realizes that the offenders have gone, he/she cannot make a 911 call because he/she forgot to bring his/her phone. The participants want to scream for help but are not able to make a sound. The injured person subsequently dies. The PU, PR, and NR scripts had a duration of 64, 77, and 60 s, respectively.

Script rating questionnaire

Participants rated their own script on vividness (How vivid was your script-induced imagery?), valence (How pleasant was the script?), and arousal (How arousing/exciting was the script?) from 0 (not at all) to 10 (extremely).

Passive Viewing Task

Pictures

Three sets of 20 stimuli were selected from the International Affective Picture System[1] [IAPS (37)]. We used the same pictures as Hagenaars et al. (12), in order to facilitate the interpretation of the results in terms of defensive freezing. The neutral set comprised 20 pictures of neutral objects. The pleasant set comprised 20 pleasant pictures depicting people in action (e.g., in a roller coaster or doing sports). The unpleasant set consisted of 20 unpleasant pictures depicting physical violence and mutilation.

Picture presentation

Pictures were presented in blocks containing 20 pictures of the same valence that were shown without inter trial interval. The pictures within each block were randomized, and block order was counterbalanced. A 10-second black screen preceded the first block, and 8-second black screens were presented between the subsequent blocks. Stimuli were presented full screen at eye-height on a 17-inch computer screen, approximately 1 m in front of the participant. The experiment took place in a dimly -lit room. The total viewing time was 3 min and 26 s.

Procedure

Participants completed a list with some basic questions [name, gender, age, and payment-type (course credits or cash money)] at arrival in the lab after which the Polar Heart Rate Monitor was placed. The participants then listened to either PU, PR, or NR script. Scripts were presented in auditory form and participants wore headphones when listening to the scripts. Participants were instructed to close their eyes and listen attentively to the script and imagine the situation (read in the first person) as vividly as possible. Closing eyes diminishes other incoming visual information, so this way they could optimally focus on the auditory information. There was a 6-s delay before the script started so that the participants had time to concentrate and prepare for the mental imagery. Participants rated their script and level of subjective anxiety after the script ended, after which the passive viewing task was started. They again rated their anxiety after the passive viewing task, after which the Polar Heart Rate Monitor was taken off.

Analyses

Repeated measures Analyses of Variance (rm ANOVA) were done with valence (neutral, pleasant, and unpleasant pictures) as a within factor, script condition (PU, PR, and NR) as between

[1]Following IAPS catalog numbers for pictures are used in this study: neutral: 7000, 7002, 7004, 7006, 7009, 7010, 7020, 7025, 7030, 7031, 7035, 7040, 7050, 7052, 7060, 7080, -7090, 7150, 7175, 7211; Pleasant: 8021, 8032, 8034, 8040, 8041, 8090, 8161, 8186, 8190, 8192, 8200, 8210, 8300, 8370, 8400, 8460, 8465, 8467, 8470, 8620; Unpleasant: 3000, 3010, 3030, 3051, 3053, 3060, 3061, 3062, 3063, 3064, 3069, 3080, 3100, 3102, 3110, 3130 3140, 3150, 3261, 3400.

factor, and heart rate as dependent variable. As fear bradycardia is a within-subjects relative response (i.e., a decrease in heart rate in response to unpleasant pictures relative to neutral or pleasant pictures), we calculated contrast scores for *post hoc* analyses [see also Ref. (12)]. All tests were two-tailed except for one-tailed tests for the main effects of unpleasant pictures on heart rate, because of clear the directional hypothesis (bradycardia) as well as the fact that opposite effects would not result in different actions (38). The significance level is set at $\alpha = 0.05$. Given the small sample size, results with $p < 0.10$ are considered a trend.

Results Experiment 1

Manipulation Checks

Physiological measures during audio script

There were no differences between conditions in mean HR during listening to the audio script ($F(2, 37) = 2.04$, $p = 0.14$, $\eta_p^2 = 0.10$, see **Table 1** for descriptives).

Script ratings

A MANOVA with vividness, valence and arousal as dependent factors revealed differences between conditions in script ratings ($F(6, 78) = 7.40$, $p < 0.001$, $\eta_p^2 = 0.36$). Most importantly, conditions differed on valence ($F(2, 40) = 40.05$, $p < 0.001$, $\eta_p^2 = 0.67$) but not on arousal ($F(2, 40) = 0.87$, $p = 0.42$, $\eta_p^2 = 0.04$). The PU script was rated as more pleasant than the PR and NR scripts (both p's < 0.001), and the PR script as more pleasant than the NR script ($p = 0.02$). Conditions also differed on vividness ($F(2, 40) = 5.65$, $p = 0.01$, $\eta_p^2 = 0.04$), with the PU script being rated as most vivid (PR: $p = 0.01$; NR: $p = 0.003$) and no differences between the PR and NR conditions ($p = 0.80$).

Subjective anxiety

A rm ANOVA with time as a within factor and condition as a between factor showed a significant main effect for time ($F(1, 37) = 4.19$, $p < 0.05$, $\eta_p^2 = 0.10$), indicating anxiety increased from pre- to post-passive viewing. There was a trend for the time × condition interaction ($F(2, 37) = 2.79$, $p = 0.07$, $\eta_p^2 = 0.13$), indicating increases in anxiety tended to differ across conditions (see **Figure 1**). *Posthoc* analyses showed that increases in anxiety in the PU condition were greater than in the PR and NR conditions ($p = 0.05$ and $p = 0.04$, respectively). Because of these differences, pre- to post-increases in subjective anxiety were entered in the heart rate analyses as a between-subject covariate[2]. PR and NR conditions did not differ in anxiety increase ($p = 0.96$).

TABLE 1 | Heart rate during scripted imagery, script ratings and subjective anxiety in Experiment 1 ($n = 42$).

	Positive unrelated, $n = 13$	Positive related, $n = 13$	Negative related, $n = 16$
Heart rate during script	79.7 (3.3)	75.2 (3.0)	71.1 (2.7)
Script rating			
Vividness**	8.39 (0.26)	7.39 (0.26)	7.29 (0.23)
Valence***	9.00 (47)	5.08 (0.47)	3.53 (0.41)
Arousal	6.00 (0.54)	7.00 (0.54)	6.65 (0.48)
Anxiety increase*	1.67 (2.50)	0.08 (1.62)	0.27 (1.53)

Anxiety increase = ratings post passive viewing minus ratings pre passive viewing.
$^*p < 0.05$.
$^{**}p < 0.01$.
$^{***}p < 0.001$

Differences in heart rate responses

A rm ANOVA showed a significant main effect of valence ($F(2, 70) = 5.56$, $p = 0.006$, $\eta_p^2 = 0.14$) with heart rate being significantly lower for unpleasant than for neutral ($p = 0.005$, one-tailed) blocks and a similar trend for the pleasant–unpleasant contrast ($p = 0.08$, one-tailed). This effect resembles the effect of Hagenaars et al. (12), who used the same task with the same pictures, suggesting a similar freezing was elicited. There was a trend for the valence × condition interaction ($F(4, 70) = 2.25$, $p = 0.07$, $\eta_p^2 = 0.11$). MANOVAs with the neutral–unpleasant and pleasant–unpleasant contrast scores as dependent variables and condition as fixed factor, showed greater heart rate decreases in the NR condition than in the PU condition in response to unpleasant versus neutral pictures ($p = 0.02$) and a similar trend for the NR relative to the PR condition ($p = 0.06$). There was no difference between PR and PU conditions ($p = 0.49$). Heart rate decreases for unpleasant versus pleasant tended to be greater for the NR relative to the PU condition ($p = 0.08$), but not relative to the PR condition ($p = 0.50$). There were no differences between the PR and PU conditions for the pleasant–unpleasant contrast ($p = 0.28$).

Discussion Experiment 1

The purpose of this study was to test whether automatic defense responses can be affected by pre-trauma mental imagery. Indeed, participants that imagined a picture-related negative scene with negative outcome experienced greater bradycardia when subsequently viewing unpleasant pictures (relative to neutral pictures) than those imagining a picture-related scene with a positive outcome, or those that imagined a PU scene. This was true for the unpleasant–neutral contrast. Moreover, there was no difference between the PR and PU groups.

The data suggest that automatic defense responses can indeed be affected by a simple and brief imagery manipulation. As both PR and PU conditions showed less bradycardia than the NR condition, it seems most likely that the two positive scripts induced a general positive mood or primed the defensive system in a positive bias rather than specifically changing the meaning of the subsequent event (unpleasant pictures). This is not in line with other findings that indicated a superior effect for trauma-related imagery with a positive outcome over non-specific positive imagery, which suggest alterations in attributions (34). However, note that participants in the NR and PU conditions tended to differ with respect to heart rate changes in the pleasant–unpleasant contrast, while NR and PR conditions did not. Speculatively, this could indicate that "attribution" processes did indeed differ for PR and PU conditions, but low power hindering the PR–PU comparison to reach significance.

In addition, both positive conditions could be effective and at the same time associated with a different mechanism. The fact that anxiety increased from pre- to post-passive viewing in

[2] Analyses without anxiety increases as a covariate yielded similar results.

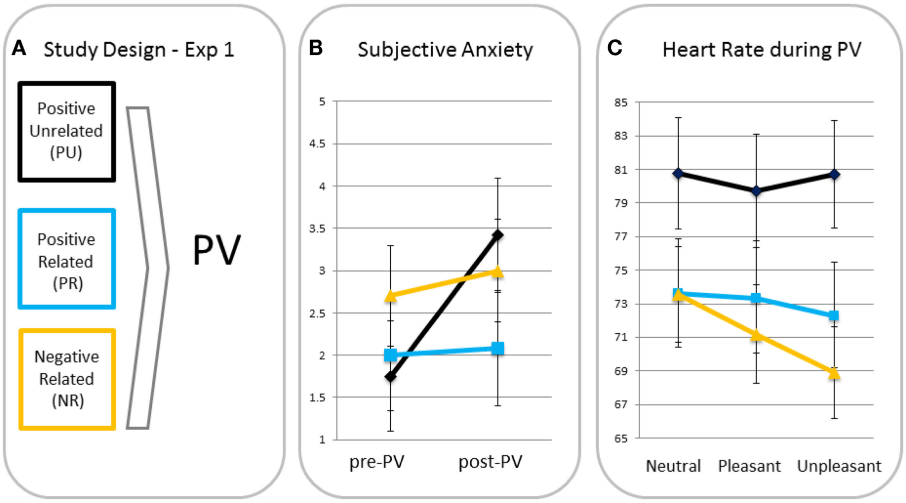

FIGURE 1 | Study design (A), subjective anxiety pre- and post-passive viewing [PV; (B)] and heart rate in response to neutral, pleasant, and unpleasant pictures (C) for participants in the positive unrelated (PU), positive related (PR), and negative related (NR) script condition.

the PU but not in the PR condition might suggest that this is indeed the case. Future studies should therefore replicate these findings with different tasks or measures, in order to examine whether general positive imagery (general positive mood) and specific positive imagery (changing the meaning of the event) tap into similar underlying mechanisms, for example, using memory tasks (e.g., cued recognition to assess memory accessibility) or symptom checks (e.g., intrusive images or negative cognitions about the world or self). Disentangling these working mechanisms is highly relevant, as they may have distinct short-term and long-term effects. For example, general positive imagery not affect long-term processes because it does not target the stressful event [see, for example, Ref. (34)]. In a treatment-context, this would increase relapse rates.

Another remarkable finding is that anxiety increases from pre- to post-picture viewing were greatest for the participants that listened to a PU script. One possible explanation could be that those were the participants that were least "prepared" for watching the unpleasant pictures, and thus, they felt more overwhelmed than the other groups. This may be in line with earlier results that showed that freezing was enhanced in traumatized but healthy participants (12). Our findings may also indicate that individuals become more cautious after having experienced stress. Speculatively, this may be an effective evolutionary strategy and underscores the relevance of freezing as a state of increased alertness (15). Interestingly, there were no differences in anxiety increase between the PR and NR conditions. Possibly, the relatedness may be of more relevance than the actual outcome of the script in terms of being "prepared." Note that it is not uncommon that analog trauma does not greatly increase subjective anxiety levels [e.g., Ref. (39)], possibly indicating that the deviating result is in the PU condition.

In addition, although mental imagery had an effect on subsequent automatic responses to stress, the direction of the effect is not clear. The findings can be interpreted in two ways: (1) negative imagery elicits stronger freezing responses or (2) positive imagery reduces freezing responses. In other words, it is not clear what the "baseline response" would be. Experiment 2 was set up to address this question by replacing the PU condition by a no imagery condition (NoI).

Experiment 2

Method Experiment 2

Participants

A total of 51 students from Leiden University took part in the study. Participants were randomly assigned to the script conditions and received course credits or cash money for their participation. Three participants were excluded from the analyses as being age-outliers (>3 SDs above the mean; $n = 2$) and bradycardia-outlier (>3 SDs above the mean; $n = 1$). As the heart rate signal of several participants showed many artifacts, all heart rate analyses were done by two independent persons. Participants were excluded if these analyses did not match ($n = 6$), leaving a total sample of 42 (10 males): NoI ($n = 15$), PR ($n = 14$) and NR ($n = 13$). Mean age was 23.2 years (SD = 2.4).

The design was exactly the same as in Experiment 1, with just one difference: the PU imagery manipulation was replaced by a group that received NoI (this group started the passive viewing task after completing the basic questions and placements of the electrodes). Also, heart rate was recorded continuously using the BioPack system (MP150: BIOPAC systems, Inc., CA, USA) with three matching Ag–AgCl (silver–silverchloride) electrodes. The signal was processed offline using Acknowledge software (BIOPAC systems, Inc.), and heart rate was calculated from the resulting interbeat interval (IBI).

Like in Experiment 1, all statistical tests were two-tailed except for the one-tailed testing of main effects of valence on heart rate. The significance level is again set at $\alpha = 0.05$ and trend level at $\alpha = 0.10$.

Results Experiment 2

Manipulation Checks

Physiological measures during audio script

Like in Experiment 1, there were no differences between conditions in mean HR during listening to the audio script ($t(25) = -0.16$, $p = 0.87$; see **Table 2** for descriptive statistics).

Script ratings

Like in Experiment 1, independent *t*-tests revealed no differences in vividness ($t(24) = 0.17$, $p = 0.87$) and arousal ratings ($t(24) = 0.25$, $p = 0.80$) between PR and NR conditions. There was a trend for the valence ratings to be higher in the PR than in the NR condition ($t(24) = 1.95$, $p = 0.06$).

Subjective anxiety

A rm ANOVA with time as a within factor and condition as a between factor showed a significant main effect for time ($F(1, 39) = 11.56$, $p = 0.002$, $\eta_p^2 = 0.23$), indicating anxiety increased from pre- to post-passive viewing. There was no time × condition interaction ($F(2, 39) = 1.61$, $p = 0.21$, $\eta_p^2 = 0.08$), indicating there were no between-condition differences in increases in anxiety (see **Figure 2**). Analyses were, therefore, run without anxiety increases as a covariate[3].

TABLE 2 | Heart rate during scripted imagery, script ratings, and subjective anxiety in Experiment 2 ($n = 42$).

	No imagery, $n = 15$	Positive related, $n = 14$	Negative related, $n = 13$
Heart rate during script	N/A	74.5 (9.9)	75.2 (11.9)
Script rating			
Vividness	N/A	6.86 (1.83)	6.75 (1.22)
Valence*	N/A	3.50 (0.86)	2.58 (1.51)
Arousal	N/A	6.00 (1.57)	5.83 (1.80)
Anxiety increase	0.75 (1.29)	1.50 (1.51)	0.38 (2.10)

Anxiety increase = ratings post passive viewing minus ratings pre passive viewing.
**p < 0.1.*

Differences in heart rate responses

A rm ANOVA showed a significant main effect of valence ($F(2, 78) = 9.44$, $p < 0.001$, $\eta_p^2 = 0.20$) with heart rate being significantly lower for unpleasant than for neutral ($p < 0.001$, one-tailed) and pleasant ($p = 0.001$, one-tailed) blocks. The valence × condition interaction was also significant ($F(4, 78) = 3.62$, $p = 0.009$, $\eta_p^2 = 0.16$) indicating different heart rate changes for the script conditions. MANOVAs revealed that relative to the PR condition, NR ($p = 0.03$) and NoI ($p = 0.002$) conditions showed greater heart rate decreases in response to unpleasant versus neutral pictures. There was no difference in neutral-unpleasant heart rate decreases between the NR and NoI conditions ($p = 0.31$). There were no differences between any of the conditions for the pleasant-unpleasant contrast (all p's > 0.12).

Discussion Experiment 2

Experiment 2 was set up in order to replicate the findings of Experiment 1 and examine whether this effect was driven by the positive or the negative scripts. The findings of Experiment 1 were indeed replicated; for the neutral–unpleasant picture contrast, imagining an event-related script with a negative outcome (NR) induced more bradycardia than the same script with a positive outcome (PR). Moreover, the fact that bradycardia was found for the NoI condition with no differences with the NR condition indicates that this effect is driven by the positive script. The PR script seems to arrest the bradycardia response rather than the NR script increasing it.

Surprisingly, although in pilot studies as well as in Experiment 1 the NR and PR scripts differed on valence, this difference reached a trend level only in Experiment 2. One could conclude the manipulation was not successful. It is indeed remarkable that the ratings

[3] As an extra check, analyses were also done with anxiety increases as a covariate, just like in Experiment 1. Findings are similar to the ones reported here.

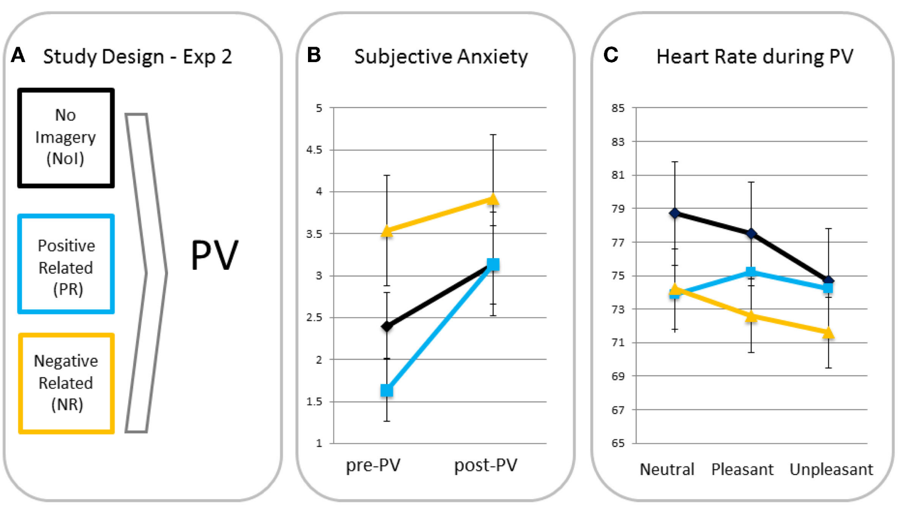

FIGURE 2 | Study design (A), subjective anxiety pre- and post-passive viewing [PV; (B)] and heart rate in response to neutral, pleasant, and unpleasant pictures (C) for participants in the no imagery (NoI), positive related (PR), and negative related (NR) script condition.

for the PR script were this low. Although the PR script describes a negative event, its ending is explicitly positive and rated as such before. There are two conclusions that have to be tested in subsequent studies: the manipulation has failed and the scripts have to be rated positive. One could examine this by comparing the participants in the PR script condition that rate the script as pleasant versus those in the PR condition that rate their script as unpleasant. Another option is that the scripts have implicit effects regardless of their explicit valence.

Note that like in Experiment 1, Experiment 2 revealed no differences in pre- to post-anxiety increases between the PR and NR conditions. Moreover, anxiety did not increase more in the NoI condition either, suggesting that indeed the "surprise-factor" induced the large anxiety increase in the PU condition in Experiment 1.

General Discussion

Both Experiments 1 and 2 show that automatic responses to threat can be altered by mental imagery. Moreover, a simple and brief (approximately 1 min) mental imagery intervention already had an effect on subsequent autonomic responses. Especially relative to neutral pictures, participants responded with attenuated bradycardia after imagining a (non-related) positive script. Previous studies have shown that positive target-related mental imagery affected mood and future behavior (29, 30), but to our knowledge, the effects of target-related imagery on automatic autonomic responses had not been examined before.

Our findings are inconclusive about the relevance of "relatedness" of the mental imagery. Experiment 1 may suggest that mood induction – and not changes in meaning – is causing the effect, as the PU condition does not differ from the PR script condition. However, a rejection of the "relatedness"-hypothesis would be more valid if the positive conditions would not differ in valence, or if the PR condition would have been valenced more positive, which was not the case here. The fact that there was a trend for the PU condition – and not the PR condition – to differ from the NR condition in the pleasant–unpleasant contrast might suggest that relatedness is at least part of the underlying working mechanism. The difference in anxiety increase between the PU and PR condition also points in that direction. This would be in line with treatment studies that have found an additive effect of rescripting the memory over pure exposure in terms of non-fear problems (40). From a treatment perspective, the emotional processing theory posits that memory structures should be activated in order to add new information (41, 42). Possibly, forming a memory structure beforehand including event-specific knowledge may determine how the subsequent trauma information will be embedded (43). Mace (44) also suggests (involuntary) memories can be activated by cueing or "involuntary autobiographical memory chaining" (spreading of activation over related memories). This would suggest that the mental imagery script in our study would be activated automatically when watching the unpleasant IAPS pictures, automatically setting the context for these pictures. Setting a different context or altering cognitive appraisal was indeed found to affect heart rate responses to mutilation pictures as well as intrusion development and voluntary perceptual memory (35, 45, 46). However, our effects may also result from a dose response effect with the PU script being more pleasant than the PR script. Future research should disentangle whether the effects are caused by positive mood induction (impeding vigilance), by changes in meaning, for example, by using a related and non-related positive script with similar valence ratings, or including a negative unrelated-script condition. Experiment 2 cannot enlighten this issue as one positive condition was included only. Another important issue to address in future research is whether the attenuated bradycardia (i.e., less freezing) effects we found in the PU (no context) condition may to some extent explain previous memory findings (35, 47), as theoretically, automatic freezing responses have been linked to enhanced attentional and sensory processing (15).

Interestingly, one could conclude from Experiment 1 that freezing is indeed enhanced after negative imagery with the negative script condition being different from the two positive conditions, at least for the neutral–unpleasant contrast. However, the results of Experiment 2 are not in line with this conclusion. Actually, participants in the NoI condition also showed a freezing response, replicating previous findings (11, 12, 14). This is interesting because it may indicate the relevance of bradycardia or freezing in response to negative stimuli. That is, the fact that participants in the NoI condition also showed bradycardia in response to the negative pictures (Experiment 2) suggests that freezing was attenuated after an unrelated positive script rather than enhanced after the negative script. Possibly, this is the result of not being prepared for negative stimuli, as the context for these PU participants was positive and relaxed. This is in line with the idea that heart rate reductions are associated with motor preparation and enhanced attention (48) as well as increased risk assessment (49). In this context, the larger increase in anxiety for the PU script condition (Experiment 1) may also indicate a sympathetically driven response like fight/flight in the PU condition. Note that this very well matches the importance of trauma-predictability, with an unpredictable stressor resulting in greater fear and arousal than a predictable stressor (50). That is, the unpleasant pictures may have been more unpredictable for those in the unrelated-script condition, where a general positive context was induced.

Our results do not mean that decreased heart rate may be more functional. Responses in all conditions may have been adequate: Bradycardia may be functional in participants that are alert to danger (because of the imagery in the PR and NR conditions or because of the general experimental instructions warning for unpleasant pictures in the NoI condition). On the other hand, heart rate increases may be functional when one is surprised or confronted with unpredicted negative material and action is needed. Our results are in line with a previous study showing freezing was attenuated in healthy participants with no prior aversive event, whereas those with one or more aversive events showed freezing (12). Note that these were all healthy participants, and enhanced freezing may indicate preparedness and/or resilience. Interestingly, PTSD patients showed almost immediate heart rate increases in response to unpleasant pictures (51). At first sight, this may seem contradictory to the link between peri-trauma immobility and PTSD that was found in several studies [e.g., Ref. (7)]. However, immobility responses may have a different role in the prediction and maintenance of PTSD. For example, speculatively, increased immobility may predict PTSD by inducing feelings of guilt (52), whereas decreased risk assessment and increased sympathetic activation (hence decreased freezing and increased fight/flight) may act in the maintenance of PTSD. Also, different immobility responses (e.g., freezing versus tonic immobility) may play a distinct role in the etiology of PTSD (3, 14).

Clearly, results should be interpreted with caution, as both Experiments 1 and 2 suffered from power problems. Careful conclusions may be justified though, as the results point in the same direction. Future replication studies are needed with larger sample sizes. Future studies are also merited in order to enlighten the underlying working mechanisms, for example, by using a negative unrelated script or general mood inductions, or by indexing implicit and explicit memory afterwards to examine its relationship with the autonomic responses during threat. Future studies should add a measure of positive mood, which would help in distinguishing alterations in meaning versus mood effects. Finally, including symptom inventories and specific populations would also enlighten underlying mechanisms. For example, imagery rescripting was found to be effective for high anxiety individuals mostly and autonomic responses to mutilation pictures were attenuated after a safety signal for participants with high positive affect only (46, 53). However, as autonomic responses are important predictors for PTSD development, this might be a first step in implementing mental imagery in populations that will encounter traumatic events such as military, police, and the fire brigade. Note, though, that at this stage it is not clear what the most beneficial type of imagery would be: an unrelated script inducing attenuated freezing and anxiety or a related (negative) script that induces freezing. Future studies should address that issue.

In sum, interventions based on mental imagery have been proven effective in the treatment of several psychiatric disorders, for example, PTSD. Although in need of replication, our findings indicate that a brief and simple mental imagery manipulation can alter autonomic responses to subsequent threat. The findings contribute to an increased understanding of the role of mental imagery in the development of clinical disorders.

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Mental imagery and post-traumatic stress disorder: a neuroimaging and experimental psychopathology approach to intrusive memories of trauma

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This hypothesis and theory paper presents a pragmatic framework to help bridge the clinical presentation and neuroscience of intrusive memories following psychological trauma. Intrusive memories are a hallmark symptom of post-traumatic stress disorder (PTSD). However, key questions, including those involving etiology, remain. In particular, we know little about the brain mechanisms involved in why only some moments of the trauma return as intrusive memories while others do not. We first present an overview of the patient experience of intrusive memories and the neuroimaging studies that have investigated intrusive memories in PTSD patients. Next, one mechanism of how to model intrusive memories in the laboratory, the trauma film paradigm, is examined. In particular, we focus on studies combining the trauma film paradigm with neuroimaging. Stemming from the clinical presentation and our current understanding of the processes involved in intrusive memories, we propose a framework in which an intrusive memory comprises five component parts; autobiographical (trauma) memory, involuntary recall, negative emotions, attention hijacking, and mental imagery. Each component part is considered in turn, both behaviorally and from a brain imaging perspective. A mapping of these five components onto our understanding of the brain is described. Unanswered questions that exist in our understanding of intrusive memories are considered using the proposed framework. Overall, we suggest that mental imagery is key to bridging the experience, memory, and intrusive recollection of the traumatic event. Further, we suggest that by considering the brain mechanisms involved in the component parts of an intrusive memory, in particular mental imagery, we may be able to aid the development of a firmer bridge between patients' experiences of intrusive memories and the clinical neuroscience behind them.

Keywords: post-traumatic stress disorder, mental imagery, intrusive memory, psychological trauma, experimental psychopathology, trauma film paradigm, neuroimaging, flashbacks

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The Patient Experience of Intrusive Memories

> I was in the car outside my house. The mugger put a knife to my neck; he said 'give me your money'. I was scared he would realise that I live here; I was worried for my daughter. He then checked my pockets and asked for my purse to check it and rummaged through it. I was feeling helpless; I was worried I had forgotten some money and he would find it and say I was lying to him. He then ran off and I looked back to my house to see my daughter crying and banging at the door. I felt guilty that she may have seen what happened and that she would be traumatised by it.
>
> A patient's description of a traumatic event, taken from Holmes et al. (1).

Most people will experience or witness a traumatic event over the course of their lifetime and a significant minority will go on to develop post-traumatic stress disorder (PTSD) (2, 3). A hallmark symptom of PTSD is the experience of intrusive memories of the trauma (4). Clinically, intrusive memories are well documented. Our understanding of intrusive memories at a neuroscientific level on the other hand is not. Here, we present a pragmatic clinical-neuroscience framework for understanding intrusive memories, breaking intrusive memories into five component parts. We suggest that mental imagery is key to bridging the experience, memory, and intrusive recollection of the traumatic event. By understanding the individual components, and how mental imagery links each component together, we hope to be able to help bridge the gap between patients' experiences as seen in the clinic and the clinical neuroscience behind them.

A traumatic event is defined not merely as a very stressful event but specifically as experiencing or witnessing serious injury or threat to the physical integrity to the self or others [Criterion A of the American Psychiatric Association (APA), Diagnostic and Statistical Manual 5 (DSM 5)] (4). This diagnostic criterion is particularly interesting as PTSD is one of the few disorders in the DSM 5 that requires an index event to have occurred for diagnosis. This opens up an area of investigation for clinical research to try to understand how PTSD arises from a specific event.

Not everyone who experiences a traumatic event develops PTSD. A diagnosis of PTSD requires four other types of symptoms in addition to experiencing psychological trauma. These are the hallmark symptoms of re-experiencing, including intrusive memories (Criterion B), persistent avoidance of trauma-related stimuli (Criterion C), persistent symptoms of increased arousal (Criterion D), and negative cognitions and mood (Criterion E), all of which need to be present for at least 1 month (Criterion F).

We focus here on the re-experiencing criterion of PTSD, specifically on intrusive memories. Most people experience intrusive memories after witnessing or experiencing a traumatic event, some of whom will go on to develop PTSD. Intrusive memories following trauma share many features between those individuals who do go on to develop PTSD and those who do not (5). Trauma can be re-experienced in different ways, all of which are highly distressing experiences. Intrusive memories are the spontaneous and repeated re-experiencing of the traumatic event, that is, involuntary images of the trauma intruding into consciousness (6). An example related to the patient description of a traumatic event described earlier [from Holmes et al. (1)] would be (1) the sudden image of the moment a mugger raised a knife, accompanied by an intense feeling of fear and (2) a separate image of her daughter's crying face with the feeling of guilt.

Intrusive memories are rarely a replay of the entire traumatic event from beginning to end. Patients often recall one specific moment of the traumatic event at a time – known as a hotspot (7, 8). Hotspots are idiosyncratic – different individuals could witness the same trauma but have different hotspots that return to mind unbidden. They can also represent a range of different emotions that the individual experienced over the course of the trauma. The events in **Table 1** are the hotspots of a different patient who was physically assaulted during a mugging. The hotspots depict a range of negative emotions, in this case, fear, humiliation, sadness, and degradation. On average, patients experience three to four hotspots per trauma, including emotions of fear, helplessness, anger, guilt, and shame (1, 9). These hotspots are those elements of the traumatic event that are re-experienced as intrusive memories.

Not all experiences of trauma result in the persistent experience of intrusive memories and a diagnosis of PTSD. The question therefore arises as to why only some moments within a trauma are later experienced as intrusive memories. This is not a straightforward question to answer, particularly as traumatic events are difficult to study. Cognitive behavioral models of PTSD suggest that cognitive processing during the traumatic event has a large impact on the nature of the trauma memory (8, 10). Indeed, one of the strongest predictors of the development of PTSD is peritraumatic psychological processing (11), i.e., the individual's experience during and immediately after the traumatic event – in particular, perceived life threat during the trauma, peritraumatic emotional responses, and peritraumatic dissociation. These processes are thought to affect the formation of the memory, the contextualization of the trauma within the experience, and subsequent appraisals of the event [see Ref. (8, 10), and neural models of PTSD and intrusive memories below]. Further, experimental studies suggest that peritraumatic psychological processes are also important for predicting intrusive memories following analog trauma [e.g., Ref. (12), see also "Intrusive Memories in the Laboratory" below]. The experience of the individual at the time of the trauma seems, therefore, to be important for predicting symptoms following trauma.

TABLE 1 | Hotspots from one PTSD patient during a mugging.

Event within trauma	Emotional reaction
Hands pulling at bag	They are trying to pull me over; Fear
Fallen down on the ground	I have lost, they have won, I am stupid; Humiliation
Kicked in stomach	They are taking away my chance to have children; Sadness
Assailants walking away slowly	They cannot even be bothered to run; Degraded

Each hotspot is associated with specific emotions and meanings that are present when the images return as intrusive memories. Taken from Holmes et al. (1).

Neural Models of PTSD and Intrusive Memories

Traditional neurocircuitry models of PTSD highlight the importance of three main brain regions; the amygdala, and its interactions with the ventromedial prefrontal cortex (vmPFC), and the hippocampus (13, 14). These models predominantly stem from animal work into fear conditioning, which has a number of parallels with PTSD symptomatology. Specifically, in response to threat-related stimuli, there is thought to be increased activation in the amygdala due to a diminished ability of the vmPFC and hippocampus to govern the amygdala responsiveness. Further, hyperactivity in the amygdala is proposed to explain the distinct emotional quality of memories of the trauma; hypo-response in the vmPFC the inability to move attention away from the trauma-related stimuli; and decreased hippocampal functionality that the poor voluntary recall patients' show in regards to the traumatic event.

Neuroimaging studies in patients with PTSD show support for these neurocircuitry models. The symptom provocation paradigm has been widely used in neuroimaging studies to examine the brain activation occurring during the patient's experience of PTSD symptoms, such as intrusive memories. The paradigm involves exposing individuals with PTSD to stimuli designed to trigger their symptoms, e.g., visual images of combat situations (15) or verbal autobiographical scripts of the patients' trauma. Reviews of symptom provocation neuroimaging studies (16–18) suggest that PTSD patients' symptom experience involves decreased activity of the anterior cingulate cortex (ACC), medial PFC, parahippocampus, and thalamus, and, generally, increased amygdala activity.

Further work suggests that abnormal interactions between the hippocampus and vmPFC may arise after developing PTSD, while abnormalities in the amygdala and dorsal ACC may be predisposing (19). However, while these structures may explain some elements of PTSD, it is unlikely that they alone can explain all symptoms associated with PTSD (20), in particular given the number of regions identified by symptom provocation studies. Thus, it is currently uncertain which of these brain regions may be associated directly with intrusive memories, and which others may be associated with, for example, increases in arousal.

A distinct model of intrusive memories stems from clinical psychology and the neuroscience of memory. Brewin et al. (21), see also Ref. (22), suggest that there are two forms of memory representations – those that are abstract and contextually bound, and those that are sensory and affective in nature and not contextually bound. In a healthy memory, these two representations are connected. An intrusive memory on the other hand has a strong sensory representation that is not connected to its contextual representation. This allows the memory to be easily cued by trauma-related information and without any autobiographical context – creating the re-experiencing feelings common to intrusive memories. Relating these concepts to neural mechanisms, Brewin et al. suggest, in line with neurocircuitry models of PTSD, that intrusive memories occur due to hyper-activation in the amygdala and insula, which is disconnected from the hippocampus and related memory structures that are required to provide contextual autobiographical information. Coupled with visual imagery (suggested to be mediated by the precuneus), the intrusive memory then appears involuntarily in mind as a visual memory.

Support for these suggestions also stems from patient studies investigating intrusive memories directly. Only a small number of studies have been able to investigate the explicit occurrence of intrusive memories. The symptom provocation paradigm does not always cause patients to experience intrusive memories. The paradigm serves as a reminder of the trauma, bringing trauma memories to mind, causing, for example, heighted emotional responses and avoidance, but does not necessarily cause involuntary intrusive memories. To our knowledge, only four neuroimaging studies of PTSD have explicitly reported the brain activation of patients experiencing "flashbacks" while undergoing symptom provocation (23–26). These studies suggest that the experience of an intrusive memory may involve increased activity in limbic and paralimbic areas including the insula, ACC, thalamus, and amygdala, and decreased activation in inferior frontal areas – presenting clues as to those regions that may be involved in intrusive memories specifically. While it should be noted that these studies did not capture the *moment* of intrusive memory involuntary recall, but rather the more general experience surrounding intrusive memories, they do share similarities with the neural mechanisms proposed to underlie intrusive memories (13, 14, 21).

The above-mentioned neuroimaging studies all examined brain activation in patients once symptoms are already established. Key questions including those involving etiology nevertheless remain. For example, why do some people experience intrusive memories and not others? Why do certain moments of the original trauma return as intrusive memories but not others? While it is not possible to investigate the brain mechanisms behind symptom development during real trauma, analog models may offer a prospective methodology to investigate the etiology of intrusive memories.

Intrusive Memories in the Laboratory

Real life traumatic events and the subsequent development of intrusive memories are difficult to study in laboratory settings due to both ethical and practical reasons. The trauma film paradigm (**Figure 1**) is a well-established method to provide an analog model to prospectively investigate intrusive memories in controlled laboratory settings (27–29). In the paradigm, healthy participants watch a film depicting traumatic events, such as the aftermath of real life car crashes. Participants typically experience several intrusive memories to events in the film during the following week, operationalized to participants as: (1) moments of the film spontaneously popping into mind unexpectedly and (2) mental images, i.e., taking the form of pictures, sounds, or bodily sensations. These intrusive memories are recorded in a diary, similar to diaries given to PTSD patients undergoing CBT. The majority of participants experience at least 1 intrusive memory to events in the film, with an average frequency (from 16 studies, totaling 458 participants) of around 5–6 (12). Information recorded in the diary allows for features of the intrusive memory

FIGURE 1 | Diagram of the general procedure of the trauma film paradigm. Participants view a distressing film as an analog of a traumatic event. Over the following week they record any intrusive memories of the film in a diary. This allows for investigation of baseline differences affecting intrusive memory development, or tasks that might increase/decrease later intrusive memories.

(e.g., number, vividness, emotional rating) to be recorded as well as identification of the film scene (analog hotspot) that the memory originated from.

We note that the trauma film paradigm is an analog methodology and not the same as experiencing real life trauma. While findings are preliminary, repeated exposure to electronic media images of the September 11th terrorist attacks in 2001 have been associated with measures of PTSD symptoms 2–3 years later, though predominantly for those individuals viewing >4 h a day for the week following the attack (30). Further, individuals repeatedly exposed to media footage of the 2013 Boston marathon bombings (6 h a day for the week following the bombings) reported higher acute stress symptoms 2–4 weeks later than those directly exposed to the event (31). While the DSM 5 has also acknowledged within the PTSD diagnosis that exposure to trauma images through electronic media, television, and movies in the line of work (4) can be sufficient to lead to PTSD, the full relationship between media exposure and PTSD symptoms is unclear. Regardless, given the potential for electronic media images to cause symptoms, understanding PTSD symptom development from electronic media images of trauma remains pertinent, in addition to being able to inform on real life symptom development.

The trauma film paradigm has allowed for detailed investigation into peritraumatic factors that may affect symptom development, which can be more difficult in clinical research studies due to data often being collected retrospectively. For example, research has shown that performing visuospatial tasks during, or soon after, exposure to analog trauma can reduce intrusive memory frequency [e.g., Ref. (28, 32)]. Further, changes in state anxiety (33) and emotional processing (12) in response to film viewing have been associated with intrusive memory frequency, as well as possible vulnerability factors, e.g., attentional control (34). The trauma film paradigm therefore offers an opportunity to investigate the development of intrusive memories in controlled settings, in particular, peritraumatic factors. The trauma film paradigm therefore opened up a possible mechanism to understand the brain mechanisms involved in intrusive memory formation.

Neuroimaging the Encoding of Analog Intrusive Memories

To our knowledge, only two studies have used neuroimaging to investigate the encoding of emotional images during a trauma film that participants later re-experience as intrusive memories (35, Clark et al., under review).

Bourne et al. (35) conducted the first study implementing the trauma film paradigm to examine the differences in brain activations when viewing "Potential scenes" (unpleasant scenes that elicited intrusive memories in other participants but not in that participant), with "Intrusive (referred to as Flashback) scenes" (those unpleasant scenes that did elicit intrusive memories). Results suggested a widespread neural signature at the time of viewing those scenes that would later be re-experienced as intrusive memories including increased activation in the amygdala, thalamus, rostral ACC, striatum, and ventral occipital cortex. Additionally, two regions seemed to distinguish between intrusive scenes and potential scenes: the left inferior frontal gyrus and middle temporal gyrus.

Given potential limitations and difficulties in studying the neural basis of rare idiosyncratic events, such as intrusive memories (e.g., low event count), replication of these results was important. We therefore conducted a second experiment using an independent sample finding an almost exact replication of our previous results (Clark et al., under review). Additionally, using multivariate pattern analysis techniques, we were also able to predict later intrusive memory occurrence solely from the brain activity at the time of viewing traumatic footage (36). Thus, these results suggest that, at the time of trauma, the brain is responding differently to those scenes that later become intrusive memories compared to those scenes that do not cause intrusive memories for that individual. Given the widespread nature of these activations, it is important to understand how these regions may be involved in the formation of an intrusive memory. That is, what is it that makes the combination of these activations lead to the later involuntary re-experiencing of that specific event during psychological trauma?

A Clinical-Neuroscience Framework of Intrusive Memories

We therefore aim to build upon previous theories and research into the underlying neural mechanisms of intrusive memories. Current neural theories suggest that intrusive memories occur due to poor integration of the trauma into memory (21). Given the proposed parallels between fear conditioning and PTSD (13), it is also possible that the brain processes involved in fear conditioning contribute directly to intrusive memory formation. We suggest that further cognitive processes in addition to fear conditioning may also be involved in intrusive memory formation and recollection. For example, intrusive memories are not purely fear based, involving multiple other emotions, for example, helplessness, anger, guilt, and shame (1, 9) – a fear conditioning account may therefore be only able to explain some of the underlying mechanisms. Brewin et al. (21) highlight disrupted autobiographical memory encoding, in combination with heightened emotional processing and mental imagery, yet our recent neuroimaging work investigating analog intrusive memory formation (35, Clark et al., under review) suggests, in contrast, heightened involvement of memory-related areas in addition to emotional processing and mental imagery. As such, we propose a pragmatic clinical-neuroscience framework of intrusive memories taking intrusive memories as part of a continuum of normal functioning. We suggest that by looking at intrusive memories as a combination of non-clinical cognitive processes that have been researched outside of the clinical literature in detail, we can use knowledge of these areas to help inform our understanding of the mechanisms behind intrusive memories.

Cognitive models and clinical descriptions suggest that intrusive memories are sensory–perceptual (predominantly visual) emotional memories of traumatic events that intrude involuntarily into consciousness, hijacking current selective attention (4, 8, 21, 22, 37, 38). We therefore divide intrusive memories into five component parts; autobiographical (trauma) memory, involuntary recall, emotional processing, attention hijacking, and mental imagery (**Figure 2**). We hypothesize that heighted involvement of each of these cognitive processes are involved in the underlying mechanisms of the formation and experience of an intrusive memory. In the following sections, we review each component in terms of its everyday cognitive process, suggest how each of these five components are involved in intrusive memories and briefly summarize what is known of the neural components behind them. We then map the patient experience of an intrusive memory onto the brain, culminating in **Figure 3**, with the components of our clinical-neuroscience framework in the center surrounded by the different brain areas involved.

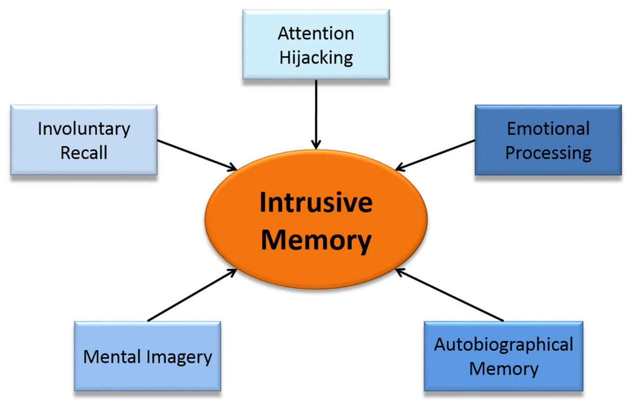

FIGURE 2 | A proposed clinical-neuroscience framework of intrusive memories breaking intrusive memories into five component parts.

Autobiographical (Trauma) Memory

An autobiographical memory is a personal memory that either corresponds to a particular episode in life, or to a more general experience that has particular personal relevance (39). The autobiographical component of an intrusive memory corresponds to the personal experiencing (Criterion A) and subsequent re-experiencing (Criterion B) of the traumatic event, as set out in the DSM 5 (4). The importance of autobiographical memory for intrusive memories is acknowledged in cognitive and clinical theories of PTSD (8, 21, 38).

The literature surrounding autobiographical memory is vast; for recent reviews on the neuroimaging of memory, see Cabeza and Nyberg (40) and Spaniol et al. (41). Overall, these reviews conclude that autobiographical memory is normally associated with activity in the right anterior and lateral prefrontal gyri, the medial temporal lobe, the lateral and medial parietal regions, and the posterior cingulate cortex. Specifically, the ventrolateral prefrontal gyrus and medial temporal lobes are thought to be involved in encoding, while the left superior parietal gyrus and the dorsolateral and anterior prefrontal gyrus are thought to play an important role in recall (41–43). The "subsequent memory effect" suggests that activity at encoding in left prefrontal and bilateral middle temporal regions can predict later successful memory recall (44, 45). Additionally, it is thought that the full encoding of a memory takes place in a 6-h window (46, 47), a process known as consolidation. Research has implicated the involvement of the hippocampus in particular, but cortical areas including the nucleus accumbens and ventral striatum are also proposed to be involved (48).

Involuntary Recall

Involuntary recall is the return of a mental state that was once present in consciousness with apparent spontaneity and without any act of will or previous attempts at retrieval (49–51). Intrusive memories come to mind spontaneously and in an unbidden manner, and are, therefore, recalled involuntarily. Thus, it is important to understand how the traumatic event is involuntarily, as opposed to voluntarily or deliberately, recalled as is often researched within autobiographical memory.

Behavioral and cognitive differences between involuntary and voluntary recall have been widely reported on. For example, involuntary recall is characterized by shorter retrieval times (52) and involuntary memories are more often of specific episodes than deliberately recalled memories [(32, 53), see also Ref. (54, 55)]. However, to our knowledge, there are only a handful of neuroimaging studies that have directly compared voluntary and involuntary recall (56–60). Further, only one study showed

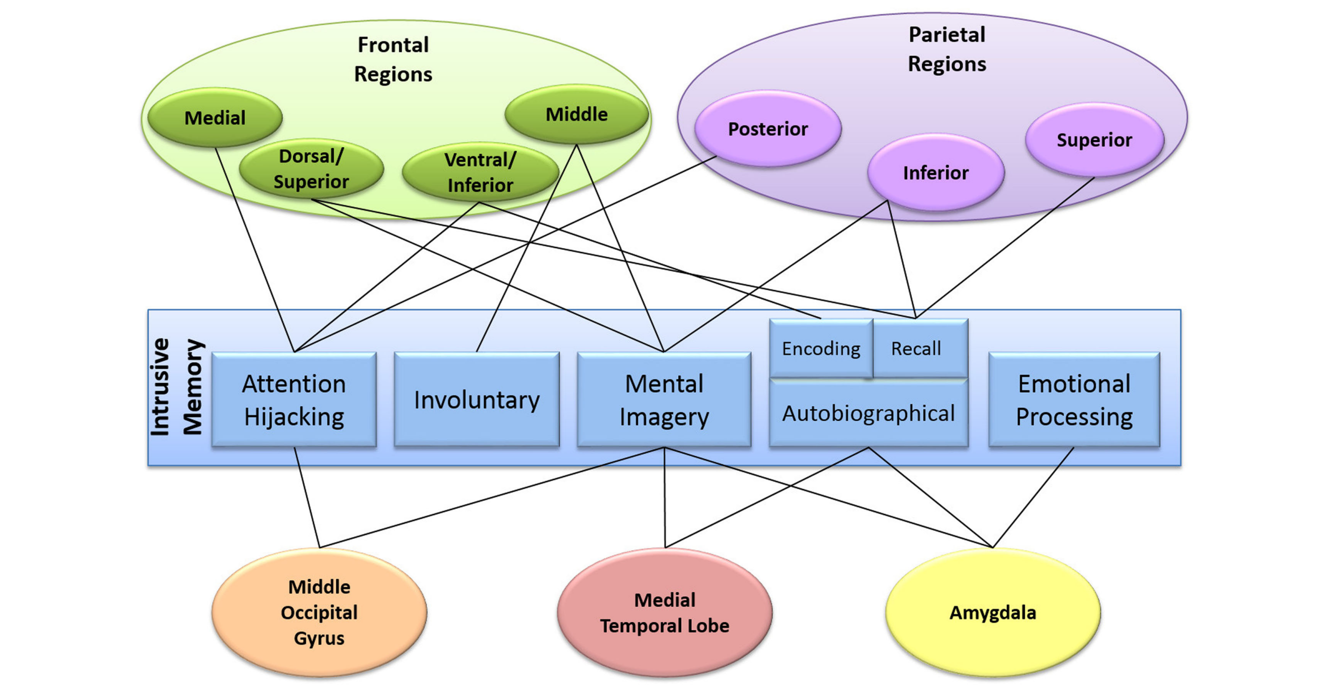

FIGURE 3 | Diagram mapping the patient experience of an intrusive memory onto the brain. The components of our clinical-neuroscience framework are in the center, surrounded by the different brain areas involved.

increased activation during involuntary compared to voluntary recall – in the left middle frontal gyrus and left superior frontal gyrus (57). On the other hand, greater activation for voluntary versus involuntary recall has been found in the right dorsolateral frontal cortex and parietal cortex (56, 58), in the right middle frontal gyrus (57), the left dorsolateral PFC (61), and the hippocampus and amygdala (59). Overall, these studies suggest that while both involuntary recall and voluntary recall activate regions associated with autobiographical memory, voluntary recall additionally activates areas associated with strategic recall. However, it remains to be established whether these findings can also be generalized to intrusive memory involuntary recall, and further replication of regions associated with involuntary over voluntary recall is required.

Emotional Processing

Emotion is a subjective, conscious experience characterized by biological reactions, and an individual's current mental state. The patient experience of intrusive memories is characterized by strong negative emotions. Emotional processing at the time of trauma has also been highlighted as important for later PTSD development (11) and for intrusive memories following analog trauma (12). Hyperactivity of emotional regions has also previously been proposed to be important in both PTSD and intrusive memory development (13, 21).

It is important to define these emotions as negative when investigating intrusive memories experimentally as involuntary memories are not always distressing. Research has found that involuntary memories are not limited to negative experiences or indeed to clinical populations – a telephone survey of 1500 Danes identified that approximately 60% of involuntary memories reported were positive in nature (62). Additionally, positive involuntary memories in the laboratory have also been associated with increased (positive) emotional processing at the time of encoding (63). Behaviorally and clinically, intrusive memories are regarded as negative, whether a distinction between negative and positive emotion is required, however, is less clear in terms of the mechanisms underlying intrusive (or involuntary) memories.

At a neural level, research into emotion often implicates the amygdala, ACC, and the PFC (64–66). The amygdala is traditionally associated with negative emotions, especially that of fear (66, 67). However, more recent work suggests that the amygdala is also involved in positive emotions (68) and that the amygdala may respond to emotional salience rather than to whether the emotion is positive or negative (69). Indeed, amygdala activation at encoding has been associated with success of recall regardless of emotional valence (70, 71). Additionally, the ACC is often implicated in threat detection, and the PFC is thought to be involved in emotion regulation – allowing top down control in response to emotional situations (64, 72). At a neural level therefore, emotional valence may be less important than the intensity of the experienced emotion, i.e., how emotionally salient the event was, or there may be a down play in top down control of emotion regulation.

Attention Hijacking

Sensory information in the world around us is abundant, and attention is used to select the information that is relevant at a given time (73). Attention hijacking is the overriding of this selective attention geared toward our current goal, transferring attention to something else. To become salient, an intrusive memory must hijack attention to some degree.

How might an intrusive memory override selective attention? Research suggests that PTSD patients have enhanced priming for perceptual and verbal trauma-related stimuli (74, 75). Measurement of this enhanced priming soon after trauma was also associated with symptom severity at later follow-ups. Comparison of PTSD patients and trauma-exposed controls suggests that enhanced priming for trauma-related stimuli may be an inability of patients to move their attention away from trauma-related stimuli and not an increase of facilitated attention to trauma-related stimuli (76, 77). A poor ability to remove information that is no longer relevant from mind, measured in non-clinical participants before viewing traumatic footage, has also been associated with intrusive memory frequency in the subsequent week (34, 78). Overall, this work suggests that an inability to move attention away from non-relevant stimuli may be a vulnerability factor for intrusive memory development. However, this work has focused upon external trauma-related stimuli, and not internal representations as per an intrusive memory. Notably, there are a number of similarities between attention toward internal and external representations, in particular, in terms of behavioral responses (79, 80). Thus, it may be possible to extrapolate the above trauma-related findings to internal as well as external representations.

In healthy individuals, visual selective attention has been associated with activity in widespread brain regions, including the parietal, temporal, and prefrontal cortices (81). It has been proposed that the frontal regions deal with specifying, consolidating, and selecting targets, while the posterior parietal, occipital, and temporal regions filter out distracting stimuli (82–84). Investigations into attention toward internal representations have shown similar patterns of activation between internal and external stimuli but with some notable differences – right inferior parietal cortex was selectively important for attention toward external stimuli, while the frontal regions (in particular left inferior frontal gyrus) were selectively important for internal stimuli (80, 85). Our work investigating intrusive memory encoding (35, Clark et al., under review) highlights possible distinguishing activity in the left inferior frontal gyrus for those moments that will later become intrusive memories compared to those that will not. The left inferior frontal gyrus has been associated with the selection of information (86) and the "flexibility" to switch from one task to another (87) and thus may represent attention hijacking within intrusive memories, but this remains to be further explored.

Neuroimaging of attention in PTSD patients has shown decreased activity in PTSD patients with high levels of symptomatology compared to low symptomatology in dorsolateral PFC and parietal regions for neutral targets, but increases in these regions for emotional distractors. Additionally, in contrast to above, bilateral inferior frontal gyrus activity was higher in patients with low symptoms than those with high symptoms in response to the emotional distractor stimuli (88). Further, attention toward emotional distractors has been associated with the dorsolateral and ventral PFC (89). Using non-emotional stimuli, research has suggested a general hyper-vigilance of PTSD patients with increased activation of somatosensory and posterior parietal attention networks, inferior frontal gyrus and vmPFC, dorsal ACC, and amygdala (90). To our knowledge, however, attention toward internal stimuli in patients with PTSD has not yet been investigated.

Mental Imagery

Mental imagery is a quasi-perceptual experience, in that it resembles perception and sensory experiences, but occurs in the absence of the appropriate perceptual and sensory stimuli (91, 92). There are arguments that intrusive memories in PTSD are not limited to sensory images, also including abstract thoughts; however, these types of "intrusions" are more like rumination and not what we aim to explain here [see also Ref. (93)]. Rather, we focus upon the more common experience of intrusive memories as sensory-based images (1, 94, 95). Mental imagery is highly connected to emotion, causing the same emotional responses as seeing an object or event itself (96). Additionally, mental imagery has been reported to have a similar effect on the body as actually seeing the object or event in question – skin conductance, heart, and breathing rate all increase when visualizing threatening objects (97). Indeed, mental imagery can also be confused with reality (96). Thus, given also that emotional memories are thought to be perceptual in nature (98), mental imagery may be an overarching component in why intrusive memories are such distressing experiences.

Neuroimaging investigations of mental imagery support the links between mental imagery, memory, emotion, and perception. First, neuroimaging research has consistently reported activation of the visual cortex during visual mental imagery (99). Additionally, visual mental imagery has been found to activate the middle frontal gyrus, the superior frontal gyrus, the middle occipital cortex, right ACC, and the left inferior parietal cortex (100), along with the hippocampus, amygdala, entorhinal cortex, parahippocampal cortex, and the anterior insula (101, 102). Thus, the experience of mental imagery additionally activates those regions previously associated with autobiographical memory and emotional processing as well as visual processing. Mental imagery may therefore be key to linking the other components of our intrusive memory framework.

We note here that the above evidence is focused upon visual mental imagery. Visual intrusions are the most common following trauma and are those that are typically studied in experimental settings; however, intrusive memories can be in other sensory modalities (e.g., audition and bodily sensations), physiological or manifest in other behavioral ways (93). On the other hand, given the connections between mental imagery and physiological arousal and related factors, it is likely that mental imagery plays a key role in all forms of intrusive recollections. Further, we suggest that while changing from visual to, for example, auditory mental imagery would change some of the brain regions activated (e.g., from visual cortex to primary auditory cortex), other underlying mechanisms would remain the same.

Mapping the Experience of an Intrusive Memory onto the Brain

Using our clinical-neuroscience framework, we hypothesize that a series of events happen simultaneously to create an intrusive memory (**Figure 2**). Neural mechanisms involved in involuntary recall activate the autobiographical (trauma) memory, which hijacks current selective attention. The mental imagery of the autobiographical memory, which is activated by the involuntary recall, intensifies the emotion of the event increasing the strength and attention hijacking nature of the intrusive memory.

Figure 3 maps our clinical-neuroscience framework onto the brain. The center of the diagram shows the different components that make up an intrusive memory. Surrounding this are the brain regions proposed to be involved. As can be seen, intrusive memories are a whole brain phenomenon with many areas involved in multiple components of the intrusive memory framework. Additionally, many of the proposed brain regions identified in each of the components (with the exception of involuntary recall) were those also observed during intrusive memory encoding (35, 36 Clark et al., under review).

What, therefore, can be seen by mapping the hypothesized components onto the brain? Interestingly, the brain areas involved in mental imagery are also involved in the other proposed components. For example, in addition to mental imagery, the frontal areas of the brain have been associated with attention hijacking and involuntary recall, suggesting that the frontal regions may be involved in the spontaneous recollection of mental images. Areas associated with autobiographical memory (predominantly the medial temporal lobe, but also parietal and frontal regions) have also been found to be involved in mental imagery, demonstrating a possible connection between the traumatic memory and mental imagery. Parietal regions, in addition to autobiographical memory are also involved in attention hijacking, suggesting a link between the traumatic memory and an overriding of attention. Amygdala activation is predominantly associated with emotional processing but also mental imagery and autobiographical memory, linking the emotional response and the mental image of the traumatic memory. Thus, there are connections between all five components of our hypothesized model of intrusive memories, linking back to mental imagery. *Combining each of these individual components via mental imagery, which on their own are required for normal functioning, may lead to the experience of an intrusive memory.*

Building Upon Previous Models of Intrusive Memories

How does this help us? What do we gain by looking at intrusive memories of trauma in this way? Much more work is needed to understand intrusive memories, especially in terms of neuroscience (50). Understanding how each component individually contributes to intrusive memories, and the neuroscience behind it, increases our knowledge of an otherwise incredibly complex phenomenon. While our understanding of the neuroscience behind intrusive memories *per se* is limited, much more is known about the neuroscience of autobiographical memory, emotion, attention, and mental imagery outside of the clinical literature.

Further, the current model differs to previous models [e.g., Ref. (21, 22)] in that we suggest that *heightened* memory processing, not disrupted processing, may be important for intrusive memory formation. Additionally, we include a separate component of attention hijacking. By doing so, we highlight the possible involvement of more frontal regions of the brain in addition to the subcortical regions noted by Brewin et al. (21). We also note the overarching connection between each of the components that make up an intrusive memory – that of mental imagery. While imagery has often been associated with intrusive memories, our framework suggests that it may be key in uniting all aspects of an intrusive memory.

Predictions and Testable Hypotheses

By tailoring research in areas identified by our framework toward intrusive memories and PTSD, we may be able to develop a better clinical-neuroscience understanding of the patient's experience of intrusive memories. Further, by breaking intrusive memories into our proposed components, we have a framework for developing and testing hypotheses.

We hypothesize that mental imagery is an overarching component of intrusive memories that has links to all of the other components – while each of the other components may overlap with others, mental imagery is the only one to unite all of the components. By removing mental imagery, or occupying mental imagery processes, we may be able to directly affect the formation and involuntary recall of intrusive memories. For example, work using the visuospatial computer game Tetris has already shown its ability to reduce visual intrusive memory frequency in experimental settings (32, 103, 104). Further, a high tendency or ability to use mental imagery may be an important risk factor in intrusive memory development [e.g., Ref. (105)]. Understanding how mental imagery relates to real world trauma may help develop easy to administer screening measures for at-risk populations.

Additionally, mental imagery is also a broad term used to encompass all aspects of perceptual information accessed from memory (92). Intrusive memories do not have to be visual in nature – some patients experience intrusive memories in the form of audition or bodily sensations. A more precise understanding of the specific aspects of mental imagery associated with intrusive memories may further refine potential treatments. Adaptation of imagery-based therapies to other modalities may be important to address other types of intrusions. Further, while we suggest that the underlying mechanisms involved in intrusive memories of these different modalities may be similar to that of visual intrusions, there may also be important differences between these types of intrusive recollections that should be investigated in future work.

We also suggest the possible importance of heightened memory processing during exposure to moments of the trauma that later return as intrusive memories (see also, 35, 36, Clark et al., under review). This is in contrast to other clinical cognitive neuroscience models of intrusive memories (22), but a proposal that has parallels with memory-based models of PTSD (38). Understanding exactly how memory processes contribute to intrusive memory formation and recall is essential for future work into the neural basis of intrusive memories.

The proposed framework also suggests that we may be able to disentangle emotional processing and the memory of the trauma. The experience and subsequent memory of the trauma is required for an intrusive memory, but the emotional reaction is what makes the intrusive memory distressing for patients. Is it therefore possible to reduce the emotion associated with the intrusive memory, while keeping the memory itself intact? Additionally, how can we go about doing this at a neural level? The overarching aim of treatment is to reduce the distress associated with intrusive memories – removing the memory itself is not necessarily the best response (106).

In addition to the negative emotions brought to mind by intrusive memories, their involuntary nature and hijacking of attention further exacerbate the distressing effects. Establishing and understanding possible neural differences between voluntary and involuntary autobiographical memory recall may help pinpoint areas of memory that are distinct to intrusive memories. From this, possible ways of reducing the frequency of involuntary recall of these memories may become further apparent.

The neural processes of attention suggest an important role for frontal regions in allowing/enabling the intrusive memory to come to the forefront of selective attention. Typically, decreased ventral–medial PFC activity is associated with PTSD, which is thought to reduce the control of the amygdala, heightening emotional responses. However, the PFC may also be important in the attention hijacking nature of intrusive memories, or toward external stimuli that then trigger intrusive memories. Further research is required to disentangle the role of attention in intrusive memories. Understanding how an intrusive memory overrides selective attention may present clues as to reducing intrusive memory impact at involuntary recall.

Finally, the neural basis of the encoding of intrusive memories is an area that has received only recent attention. Further work to understand the identified neural signature and how the brain activity relates to underlying cognitive processes will help in translating findings toward possible treatment development.

Discussion and Conclusion

We set out here a clinical-neuroscience framework that considers intrusive memories as a combination of five component parts: autobiographical (trauma) memory, involuntary recall, negative emotions, attention hijacking, and mental imagery (**Figure 2**). Our clinical-neuroscience framework aims to set out some experimental hypotheses for mapping the brain processes that contribute to the experience of intrusive memories. Intrusive memories are a highly complex phenomenon – by considering them as a combination of component parts, which individually have received substantial research, we hope to suggest alternative hypotheses that may otherwise go overlooked.

The need to bridge the gap between neuroscience and mental illness is becoming increasingly recognized as a necessity for continued improvement of psychological therapies [e.g., Ref. (107–109)]. Understanding mechanisms, both at the cognitive and neural level, behind both symptom development and symptom experience may go some way to help increase treatment efficacy. Neuroscience provides a potential tool to help improve understanding of psychological symptoms. Our clinical-neuroscience framework of intrusive memories presented here presents additional steps to help bridge neuroscience and the presentation of intrusive memories, demonstrating the possibilities of combining these two disparate areas.

Overall, we suggest that mental imagery may be key to the formation and experience of an intrusive memory. Mapping the neural correlates of the five component parts together (**Figure 3**) suggests that mental imagery may be involved in combining the components into the experience of an intrusive memory. That is, mental imagery may bridge the experience, memory, emotional processing, attentional hijacking, and intrusive recollection of the traumatic event. By understanding the contribution of mental imagery in particular to the development of intrusive memories, we hope to be able to build a firmer bridge between patient's experiences and their psychological and neuroimaging underpinnings.

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OPINION ARTICLE
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Motor imagery in clinical disorders: importance and implications

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One of our most remarkable mental capacities is the ability to use our imagination voluntarily to mimic or simulate sensations, actions, and other experiences. For example, we can "see" things in our mind's eye, "hear" sounds in our mind's ear, and imagine motor experiences like running away from, or perhaps "freezing" in the face of, danger. Since the early 1900s (1), researchers have investigated "mental imagery" or the multimodal cognitive simulation process by which we represent perceptual information in our minds in the absence of sensory input (2).

Although visual imagery has attracted most research attention to date (3), there has been an upsurge of interest in cognitive neuroscience and sport psychology in non-visual simulation processes such as "motor imagery" (MI) - or the mental rehearsal of actions without engaging in the physical movements involved (4). This trend is attributable mainly to the discovery of close parallels between the neurocognitive mechanisms underlying imagination and motor control. Specifically, inspired by Jeannerod's (5–7) simulation theory of action representation, researchers have discovered that MI recruits similar neural pathways and mechanisms to those involved in actual movements. For example, Hétu et al. (8) showed that the neural network of MI includes several cortical regions known to underlie actual motor execution. Building on this apparent functional equivalence between imagined and executed actions, the present article explores the implications of research on MI for increased understanding of three clinical conditions – post-traumatic stress disorder (PTSD), personality disorder, and social anxiety disorder (SAD). Before we begin, however, some background information on imagery processes in psychopathology is required.

Arising from Kosslyn's proposition that mental imagery plays "a special role in representing emotionally charged material" [(9), p. 405; see also Ref. (10)], researchers have examined the role of imagery processes in the onset, maintenance, and treatment of various psychological disorders (11–13). A consistent finding is that negative, vivid, and distressing *involuntary* ("intrusive") imagery is a "transdiagnostic" feature of depression (14), SAD (15), PTSD (16), and obsessive-compulsive disorder [OCD; (17)]. For example, Weßlau and Steil (14) reported that more than one in three depressed people suffer from involuntary negative mental imagery. Furthermore, people's capacity to use imagery prospectively is significantly impaired in certain clinical disorders. Thus, Morina et al. (18) discovered that depressed patients were less capable of imagining positive future outcomes than were non-depressed controls. Imagery processes also help in the treatment of psychopathology. Indeed, Holmes et al. (19) evaluated the therapeutic value of "imagery rescripting" [where distressing images are modified to change their associated thoughts, feelings, and behavior; (20)] in the treatment of PTSD. Clearly, imagery research represents "a new and important arena" [Pearson et al. (13), p. 3] for clinical psychology.

Despite increased awareness of imagery processes in psychopathology, there is at least one significant gap in research in this field. Specifically, little is known about the role of MI in clinical disorders. Curiously, despite the multimodal nature of imagery (21), clinical researchers have tended to focus mainly on its *visual* component. Thus, Weßlau and Steil (14) proclaimed that in imagery, although "other sensory components such as smells, sounds, or haptic sensations . . . may be present . . . *the visual aspect is the necessary and sufficient condition*" (our italics, p. 274). This proposition may be challenged, however, by evidence that mildly to moderately depressed patients experience proportionately more *somatic* (39.6%) than visual (27.2%) imagery (17). More importantly, MI processes may help to elucidate the mechanisms underlying clinical conditions with distinctive motor components. For example, Chen et al. (22) discovered that depressed patients have difficulties in the mental rotation of hand stimuli. These imagery deficits reflect "an underlying slowing down of motor preparation, which may contribute to psychomotor retardation" (p. 341).

Let us now consider three specific disorders in which MI processes are potentially significant - PTSD, personality disorders, and SAD.

POST-TRAUMATIC STRESS DISORDER

Post-traumatic stress disorder typically involves a threat to an individual's physical integrity [DSM-V; (23)]. This threat may prompt movement execution either through resistance to attack (fight) or through intended escape (flight) (24). Accordingly, it seems plausible that *re-experiencing* a traumatic event in the form of "flashbacks" will involve MI. Corroborating this hypothesis, research shows that flashbacks are associated with increases in various types of motor behavior (25). More recently, neuroimaging paradigms in which individuals with PTSD imagine their traumatic experience or simulate flashbacks have shown increased cerebral blood flow to the motor cortex including the pre-central gyrus and supplementary motor area (26, 27). These findings shed light on the neurocognitive mechanisms underlying PTSD disorders because they confirm the involvement of motor cortex in the simulated re-experiencing of traumatic events.

Another link between PTSD and MI processes has emerged from recent studies of the "freeze" response or tonic immobility. Briefly, tonic immobility is an involuntary, reflexive state, characterized by apparent physical paralysis, muscular rigidity, and inability to vocalize (28, 29). For animals, it may be a last line of defense because it reduces the likelihood that predators will continue to attack them (30). The freeze response is more complex in humans, however, as it may be triggered by symbolic events such as the perception that a situation is inescapable (31). Interestingly, although "freezing" was first noted as a characteristic of sexual assault (32) - with up to 37-52% of such assault survivors reporting tonic immobility - it has also been identified among victims of other traumas including physical assault and natural disasters (33). Accordingly, tonic immobility has been proposed as a core sign of trauma in PTSD (34). Unfortunately, peri-traumatic tonic immobility has been shown to predict a poor response to pharmacological treatment (35, 36) - which suggests that psychological processes may be especially significant in this form of PTSD. Recently, Bovin et al. (37) discovered that guilt (i.e., negative evaluation of an action or inaction) mediated the association between tonic immobility and PTSD symptom severity. These authors speculated that guilt may be a mechanism through which individuals develop PTSD following tonic immobility. The argument here is that during the tonic immobility experienced in the trauma situation, victims may feel guilty about their lack of action – which renders them especially vulnerable to developing PTSD. As tonic immobilization is a key risk factor for PTSD, interventions that are targeted to remediate the impact of the freeze response could provide a fruitful strategy for the reduction or prevention of PTSD symptoms (36). Therefore, we propose that rescripting based on MI ("remobilizing") could prove valuable as an intervention technique for PTSD (38).

Recent studies show that tonic immobility during childhood sexual abuse is associated with the onset of subsequent PTSD symptomatology in adulthood (39). The freeze response, or "learned helplessness," is especially likely in cases of trauma experienced by infants or young children who are physically unable to escape (40). Further insights into MI processes in PTSD spring from research on the differences between patients' memories of traumatic events and those of non-traumatic events. Thus, van der Kolk and Fisler (41) suggested that trauma is initially represented using somatosensory information - with traumatic experiences being remembered as bodily sensations. Consistent with this proposal, Malmo and Suzuki Laidlaw (42) found that people who had no memory of childhood sexual abuse prior to therapy were "more kinesthetic than visual" in their orientation to the world. Remarkably, during therapy, the "no memory of trauma" participants became aware of their traumatic memories, and were consistently able to report kinesthetic memory details such as their bodily position in relation to that of the perpetrator (42).

PERSONALITY DISORDERS

The development of personality disorders, particularly borderline personality disorder, has been strongly associated with early trauma and neglect (43–45). Interestingly, certain kinds of imagery rescripting such as re-imagining adverse early childhood events from an adult perspective have been used to treat personality disorders (46). Imagery rescripting was first used by Arntz and Weertman (47) with the primary objective of revising the perceived meaning of events. For example, an image of a childhood memory might be rescripted constructively by imagining an adult entering the scene and intervening in a positive way (e.g., comforting the child concerned). Typically, the rescripting session with the therapist is recorded and the patient then listens to the recording and practices the exercise again at home, where possible using imagery. Later, patients themselves are required to rescript the adverse event. Although imagery rescripting in a promising therapeutic strategy, its efficacy is mediated by many psychological variables. For example, consider the role of "imagery perspective" or the virtual vantage point-of-view adopted by the person imagining [e.g., first-person versus third-person perspective; (48)]. To illustrate, one can "feel" oneself performing an action with one's body (first-person perspective) or one can "see" oneself or someone else performing that action (third-person perspective). Imagery perspective is important in the treatment of trauma because McIsaac and Eich (49) found that traumatic images retrieved from a third-person perspective were experienced as less emotional than those retrieved from a first-person perspective. Unfortunately, few studies have explored the relative efficacy of different perspectives [which may involve different levels of embodiment (48)] in rescripting imagery interventions.

SOCIAL ANXIETY DISORDER

Social anxiety disorder is a highly prevalent and disabling condition that involves fear and avoidance of interpersonal interactions, particularly those that involve potential for social evaluation (50). This disorder is typically characterized by vivid visual imagery, particularly that generated from a third-person perspective (51). According to cognitive models of social anxiety [e.g., by Clark and Wells (52)], people with SAD habitually generate negative images from thoughts, feelings, and bodily sensations to create impressions of how they appear to others from a third-person ("observer") perspective. Intriguingly, Spurr and Stopa discovered that imagery experienced from a third-person perspective is associated with increased negative self-evaluation by comparison with that occurring from a first-person perspective (53).

One strategy for treating social anxiety involves helping patients to restructure their imagery experiences (54). Thus, Wild et al. (55) developed an imagery-based technique to help people to modify traumatic memories. This technique is effective as a brief treatment for social phobia (56). Its use of imagery rescripting is similar to that pioneered by Arntz and Weertman (47) and involves closing one's eyes, describing recurring images in social situations, and then imagining that the current self is present at the scene and hence, intervening appropriately. This latter imagery clearly has a motor component as it involves re-imagining actions or movements. Accordingly, MI may be helpful for the treatment of SAD because it can orient patients away from the critical self-focused perspective, thereby reducing "egocentric awareness" (57). By contrast, self-focused attention may impair people's capacity for perspective-taking, thereby maintaining social anxiety (58).

CONCLUSION AND FUTURE DIRECTIONS

In this article, we have presented two main arguments concerning imagery processes in psychopathology. Firstly, we postulated that research on MI processes offers intriguing insights into the neurocognitive mechanisms underlying, and psychological treatment of, certain clinical disorders (specifically, PTSD, personality disorders, and SAD). In addition, we proposed that clinical researchers have much to learn from an emerging theoretical theme in cognitive neuroscience – namely, the idea that the brain is a dynamic predictive system (59) which uses *simulation* as a mechanism for integrating the psychological processes of imagination, perception, and action. More immediately, however, several priorities may be identified for future research on MI in clinical disorders. Firstly, greater theoretical and linguistic precision is required in the delineation of different imagery modalities and experiences. For example, some researchers [e.g., Arntz (46)] use the generic term "imagery" to refer to quite different simulation phenomena such as imagining bodily movements and visualizing scenes. Secondly, in assessing problems such as psychomotor retardation, clinical researchers can benefit from the systematic use of objective measures of MI (60) - especially recently developed psychometric tests (61). Finally, on the basis that dynamic mental practice (i.e., imagining a skill while making associated physical movements) can improve skilled performance through enhanced mental representation (62), it seems plausible that dynamic imagery rescripting could enrich therapeutic interventions for patients suffering from certain disorders (e.g., PTSD).

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On the relevance of mental imagery beyond stress-related psychiatric disorders

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If a patient with major depressive disorder (MDD) reported that he is hearing self-derogatory thoughts aloud he would probably be diagnosed with psychotic depression. This might be followed by a change in medication rather than the offer of specific therapeutic strategies that target intrusive mental images. Yet in support of a growing literature of mental imagery in psychiatric disorders (1), recent research by our group shows that about one in two patients with mild to moderate MDD and three in four patients with obsessive–compulsive disorder (OCD) report sensory properties of their cognitions (2, 3).

In fact, most of us share such experiences: if we remember how we met our loved one, we sometimes see a visual image of how we first met them and this visual image can be accompanied by intense positive emotions. Similarly, we may vividly remember how it hurt when we were beat up in the school yard and again this tactile image may come with intense negative emotions.

On a more systematic level, mental imagery has been defined as the experience of conscious contents that possesses sensory properties and therefore resembles actual perceptual experience (1, 4, 5). The perceptual properties can be visual but can also cover other sensory modalities such as tactile, acoustic, or somatic experience. In contrast to cognitions, mental images are not purely verbal or abstract (5).

If these mental images occur involuntarily they are also referred to as "intrusions" (5). Mental imagery has been recognized in a number of disorders (5). Intrusions are a diagnostic feature of stress-related disorders such as acute stress disorder, post-traumatic stress disorder (PTSD), and dissociative disorder (6). While intrusive mental images are also recognized in OCD, they are not part of the diagnostic criteria of depressive disorders (6).

Intrusive mental images can be regarded to exist on a spectrum where actual psychotic symptoms are at the far end and defined by impaired reality testing [Ref. (7), p. 371]. Interestingly, the definition of hallucinations [Ref. (6), p. 87] overlaps with that of intrusive mental images. Just like hallucinations, intrusive mental images may at times be vivid and clear, have the full force and impact of normal perceptions and be out of voluntary control (8).

To illustrate this point, it has been found by our group that a considerable number of healthy controls and patients with OCD also report hearing voices (8). The same study showed that only about a third of schizophrenics (31.1%) but a full-third of healthy "voice-hearers" (33.3%) experience their voices as not distinguishable from real voices. One distinguishing factor between acoustic mental imagery and hallucinations that emerged from that study was the conformity with personality: while two-thirds (66.7%) of healthy voice-hearers reported that their voices reflected their inner thoughts, only 15.6% of schizophrenics experienced it this way. Schizophrenics often describe their voice as someone else talking to them.

These findings can be interpreted in the context of a growing body of evidence that hallucinatory experience may not be confined to psychotic disorders as previously thought. In one recent meta-analysis, the annual incidence of psychotic experiences was reported to be as high as 2.5%, the meta-analysis also found that $<10\%$ of patients reporting psychotic experiences actually go on to develop a psychotic disorder (9).

In conclusion, there is growing evidence that intrusive mental images are probably present in a wide range of mental disorders and lie on a continuum that ends in frank hallucinatory experiences (1, 5). To complement and expand the knowledge of mental imagery in mental disorders, we have recently completed two online studies that tapped into sensory properties of cognitions in MDD and OCD.

One study was conducted as part of large randomized trial (10). Here, we examined to what extent depressive thoughts are accompanied by mental imagery and how this is associated with symptom severity, insight, and quality of life (2). We recruited a large sample of mildly to moderately depressed patients ($N = 356$) from multiple sources and asked them about sensory properties they may have experienced in association with their depressive thoughts and ruminations. Answers were collected on a five-point Likert scale (from none to extreme sensory experiences) on separate scales for each modality: visual, auditory, tactile (touch), somatic (i.e., bodily sensations), olfactory (smell), and other. We provided examples to illustrate possible sensory properties of thoughts. For instance, an auditory sensation would be that one perceives an "inner critic" who seems to have an actual voice and may call one a "loser."

A total of 56.5% of our sample reported mental imagery in at least one sensory modality that was associated with their cognitions. The highest prevalence was seen for somatic (39.6%) followed by auditory (30.6%) and visual (27.2%) sensations. Strong or extreme sensory properties were reported by 10.7% for bodily, 5.6% for auditory, and 4.8% for visual sensations. Patients reporting sensory properties of thoughts showed more severe symptoms on the quick inventory of depressive symptoms (QIDS) and had more previous depressive episodes and were more often hospitalized in the past than those who did not.

In a separate study, we examined the prevalence of mental imagery associated with obsessions and its relationship with illness insight and depression (3). Here, we examined just 26 patients with OCD whose diagnosis was confirmed on a structured diagnostic interview that was conducted over the telephone. They were asked to indicate on the same scale as above if their obsessions were associated with perceptual features. Again, examples were given such as the tactile sensation of dirt on the skin in patients with washing compulsions.

A total of 73% of patients reported at least mildly perceptual features that were associated with their obsessions. Here, the predominant perceptual channels were somatic (54%, strong or extreme: 23%), visual (46%, strong or extreme: 19%), and tactile (35%, strong or extreme: 4%); only 12% reported that their obsessive thoughts hat acoustic properties (strong or extreme: 4%). The extent of perceptuality strongly correlated with lack of insight item on the Yale Brown Obsessive–Compulsive Scale (YBOCS) but only mildly with depression severity on the Beck Depression Inventory (BDI).

In summary, about one in two patients with mild to moderate MDD and a full three in four patients with OCD report mental imagery associated with their cognitions. The proportion may be even higher in severe depression; this is the subject of a currently ongoing study. The most common perceptual channels in both disorders are bodily and visual sensations; auditory sensations were common in MDD but not in OCD and tactile sensations were common in OCD but not in MDD.

One important limitation in these studies is that they rely on patients self-report regarding the sensory properties of cognitions. If confirmed in further studies, our findings could support the notion that we should recognize the presence of mental imagery in mental disorders other than just stress-related disorders. This may have implications for the understanding and treatment of these disorders. It has repeatedly been shown that interventions primarily targeting the verbal cognitive content do not significantly increase the effectiveness of cognitive behavioral therapy (3, 11). In spite of this, research of most mental disorders has focused on cognitive contents rather than other aspects of content such as mental imagery (5). Still, theories and therapies have been developed that go beyond targeting cognitive content (12). These include the theory that metacognitive beliefs (i.e., beliefs about the significance of cognitions: "If I think long enough I will find out what is wrong with me.") rather than the cognitive content *per se* has negative consequences for self-regulation [Ref. (13), p. 232].

The current research presented here adds to this literature and suggests that in addition to cognitive content and metacognitive beliefs, mental imagery associated with cognitions may also impact the onset and maintenance of disorders such as depression and OCD. In support of this notion, a recent review came to the conclusion that mental imagery can contribute to the onset and maintenance of mental disorders as imagery invokes greater emotional responses than the verbal representation of similar events (1).

This may also have consequences for the treatment of these disorders (14), especially for those patients who are troubled by vivid and disturbing mental imagery. Our study suggests that this may be a considerable number of patients. We found that about 1 in 5 patients with OCD and 1 in 10 patients with mild to moderate MDD report strong to extreme mental imagery associated with their cognitions. Therapeutic techniques have been developed that aid in rescripting distressing imagery by having the patients focus on the intrusive sensory experience (most commonly visual experiences) and aiding them in vividly constructing an alternative outcome (5, 14).

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