Eye Movements and Hemodynamic Response during Emotional Scene Processing: Exploring the Role of Visual Perception in Intrusive Mental Imagery

Stephanie Marie Roldán

Dissertation submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of:

Doctor of Philosophy
in
Psychology

Anthony D. Cate, Chair

Rachel A. Diana

Martha Ann Bell

Stephen LaConte

May 5, 2017
Blacksburg, VA

Keywords: Scene perception, eye movements, near-infrared spectroscopy, mental imagery

Eye Movements and Hemodynamic Response during Emotional Scene Processing: Exploring the Role of Visual Perception in Intrusive Mental Imagery

Stephanie Marie Roldán

ABSTRACT

Unwanted and distressing visual imagery is a persistent and emotionally taxing symptom characteristic of several mental illnesses, including depression, schizophrenia, and posttraumatic stress disorder. Intrusive imagery symptoms have been linked to maladaptive memory formation, abnormal visual cortical activity during viewing, gaze pattern deficits, and trait characteristics of mental imagery. Emotional valence of visual stimuli has been shown to alter perceptual processes that influence the direction of attention to visual information, which may result in enhanced attention to suboptimal and generalizable visual properties. This study tested the hypothesis that aberrant gaze patterns to central and peripheral image regions influence the formation of decontextualized visual details which may facilitate involuntary and emotionally negative mental imagery experiences following a stressful or traumatic event. Gaze patterns and hemodynamic response from occipital cortical locations were recorded while healthy participants (N = 39) viewed and imagined scenes with negative or neutral emotional valence. Self-report behavioral assessments of baseline vividness of visual imagery and various cognitive factors were combined with these physiological measures to investigate the potential relationship between visual perception and mental recreation of negative scenes. Results revealed significant effects of task and valence conditions on specific fixation measures and hemodynamic response patterns in ventral visual areas, which interacted with cognitive factors such as imagery vividness and familiarity. Findings further suggest that behaviors observed during mental imagery reveal

processes related to representational formation over and above perceptual performance and may be applied to the study of disorders such as PTSD.

Eye Movements and Hemodynamic Response during Emotional Scene Processing: Exploring the Role of Visual Perception in Intrusive Mental Imagery

Stephanie Marie Roldán

GENERAL AUDIENCE ABSTRACT

Intrusive imagery describes the visual components of flashbacks that are common to mental disorders such as posttraumatic stress disorder (PTSD), obsessive-compulsive disorder, and schizophrenia. Several explanations for this symptom have been suggested, including incomplete memories, changes in visual brain structures and function, inappropriate viewing patterns, and an individual's ability to imagine visual scenes in detail. The emotional tone of a scene has also been shown to affect viewing patterns, which may lead to attention being narrowly directed toward specific visual details while ignoring surrounding information. This study tested whether inappropriate viewing patterns to central and outer image regions in negative images influence narrow focus to emotional details, thereby allowing flashback-type imagery to occur following a traumatic or stressful event. Viewing patterns and blood flow in brain regions were measured while participants (N = 39) viewed and imagined scenes with negative or neutral emotional tone. Self-reported detail of voluntary mental imagery and other cognitive factors such as content familiarity and pleasantness were used to investigate a relationship between viewing and imagery of emotionally negative scenes. Results showed that certain cognitive factors as well as the type of visual task significantly affected particular eye movements and patterns of blood flow in visual regions of the brain. These measures interacted with cognitive factors such as imagery detail and content familiarity. Findings further suggest that behaviors observed during mental imagery reveal cognitive processes over and above those during viewing and may be useful in the study of disorders such as PTSD.

Acknowledgements

I would like to thank my advisor, Dr. Anthony Cate, for extending the opportunity for me to study at Virginia Tech and for sharing his expertise and guidance in the field of visual perception. I appreciate your confidence, support, and advice in both academic and professional matters over the last four and a half years. This experience has helped me grow as a scientist, a researcher, and a person, and I have truly enjoyed the journey.

I am grateful to my committee members, Drs. Rachel Diana, Martha Ann Bell, and Stephen LaConte for their insightful perspectives and for challenging me to push myself as a scholar. Many other faculty have contributed to this work through various conversations and ideas which encouraged me to learn new skills and refine old ones. I would particularly like to thank Dr. Robin Panneton for the opportunity to explore eye tracking methodologies for the first time, as well as the members of the fNIRS working group for generously sharing their time and knowledge.

I am grateful for all of the wonderful and intelligent people I have had the privilege of meeting during my time at Tech. To my labmates, James and Priya, I have enjoyed our many diverse conversations, both work-related and personal, and I am glad we were able to share this experience together. This project was greatly helped by the efforts of three enthusiastic and impressive undergraduate researchers, Olivia O., Nureen S., and Olivia B., who made the work much less overwhelming and a lot more fun. I would especially like to thank my cohorts: Fang Wang, for her endless patience and positivity as she guided me through every step of this process, and Meg O'Neill for her advice and friendship. These and many others have made the past several years meaningful and enjoyable in ways that will last far beyond graduation.

I would not be who and where I am today without my dearest friends, Scott Burton, Sarah Sheffield, and Monèt Sutton. Thank you for rooting for me and sticking by my side even when I couldn't be near. My sincerest appreciation goes to Aschvin Chawan for his immeasurable support and understanding. Thank you for listening to me, helping me, and for believing in me when the going got rough and I had my doubts. You have truly been my rock throughout this entire process. This win is for us.

Finally, I can never fully express the gratitude and love I have for my family and the continued support they have shown throughout my life. Though they may be far, I know that my sister, Jennifer Schultz, grandparents, aunts, and uncles have been rooting for me since the beginning. Above all, I wish to thank my parents, Daniel Roldan, Jr. and Rosalie Seawell, without whom none of this would be possible. Your unending love, support, foresight, and teaching have allowed me achieve this accomplishment, and I am forever grateful for the opportunities you have provided me.

I dedicate this work to my father, who has shared in this journey every step of the way.

Table of Contents

List of Tables x

List of Figures xii

Introduction 13

Memory and PTSD 14

Visual Processing in Healthy and Disordered Systems 15

Neural Correlates 15

Eye Movements 16

Eye Movements During Visual Processing 16

Mental Imagery in PTSD 18

Assessment of Visual Processing and Mental Imagery 20

Eye Tracking. 20

Neural Correlates 21

Behavioral 22

Hypotheses 24

Method 25

Participants 25

Behavioral Questionnaires 26

Mental Health Screening 26

Demographics 26

Baseline Mental Imagery 26

Post-Task Survey 27

Intrusive Imagery Survey 27

Procedure 27
Eye Tracking 27
Hemodynamic Response 28
Baseline Blocks 30
Visual Task 30
Stimuli 30
Presentation Order 31
Viewing Trials. 31
Analyses 32
Behavioral Data 32
Eye Tracking 32
fNIRS. 33
Results 35
Behavioral Data 35
VVIQ-2 35
Post-Task Survey 35
Comparison of Valence Ratings. 35
Intrusive Imagery Survey 36
Eye Tracking 37
Valence and Vividness Ratings. 37
Total Fixations. 38
First Fixations. 39
Item AOIs 40

Hemodynamic Response 41

Functional Localization. 43

Discussion 43

Behavioral Data 44

Eye Tracking 45

Hemodynamic Response 49

Summary and Implications 54

References 57

Appendix A 105

Appendix B 106

Appendix C 107

Appendix D 109

Appendix E 112

Appendix F 117

Appendix G 123

Appendix H 129

Appendix I 132

Appendix J 134

List of Tables

Table 1: General Category Descriptors for Negative and Neutral Stimuli 68

Table 2: Post-Task Survey Familiarity and Pleasantness Ratings 69

Table 3: Qualitative Summary of Intrusive Imagery Survey Responses 70

Table 4: Average Pleasantness and Vividness Ratings for 37 Participants 71

Table 5: Regression of Vividness of Mental Imagery and VVIQ Score 72

Table 6: Summary of Total Fixations for Negative Stimuli 73

Table 7: Summary of Total Fixations for Neutral Stimuli 74

Table 8: ANOVA for Total Count and Duration Difference Scores 75

Table 9: Linear Mixed Effects Regression for Total Fixation Difference Scores 77

Table 10: Summary of First Fixations during Viewing Tasks 79

Table 11: Summary of First Fixations during Imagining Tasks 80

Table 12: ANOVA for Difference Scores of First Fixation Measures with Interaction Terms 81

Table 13: Linear Mixed Effects Regression for First Fixation Difference Scores 82

Table 14: Item AOIs Descriptive Statistics for 40 Images 84

Table 15: ANOVA for Item Count and Duration Ratio 85

Table 16: ANOVA for Mean Occipital OxyHb 86

Table 17: Linear Mixed Effects Regression for Mean Occipital OxyHb 87

Table 18: Selected Effects Identified by Interactive Mixed Effects Regression of Mean Occipital OxyHb 88

Table 19: Peak and Latency to Initial Peak Values for Mean OxyHb 89

Table 20: ANOVA for Mean OxyHb - Motor vs. Occipital Optodes 90

Table 21: Linear Mixed Effects Regression - Motor Regions.....91

List of Figures

Figure 1: Conceptual model 92

Figure 2: Progression of the experimental study 93

Figure 3: fNIRS optode layout.....94

Figure 4: Progression of visual task trials.....95

Figure 5: AOI selection 96

Figure 6: Rating screen AOIs 97

Figure 7: Mean difference score for total fixation measures 98

Figure 8: Mean difference scores for first fixation measures 99

Figure 9: Sample gaze plot data.....100

Figure 10: Number of observations per optode channel.....101

Figure 11: Probe plots for occipital optode locations.....102

Figure 12: Group mean OxyHb concentration averaged across occipital channels 104

Introduction

Persistent re-experiencing of involuntary mental images is a hallmark characteristic of several psychopathological disorders (Holmes & Mathews, 2010 & Pearson, Naselaris, Holmes, & Kosslyn, 2015), including posttraumatic stress disorder (PTSD), obsessive compulsive disorder (OCD; see Blackwell et al., 2015), depression (Holmes & Mathews, 2010), and schizophrenia (Sack, Ven, Etschenberg, Schatz, & Linden, 2005). These recurrent and intrusive mental images contribute to significant stress and reduced life satisfaction for those affected by them. Mental imagery - described as the ability to mentally reproduce the experience of a familiar or novel visual stimulus in the absence of appropriate concurrent physical stimulation (Pearson & Kosslyn, 2013) - allows individuals to revisit past events and visualize those that may occur in the future (Gilbert & Wilson, 2007; Moulton & Kosslyn, 2009). Previous research has implicated abnormal patterns of mental imagery processes in psychopathological disorders, including reduced vividness of detail in mental imagery in patients diagnosed with PTSD and comorbid depression (Karatzias, Power, Brown, & McGoldrick, 2009) and increased detail of mental imagery in patients with schizophrenia (Sack et al., 2005). In the particular case of PTSD, vivid re-experiencing of distressing visual imagery, commonly referred to as flashback, has been theorized to result from incomplete or maladaptive memory encoding (American Psychiatric Association, 2000, 2013; Rubin, Berntsen, & Bohni, 2008). Although the neurobiological and psychological mechanisms underlying these atypical patterns of mental visualization remain unclear, evidence from several psychological fields of research suggests that aberrant perceptual strategies during the initial event, influenced by both bottom-up sensory and top-down cognitive and emotional factors, may underlie the formation of these maladaptive memories and their associated visual mental representations.

The current study evaluated a potential perceptual mechanism for the formation of maladaptive or incomplete visual representations by investigating whether the areas toward which non-clinical individuals tend to direct fixations vary as a function of the emotional content of a visual scene. The relationship between fixation patterns and the formation of mental representations were examined by comparing eye movement and hemodynamic response data collected during viewing and voluntary mental imagery of the same images. Gaze patterns and hemodynamic response were explored to identify significant variations related to stimulus valence and visual task. The findings of this study may be used to inform a model of healthy perceptual and cognitive processes underlying the creation of visual mental representations. Further expansion of these results in patients who experience intrusive imagery may lead to an improved understanding of how these processes are altered in clinical samples. Due to its unique and prevalent association with intrusive visual imagery in the form of flashbacks, PTSD is the target of discussion and illustration within this study. However, the perceptual and cognitive mechanisms and processes investigated herein may or may not be unique to that particular disorder.

Memory and PTSD

Researchers and clinical diagnostic manuals historically acknowledge, either explicitly or implicitly, the influence of memory processes as a key component of PTSD, although the exact role of memory in the development of the disorder remains the subject of debate. Re-experiencing, included as one of the criteria for diagnosis outlined by the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-V) includes “spontaneous memories of the traumatic event” as part of its definition (American Psychiatric Association, 2013). Memory was proposed as an explicit mediator of PTSD symptomatology as recently as

within the past decade (Rubin et al., 2008). Importantly, the memory component in Rubin et al.'s (2008) proposed model encompasses the constantly evolving distortions and interpretations imposed by repeated reconstruction of past experiences. Behaviorally, adding context to a memory as a part of therapeutic intervention has been shown to reduce distressful symptoms of the disorder, including flashbacks (Adenauer et al., 2011); this is discussed further in later sections. Together, these findings support a distinct relationship between imagery-related symptoms and the memory characteristics associated with a traumatic event.

Visual Processing in Healthy and Disordered Systems

Neural correlates. Disparities in low-level visual processing have been implicated by both behavioral assessments and measurements of direct neural activity in PTSD patients. When two trauma-exposed groups were presented with blurred images containing trauma-related, general threat, or neutral visual content, individuals diagnosed with acute stress disorder (ASD) or PTSD identified trauma-related images better than neutral images (Kleim, Ehring, & Ehlers, 2012). This effect was stronger in survivors diagnosed with a clinical disorder, and the observed advantage for perceptual processing was found only for trauma-related images and not for those depicting general threat. Importantly, these perceptual effects correlated with re-experiencing, dissociation, and likelihood of developing PTSD (in ASD patients) at 6-month follow-up. An abnormal bias in visual perceptual processing of trauma-related stimuli may therefore facilitate later triggering of involuntary and intrusive trauma memories in PTSD (Kleim et al., 2012). In addition, resting-state functional magnetic resonance imaging (fMRI) of PTSD patients implicates decreased functional connectivity within low-level visual perceptual networks (Shang et al., 2014). Decreased neural activation in response to visual scenes with varying emotional salience has also been identified within the striate, extrastriate, inferior temporal, and entorhinal

cortices of the ventral visual processing stream (Mueller-Pfeiffer et al., 2013). Such distinct patterns of neural activity in patients with PTSD suggest observable differences in neural processing of visual stimuli.

Eye movements. Several factors are known to influence eye movement patterns in healthy individuals, including stimulus valence (Broadbent & Gregory, 1967) and the top-down direction of attention (Baruch, Kimchi, & Goldsmith, 2014). The effect of emotional content on neural perceptual processes is particularly apparent in patients with PTSD. After viewing repeated images of emotionally transfigured faces, combat-exposed veterans with PTSD showed a marked decrease in amplitude of fMR adaptation effects within visual cortical areas compared to non-clinical controls, despite the low-level visual features remaining largely the same across emotional content conditions (Hendler, Rotshtein, & Hadar, 2001). Increased activation in visual cortex has been observed in response to backwards-masked combat images in PTSD veterans (Hendler et al., 2003). In this study, patterns of visual cortex activity in PTSD veterans was significantly different from that of healthy veterans only for images that fell below the perceptual threshold for conscious recognition, suggesting increased vigilance independent of top-down direction. Greater overall amygdala activity was also observed in the PTSD group, regardless of whether images were subthreshold (Hendler et al., 2003). Emotional attributes of a stimulus therefore appear to modulate early levels of attention and visual cortical activity, over and above low-level visual features and conscious recognition, although the exact mechanisms facilitating preattentive visual processing related to emotional context remain unclear.

Eye Movements during Visual Processing

Eye tracking during emotionally neutral objection recognition tasks reveals that saccades and duration of fixations tend to be biased toward categorically informative object features

(Baruch et al., 2014). These features, referred to as diagnostic or distinguishing features, enhance the efficiency and speed of object identification by eliminating possible alternatives during object identification within a specific context. The properties of a distinguishing feature in any given situation vary according to visual context (Baruch et al., 2014; Schlangen & Barenholtz, 2015) as well as top-down cognitive factors (e.g., selective attention; Ballesteros & Mayas, 2015). The semantic cognitive significance, condensed information form, and emotional context properties of distinguishing features make them likely to be influential components of visual mental representations (see Arntz, de Groot, & Kindt, 2005) which may be particularly susceptible to cognitive distortions; inefficient perception of distinguishing features may then facilitate maladaptive mental representations that lend themselves to intrusive re-experiencing.

The so-called weapon focus effect (WFE) illustrates the influence of emotional context on gaze (Loftus, Loftus, & Messo, 1987). This term describes the tendency for typical observers to preferentially focus on a weapon in a scene within specific contexts, leading to decreased accuracy for memory of contextual, but relevant, visual details (e.g., the face of the assailant). This effect depends heavily on the overall context of the scene; when the same image is manipulated to depict a person holding a check rather than a gun, fixations to the object are reduced and memory for the perpetrator's face improves (Loftus et al., 1987). Further research has shown that the WFE is unlikely to be mediated by the visual properties of the gun itself; emotionally neutral yet unexpected objects (e.g., a tomato) triggered gaze patterns similar to those observed when the target object was a gun (Flowe, Hope, & Hillstrom, 2013). Critically, the WFE appears to be mediated almost entirely by the observer's perception of whether the gun is threatening or not - a property dependent upon the larger context of the scene in which it appears.

Emotional tone and perceived arousal in response to visual content have been found to differentially modify visual processing of central and peripheral visual information. Images from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 1997), rated to have either neutral valence and neutral arousal or negative valence and high arousal were manipulated to occlude either the central or peripheral image regions (Yegiyan & Lang, 2010). Following the rule of thirds, the researchers operationalized the central field as the innermost one third of an image and the peripheral field as the outer two thirds. They then created two versions of each image in which one field or the other was occluded. Participants were tested for recognition of visual details in both conditions by responding yes or no to questions assessing memory for specific image details. Results showed that recognition for central visual details increased as arousal increased. Recognition for peripheral detail, however, decreased at different rates for positive and negative details, with recognition performance of peripheral negative details decreasing more rapidly than that of peripheral positive details. Although it is unclear whether this manipulation generalizes to natural visual search patterns in an intact scene, patterns of recognition deficits in peripheral and central visual details and their interaction with emotional valence suggest a possible perceptual mechanism that may be affected in individuals with PTSD.

Mental Imagery in PTSD

Substantial evidence points to mental imagery as an influential component of psychopathological disorders. In healthy individuals, mental imagery tends to evoke a stronger emotional response than verbal representations - an effect which may be attributed to shared neural mechanisms of perception and imagery (see Holmes & Mathews, 2010 for review). Neural systems responsible for encoding perceptual and emotional experiences overlap with those that facilitate mental fabrication of these experiences (Naselaris, Olman, Stansbury,

Ugurbil, & Gallant, 2015; Slotnick, Thompson, & Kosslyn, 2005, 2012), resulting in reactivation of relevant visual regions during mental imagery. A parallel pattern is observed in neural systems of memory: brain areas active during memory encoding tend to be reactivated during retrieval (Nyberg, Habib, McIntosh, & Tulving, 2000). Patterns of neural reactivation at time of memory retrieval may extend beyond the sensory modality explicitly demanded at the time of recall, thus reflecting involuntary activation of context at the time of memory encoding (Nyberg et al., 2000; Wheeler, Petersen, & Buckner, 2000). These neural mechanisms suggest a physiological route that directly connects cognitive and perceptual processing during the initial experience to later recall through mental imagery. Based on these findings, the current study explores whether mental imagery abilities interact with patterns of perceptual encoding to produce intrusive and involuntary re-experiences following a traumatic event.

Empirical research and observations through clinical practice support an interaction between mental imagery and emotional and psychological disorders. Patients diagnosed with PTSD and comorbid depression tend to report lower ratings of vividness during voluntary mental imagery as compared to healthy controls (Karatzias et al., 2009). Higher self-reported ability to control mental images is associated with fewer intrusive PTSD symptoms (Laor et al., 1999). In practice, targeting mental imagery as a part of treatment for this disorder has been shown to effectively reduce the occurrence and magnitude of intrusive symptoms (Adenauer et al., 2011; Holmes, James, Kilford, & Deeprose, 2010; Holmes & Mathews, 2010; Pearson et al., 2015). Exercises such as narrative exposure therapy, which require voluntary mental imagery, encourage top-down processing of aversive stimuli and have been shown to improve symptoms associated with flashback experiences (Adenauer et al., 2011).

Interventions that target the time period immediately following a traumatic event also implicate memory and mental imagery processing in outcomes related to intrusive imagery. Playing 10 minutes of the computer game Tetris® up to 4 hours past exposure to traumatic content has been shown to decrease the frequency and vividness of flashbacks in healthy individuals over the following week (Holmes et al., 2010). These moderating effects were not found in participants who were asked to complete a word-based game following traumatic exposure, indicating that symptom benefits do not result purely from cognitive distraction, but from some aspect of visual engagement. This intervention is unique in that it exclusively targets post-event visual perceptual processing without explicitly addressing the event through direct instruction of cognitive strategies. Although the resulting effects were identified in a non-clinical sample exposed to a traumatic video paradigm, the findings suggest that some significant process occurs after exposure to the initial traumatic stimulus; the unique efficacy of visual-based distraction implicates visual perceptual processes which take place in the absence of the original event. The following study aims to test the hypothesis that mental representations, or memories containing constructed and distorted cognitive properties, are the mechanisms functioning during this time period, and that these mental representations are reflected in mental imagery of past experiences.

Assessment of Visual Processing and Mental Imagery

Eye tracking. Multiple studies support a consistent, though indirect, relationship between saccadic eye movements and attention to specific visual features (Herwig & Schneider, 2014). These fixations are guided by expectations derived from peripheral visual information (Becker, Pashler, & Lubin, 2007). Eye movements serve as a reliable proxy of cognitive processes due to their demonstrated independence from conscious memory or verbal recognition;

a study of amnesic patients demonstrated that eye movements observed when viewing an image predicted whether the image had been presented previously or not, even in cases when the participant failed to remember seeing the image before (Ryan et al., 2007). Gaze patterns, fixation durations, and spatial gaze location between mental imagery and viewing have been found to be positively correlated (Laeng, Bloem, D'Ascenzo, & Tommasi, 2014; Richardson & Spivey, 2000), suggesting eye tracking as a potential index of visual perceptual and imaginary processes. Restricting fixation patterns to regions unrelated to the target stimulus during mental imagery is associated with decreased memory accuracy, indicating that the recreation of perceptual eye movement patterns may be an important component of visual memory (Laeng et al., 2014). Indeed, there is evidence that eye movements play in active role in memory retrieval processes, particularly memory for spatial relationships among objects (Johansson & Johansson, 2014; Richardson & Spivey, 2000).

Neural correlates. Neural activity as reflected by cortical blood flow measured by functional near-infrared spectroscopy (fNIRS) has shown some success as an indicator of low-level visual processing. NIRS is a portable, flexible experimental tool that non-invasively measures the diffusion rate of near-infrared light projected through the skull to detect changes in oxygenated and deoxygenated hemoglobin concentrations in cortical tissue (Kamran & Hong, 2013). In practice, studies have shown that oxygenated hemoglobin concentration best captures changes in blood flow related to cognitive tasks (Shi, Sakatani, Okamoto, Yamaguchi, & Zuo, 2014). In addition to allowing free and natural movement during testing, the system provides finer temporal resolution than fMRI and moderate spatial resolution limited by the lateral and depth penetration afforded by the infrared emitter. Although fNIRS is only capable of accessing areas of cortex lying closely beneath the skull and approximately 2 to 3 cm below the cortical

surface, previous studies have shown that fNIRS can be used to successfully index hemodynamic changes in human adult early and ventral visual cortex (Meek et al., 1998; Takahashi et al., 2000; Wilcox, Bortfeld, Woods, Wruck, & Boas, 2005). Recordings of adult primary visual cortex and supplementary neurophysiological measures indicate that fNIRS is capable of distinguishing patterns of stimulus-dependent effects as well as area specificity in the visual modality (Chen, Sandmann, Thorne, Herrmann, & Debener, 2015; Toronov, Zhang, & Webb, 2007; Ward, Morison, Simpson, Simmers, & Shahani, 2016; Wijeakumar, Shahani, Simpson, & McCulloch, 2012).

Behavioral. Survey questionnaires have been used to assess trait characteristics in mental imagery ability. The Vividness of Visual Mental Imagery Questionnaire – 2 (VVIQ-2; Campos, 2011; Marks, 1995) has been demonstrated to yield a successful and reliable measurement of various aspects of visual representations. The survey prompts respondents to visualize specific scenes, such as a sunset, and report on the clarity and detail of the generated images using Likert scale responses. Critical statistical testing of the VVIQ-2 and its variants indicate high internal validity for measuring the mental imagery construct (Campos, 2011). Furthermore, behavioral evidence suggests that metacognition of one's own imaginative experience is reliable and accurate (Pearson, Rademaker, & Tong, 2011).

Theoretical Model

The current study proposes that aberrant representations underlie intrusive mental images characteristic of mental disorders such as PTSD. These aberrant mental representations are expected to result from perceptually incomplete or inefficient binding of the item and the context in which it is first experienced, leading to maladaptive mental representations which become overgeneralized to and cued by novel situations.

The relationship between an item, generally defined as the subject of cognitive, attentional, or emotional relevance, and its context, or surrounding information has been addressed both explicitly and indirectly in the study and treatment of PTSD and the mechanisms underlying PTSD-related symptoms. In healthy systems, the binding of item in context theory (BIC) of memory emphasizes the distinction between the target item (Diana, Yonelinas, & Ranganath, 2007) and the surrounding information in which it is presented, or context. Perceptually, behavioral performance suggests that healthy memory for neutral visual objects represents some item properties more strongly than others, as evidenced by different forgetting rates for item properties such as object state (e.g., open vs closed) and color (Brady, Konkle, Alvarez, & Oliva, 2013). This distinction is important because it suggests that lack of binding or bound recall between items, whether perceptual scenes or individual visual objects, and the details of their original context may lead to more generalized activation of their associated properties. The lack of context then becomes a mechanism by which images are involuntarily activated in future situations, resulting in intrusive and persistent re-experiences. As suggested by the previous study performed by Yegiyan & Lang (2010), one possible mechanism for this inefficient binding may be reflected in differential visual attention directed toward central and peripheral regions of a visual scene.

Based on the evidence for a relationship between mental imagery and intrusive imagery symptoms, this study investigated potential perceptual mechanisms underlying the formation of mental representations that facilitate involuntary reimagining. The following experiment examined the interaction between gaze patterns toward central and peripheral regions of emotional scenes and subsequent mental imagery. Variations in attention to these regions may indicate a lack of binding for relevant items with their appropriate context, leading to incomplete

mental representations that are easily cued by inappropriate or novel scenarios and situations. Perceptual processes were investigated via eye movements and hemodynamic response during viewing and mental imagery of neutral valence, moderate arousal and negative valence, high arousal scenes. Baseline mental imagery abilities and subjective reports of arousal, affect, and mental representations were assessed through self-report.

Figure 1 presents an overarching theoretical model which synthesizes previous literature and the predictions of the current experiment. Fixation patterns and hemodynamic response are considered to be observable behaviors necessary for and affecting the formation of mental imagery representations. Scene valence is expected to moderate these measures. These factors at play during the initial formation of the representation are then reflected during voluntary mental imagery and are predicted to influence later intrusive, involuntary re-experiencing.

Hypotheses

Specific outcomes predicted for this study were as follows:

1. Stimulus valence is expected to have a significant main effect on eye movement patterns during viewing and imagining tasks.
    a. Specifically, number and duration of fixations are expected to be greater to central image regions than for peripheral during both viewing and imagining of negative stimuli as compared to neutral.
    b. Number and duration of fixations to individual items in the central image region are predicted to increase during viewing of negative stimuli.
2. Patterns of hemodynamic response in visual cortical optode locations are predicted to be highly similar across viewing and imagining tasks, but moderated by stimulus valence.

3. Gaze patterns and hemodynamic response are expected to be moderated by baseline vividness of mental imagery scores.
    a. Lower vividness scores are expected to predict larger number of fixations to central image regions during viewing and imagining of negative stimuli.
    b. Valence is expected to have a greater moderating effect on hemodynamic response during viewing and imagining in observers with lower vividness scores.

Method

The current study employed 1) self-reports of baseline mental imagery abilities; 2) eye movement patterns during viewing and imagining of negative and neutral valence images, and 3) hemodynamic response in visual cortical areas during viewing and imagining of the same images, as indexed by the BOLD response captured by fNIRS. An outline of the progression of the experiment is provided in Figure 2.

Participants

A total of 39 participants (21 female, 18 male) aged 18 or older with normal or corrected-to-normal vision were recruited from the Virginia Tech and surrounding communities. Ages of participants ranged from 18 to 59 years, with a mean age of 22.67 and a median age of 20. The majority of participants (66.7%) self-identified as White/Caucasian, 25.6% as Asian, 5.1% as Black/African American, 5.1% as Hispanic/Latino, and 2.6% as Native Hawaiian/Pacific Islander. All participants provided informed consent and indicated no prior history of psychological illness; study procedures conformed to institutional IRB guidelines. Participants were compensated for time needed to complete the in-lab study; completing the follow-up survey earned an entry to a raffle for additional compensation. One male participant was excluded from analyses due to an error in sequence presentation, resulting in 38 participants with viable data (17

males, 21 females). Race distribution and age measures in the final sample did not vary significantly from the original sample.

Behavioral Questionnaires

After providing informed consent, participants completed several brief electronic surveys administered through Qualtrics online survey software (Qualtrics, Provo, UT).

Mental health screening. Prior to participation, volunteers completed a general mental health screening form indicating that they had never been diagnosed with nor suspect that they may have any psychological or emotional disorders, including depression, PTSD, anxiety, or schizophrenia and had not experienced one or more severely upsetting or traumatic events which caused lasting psychological distress (Appendix A). The form also identified medical contraindications such as history of epilepsy. Participants who responded "yes" to any question, with the exception of "…able to tolerate viewing offensive images…," were not permitted to continue in the study.

Demographics. A standard demographics form was used to collect data on participant age, gender, ethnicity, race, and any history of vision abnormalities.

Baseline mental imagery. Vividness of voluntary mental imagery was assessed using a version of the VVIQ-2 (Marks, 1995) adapted from the online version offered by Millisecond Software (http://www.millisecond.com/) and recreated in Qualtrics software. The VVIQ-2 requires participants to rate the clarity and detail with which they visualize details related to four written scenarios using a scale of 1 to 5 (1 = "No image at all," 5 = "Perfectly clear & vivid as if I was actually seeing it"). Visual imagery prompts were performed and reported first with eyes closed and then repeated with eyes open. Appendix B contains an example of a question transposed from the online VVIQ-2 as it was presented in the current study.

Post-Task survey. After completing the visual task, participants provided ratings on a scale of 1 to 5 regarding 1) pre-task familiarity with the subject matter of the experimental images and 2) general pleasantness of the subject matter categories (Appendix C). Limited responses related to the participant's emotional experience during the visual task were also collected.

Intrusive Imagery survey. A brief online survey was distributed to participants via email one week following completion of experimental trials. The survey asked participants to report on the frequency and characteristics of any involuntary re-experiences (intrusions) of the images involved in the experiment. Although the experimental paradigm was not designed nor expected to be particularly traumatic, at least one previous study has demonstrated meaningful involuntary mental visual recollections related to research content in healthy participants (Holmes et al., 2010). Data collected from this survey were used to identify the frequency and content of involuntary recollections in the study sample, thereby allowing for speculation on the relationship between experimental measures and the flashback experiences observed in PTSD.

Procedure

After completing the mental health screening form, demographics survey, and VVIQ-2, participants were seated in front of a 32 inch Samsung LED monitor, underneath which a portable infrared eye tracker was mounted. An fNIRS recording system was stationed on a moveable cart behind the participant.

Eye tracking. Eye movement data were collected using a Tobii X2-60 eye tracker (60 Hz sampling rate). Prior to beginning the experiment, participants were positioned to be within 55-65 cm of the eye tracker to ensure optimal tracking. The lights of the testing room were dimmed and 5-point adult calibration was performed through Tobii Studio testing software (v. 3.3).

Calibration was accepted when high overlap was achieved over at least three of the five calibration points; due to complications with recording angle, several participants were not well-tracked at the top left and right corners of the screen. However, subsequent calibration checks indicated tracking fidelity within a reasonable margin of error given the size of the regions of interest.

Experimental stimuli were presented using Tobii Studio operating on a Dell laptop computer entirely separate from the fNIRS system. Default I-VT fixation filter was applied to identify fixations lasting 60 ms or longer. During the study, participants were instructed to view the experimental images as they normally would and were allowed brief break periods between each block. Stimulus presentation was time-locked with hemodynamic response data via a Cedrus® StimTracker (http://www.cedrus.com/stimtracker/) that detected audio signals embedded within the Tobii Studio protocol prior to the onset of viewing and imagining trials. These audio signals triggered the creation of automatic event markers within the fNIRS recording. Event triggers sounds (consisting of a brief computer-generated tone) were not audible to the participant and served only as a digital signal to be recorded by the fNIRS system.

Hemodynamic response. A 42-channel NIRScout fNIRS system (NIRx Medical Technologies) continuously recorded blood flow reflecting metabolic demands in cortical tissue during experimental tasks. NIRStar 13 software (NIRx Medical Technologies; http://nirx.net/nirstar-1/) was used to perform signal calibration and collect experimental recordings. Optodes were placed according to the default occipital-motor 16x16 channel montage provided by the NIRStar program (Fig. 3). Although visual occipital cortex was the target region of interest, recordings were collected from motor areas to provide a functional comparison of task-related hemodynamic response (HDR) between the two areas. Approximate

distance between source and detector optodes was 2 cm. Source wavelengths were recorded at 760 nm and 850 nm, with a sampling rate of 3.91 Hz.

Cap preparation. Head circumference was measured roughly an inch above the eyebrows using a flexible measuring tape. When head size fell between the two-centimeter interval of the available caps, the measurement was rounded down to the next smallest size in order to provide a snug fit. Center cap placement was verified by ensuring that the center optode holder, which corresponds to Cz in the 10/20 system, was positioned approximately halfway between the distance from nasion (between the eyebrows) to inion (apex of the occipital ridge). A chin strap was used to ensure cap stability.

Due to limited supplies, spring-loaded grommets were used for occipital channels only. Standard optode holders were used over motor regions; motor channel optodes were positioned prior to cap placement in order to prevent undue discomfort to the wearer. Prior to attaching occipital optodes, cotton swabs were used to gently brush hair away to reveal the scalp surface; ultrasound gel was applied as needed to improve hair clearance. These steps significantly improved calibration quality by reducing obstructions to the path of infrared light between scalp surface, sources, and detectors. Protruding spring-loaded caps prevented the use of an overcap. Prior to experimental trials, a privacy screen was placed between the participant and the experimenter to reduce distractions and minimize light reaching recording optodes. Calibration was accepted when as many occipital channels as possible displayed a signal quality value of "Acceptable" or "Excellent" within 2-4 readjustment attempts. Participants were instructed to remain as still as possible during visual tasks; they could stretch and reposition during regular break intervals as necessary.

Baseline blocks. Baseline blocks, consisting of a fixation stimulus lasting 20 s, were collected twice during the study; once prior to beginning visual trials and once at the end of the study. Participants were asked to fixate the cross and remain as still as possible during these periods.

Visual Task

Stimuli. Visual stimuli consisted of 40 images selected from the IAPS database (Lang et al., 1997). Images were grouped into negative (Negative) or neutral (Neutral) emotional categories based on valence and arousal ratings on a scale of 1 - 9 (1 = negative valence/lower arousal) provided by the IAPS. Negative stimuli were selected from images with IAPS mean valence ratings of 1.0 – 4.0 (high negative emotion) and arousal ratings of 5.5 – 9.0 (high arousal). Selection criteria for Neutral stimuli included valence ratings of 4.5 – 5.5 with arousal ratings of 3.0 – 5.0. Valence and arousal ratings for the final set of Negative images used in the current study ranged from 1.69 – 3.9 and 5.5 – 6.94, respectively. In comparison, valence and arousal ratings for Neutral images ranged from 4.55 – 5.48 and 3.0 – 4.97, respectively. Mean valence rating for Negative images was 2.63 (SD = 0.12); mean arousal rating was 6.04 (SD = 0.24). Mean valence rating for Neutral stimuli was 5.14 (SD = 0.09); mean arousal rating was 3.64 (SD = 0.25). Stimuli were grouped into general emotional and content categories to collect familiarity and pleasantness ratings in the Post-task Survey (Table 1).

An attempt was made to choose images portraying rich realistic scenes and which contained an identifiable center of focus and at least 1-2 potential areas of focus in the periphery (e.g., images of single objects against blank backgrounds not considered). In order to improve standardization of potential fixation targets, some images were cropped to better identify a central region of focus; in these cases, the native aspect ratio was maintained. Shocking, gory,

and erotic content were avoided to minimize the influence of between-subjects cognitive factors on patterns of gaze and HDR.

Presentation order. Stimuli from each emotional category were blocked into four groups of five and counterbalanced to create four predefined presentation sequences consisting of blocks with similar mean valence ratings (Appendix D). Two of the four presentation sequences began with Negative blocks and two with Neutral. Sequences were pseudorandomly preassigned to participants to provide a roughly equal number of instances of each sequence.

Viewing trials. During Viewing trials, stimuli were presented at full size (1720 x 1280 px), in full color (Fig. 4.A.). Due to the widescreen format of the monitor, black bars appeared on the left and right side of the image when presented the monitor. Stimuli were presented for 5 s, preceded by a fixation period of 6 s and followed by a 12 s fixation cross. Fixation crosses consisted of a black 72 pt plus sign against a medium gray background (RGB [158 158 158]).

Following image presentation and the 12 s fixation trial, participants were shown an instruction screen (5 s) asking them to rate the pleasantness of the preceding image. The numbers 1 through 5, bounded in rectangles, appeared along the bottom of the screen. Participants were instructed to indicate their response by fixating on the number corresponding to their chosen rating for the duration of the instruction screen (1 = unpleasant, 5 = pleasant; Fig. 4.B.). This screen was then proceeded by a 4 s fixation cross leading into a mental imagery trial.

Mental imagery trials. Imagining trials began with the word “Imagine” in all capital letters appearing briefly on the screen (2 s) to prepare participants to perform mental imagery of the scene they most recently viewed on the following blank screen (5 s). Participants were instructed to keep their eyes open during the task and to visualize the scene “as if it were back on the monitor,” but were not directly instructed to make eye movements during the imagery task. A

12 s fixation stimulus proceeded this trial, followed by a rating of prompt for the vividness of the mental imagery they had just performed (5 s; 1 = low vividness, 5 = high vividness; Fig. 4.B.).

Analyses

Analysis of variance (ANOVA) and linear regression analyses investigating relationships between relevant variables were performed in R Studio (R Core Team, 2013). Correlations were performed in MATLAB (Mathworks). Unless otherwise noted, linear mixed effects regressions included subjects as random effects.

Behavioral data. Behavioral data were exported from Qualtrics and analyzed for descriptive statistics. Total VVIQ-2 scores were regressed against fixation patterns and hemoglobin concentration values during Viewing and Imagining trials. Familiarity and pleasantness ratings were averaged across emotional category for each participant. Responses to the Intrusive Imagery survey were averaged and qualitatively summarized by four raters for classification of emotional content and level of detail. Mental health screening surveys were not subjected to statistical analysis.

Eye tracking. Participants with 50% more overall valid tracked time were retained for analyses. Individual Viewing or Imagining trials with less than 50% tracked time were also excluded on a trial-by-trial basis.

Areas of interest. Central areas of interest (AOIs) were operationalized to the pixels overlapping the central 25% the image; peripheral AOIs covered the remaining portions of the image (Fig. 5.A.). Additional Item AOIs delineating cognitively salient features throughout the scene were defined for each image and analyzed for Viewing trials only (Fig. 5.B.). Item AOIs were subjectively defined by two independent groups of two raters with high degree of overlap and limited to polygons or rectangles which enclosed and extended slightly beyond the perimeter

of potential regions of visual attention (e.g., faces, limbs, weapons, etc.). Central and Outer AOIs were recreated on the corresponding blank screens presented during Imagining trials (Fig. 5.C.).

Eye tracking data containing gaze event classification, AOI activity, pupil size, and validity codes were exported from Tobii Studio and imported into MATLAB for preprocessing via a customized script. Data were analyzed to identify latency, duration, and AOI of first fixations as well as number, duration, and AOI of total fixations for each stimulus. First fixations were defined as the first fixation lasting 100 ms or longer. Only image trials for which the preceding fixation stimulus was fixated at least once within the 500 ms period immediately prior to stimulus onset were considered for first fixation analyses.

Valence and pleasantness ratings. Rating scores were bounded by individual AOIs to identify total fixation duration (Fig. 6). Final rating scores were determined by identifying the score AOI with maximum fixation duration. If a maximum fixation could not be identified, the rating trial was discarded.

fNIRS. Raw fNIRS data were exported from NIRStar and converted to .nirs files with the help of a customized MATLAB script created and shared by another laboratory. Probe layout was defined within this script to match the optode layout used by NIRStar. NIRS data were preprocessed offline in HOMER2 software (v. 2.2; http://homer-fnirs.org/). Breaks and motion artifacts were excluded based on visual inspection of the raw signal; any visual task trials occurring during these time periods were also excluded from the calculation of the HRF. Oxygenated hemoglobin (OxyHb) and deoxygenated hemoglobin (DeoxyHb) signals were band-pass filtered at 0.015 Hz and 0.08 Hz as employed by Chen et al. (2015). Channels per participants were excluded based on coefficients of variation (CV) calculated by nirsLAB (NIRx; http://nirx.net/nirslab-1/). Group average CV during the first 10 - 60 s of baseline was 13.84%

for the 760 nm wavelength and 11.27% for the 850 nm wavelength. All channels for which CV exceeded 15% with a gain setting of 8 were excluded for each participant prior to calculating the mean HRF.

The StimGUI toolbox within HOMER2 was used to assign unique values to stimulus triggers that identified Viewing and Imagining trials based on the presentation sequence assigned to each participant. Blocks were averaged over the 6 s preceding a stimulus and 12 s following to capture the full range of task-related hemodynamic response. Raw signal data were cleaned using the default HOMER2 processing stream which involved the following steps: motion artifact (tMotion = 0.5, tMask = 1.0, SD threshold = 20, amplitude threshold = 5.00), stimulus rejection (tRange = -5 – 10 s), band pass filter (high-pass filter = 0.15 Hz, low-pass filter = 0.08 Hz), HDR optical density to concentration (6 – 6 partial pathlength factors), and block averaging (tRange = -6 – 17 s). All other parameters retained default values of 0.

Preprocessed OxyHb and DeoxyHb values, separated by motor and occipital areas, stimulus condition (Negative or Neutral), and task condition (Imagining or Viewing), were exported as text files and imported to MATLAB. Mean OxyHb values, shown to be most closely associated with task-related HDR (Shi et al., 2014), were calculated for each channel per participant and subjected to ANOVA and regression analyses (Chen et al., 2014 & Kojima & Suzuki). In a separate analysis, group mean OxyHb values were calculated across all occipital channels over the full response time course (-6 – 17 s) to identify peak OxyHb values and latency to the initial peak, relative to stimulus onset.

Functional localization. Participants with 5 or fewer invalid channels were analyzed for a separate comparison of activity within these cortical regions (N = 5). An ANOVA and linear

mixed effects regression were used to compare mean OxyHb in motor and occipital channels to exclude the possibility that responses were a result of global HDR changes in scalp blood flow.

Results

Behavioral Data

VVIQ-2. Final VVIQ-2 scores (N = 38; max possible score = 160) ranged from 42 to 131 points with an average of 74.8 points ± 19.75. Due to the inverse rating scale employed by the VVIQ-2, higher scores indicate weaker vividness of mental imagery. No participants reported a complete inability to perform mental imagery.

Post-Task survey. General familiarity and pleasantness scores for Negative and Neutral content categories are provided in Table 2. On a scale of 1 (not familiar at all) to 5 (extremely familiar), familiarity scores for Negative stimuli ranged from 1.15 – 4.54; pleasantness scores from 1 – 4.31 (1 = very unpleasant, 5 = very pleasant). Familiarity for Neutral stimuli ranged from 2.56 – 4.56; pleasantness from 2.78 – 4.11. Overall, ratings for Neutral stimuli were less variable than those for Negative stimuli with slightly higher minimum values for both familiarity and pleasantness.

Comparison of valence ratings. Mean valence ratings collected during the visual task were compared to those contained in the IAPS to verify valence manipulation. The scale employed in the current study ranged from 1 – 5 to allow clear distinction of eye movements and swift response time; this prevented scores from being directly compared to the 1-9 scale used in the IAPS. Scores from both datasets were converted to Z-scores and compared using one-tailed t-tests. Mean valence ratings for Negative stimuli as identified by the IAPS were not significantly different from scores recorded in the current study [$t(38) = .0016$, $p = .999$]. Valence ratings for Neutral images also showed no significant difference [$t(38) = .0047$, $p = .996$].

Intrusive Imagery survey. A total of 31 participants successfully completed and returned the online follow-up survey within two days of receipt (mean time between study participation and survey completion = 7.19 days). Of the 31 respondents, 8 indicated that they had involuntarily thought about or been reminded of the images viewed during the study since participating. Of these, 62.5% (N = 5) indicated that they thought of images 1-2 times, 12.5% (N = 1) responded 3-4 times, and 12.5% (N = 1) indicated 7-8 times. 1 participant (12.5%) responded "Not sure/can't remember." VVIQ-2 scores were not found to be significantly correlated with frequency of intrusions [$r(6) = -0.62$, $p = .1013$], or response detail [$r(6) = 0.3$, $p = 0.475$]. A t-test revealed no significant difference in the average VVIQ-2 score of those who answered "yes" (mean VVIQ-2 = 69.88) and those who did not [mean VVIQ-2 = 78.04; $t(15) = .88$, $p = .20$].

Four respondents further reported that their involuntary thoughts were accompanied by an emotional response or feeling that ranged from "somewhat weak" (N = 2) to "neither strong nor weak" (N = 2). When asked to choose up to 5 emotions experienced during these events from a list of common emotions, sadness was most common (N = 4), followed by anger, sadness, fear, disgust, anxiety, shock (N = 2), and aggression (N = 1).

Qualitative analysis of free responses revealed an apparent bias in the emotional content described by the 4 participants who reported involuntary imagery related to the experimental stimuli, with a majority of descriptions referring to images from Negative content categories (Table 3). A separate question which asked all participants to describe any images they recalled vividly from the study, independent of their re-experiencing, also revealed a bias to Negative images with notably more Neutral content descriptions. Ratings categorizing the amount and relative detail of images described were assigned based on agreement between four researchers

(1 = general or vague description – 5 = very detailed and clear; Table 3). Complete survey responses appear in Appendix E.

Presentation sequence was qualitatively explored as a potential confound influencing intrusion frequency and valence of described images. Of the 8 participants who indicated at least 1 involuntary experience, 5 had been tested with an experimental sequence beginning with a Neutral block and ending with a Negative block. Of the 3 participants who described at least one Neutral image, 2 received sequences that began with a Neutral block and ended with a Negative block. Due to the small sample size, further analyses were not conducted on these data.

Eye Tracking

Among the 37 participants included in the eye tracking analysis, average valid tracked time was moderately high at 79.5% (min = 50.8%, max= 97.5%, SD = 13.4%). One participant with 42.5% valid tracked time was excluded from further analyses.

Valence and vividness ratings. Between-subjects mean valence and vividness ratings appear in Table 4. Average ratings for Negative images ranged from 1.05 – 3.55; Negative imagery vividness ranged from 1.65 – 5.0. In the Neutral category, average valence ratings ranged from 2.7 – 4.6; Neutral imagery vividness from 1.6 – 4.8. Within-subject pleasantness ratings collected during the visual task were moderately and significantly correlated with Post-Task survey responses [Negative and Neutral categories: $r(35) = .51$, $p = .001$]. An ANOVA revealed no significant group mean difference between participant ratings collected during the study and the behavioral survey [Negative category: $F(1,36) = 0.15$, $p = .70$; Neutral category: $F(1,36) = 0.13$, $p = .72$].

Linear regressions showed that VVIQ-2 score was a significant predictor of vividness scores for Negative [$B = -0.014$, $t(35) = -2.876$, $p = .007$] and Neutral imagery [$B = -0.013$, $t(35)$

= -2.847, p = .007; Table 5]. This relationship indicates that, with less vivid VVIQ-2 score (indicated by a higher score on the inverse scale), vividness of mental imagery during imagining tasks decreased by approximately .014 points on a scale of 1 to 5.

Total fixations. Average number of total fixations to the Central AOI and Outer AOI were highly correlated across Negative and Neutral images [Central: $r(35) = .84$, $p < .000$; Outer: $r(35) = .85$, $p < .000$; Tables 6 & 7]. To improve clarity of analyses, difference scores were calculated for each participant by subtracting mean number and duration of Central AOI fixations from Outer AOI fixations, resulting in a single number representing gaze bias to the Central AOI region.

A preliminary ANOVA indicated no significant effect of age [$F(1,29) = 0.021$, p = 0.887], gender [$F(1,29) = 2.177$, $p = 0.151$], sequence [$F(1,29) = 2.353$, $p = 0.0928$], or Intrusive Imagery survey response [at least one involuntary imagery experience; $F(1,29) = 0.115$, p = 0.737] on total fixation count difference scores; results were similar for duration difference scores. An ANOVA in which subjects were identified as random errors explored mean differences in fixation count and duration difference scores relative to VVIQ-2 score, task (Viewing or Imagining), vividness for each image as collected during the visual task (Vivid), average familiarity as reported in the Post-Task survey (Fam.), and stimulus valence (Negative or Neutral). Results appear in Table 8 and graphically in Figure 7, illustrating the main effect of task on fixation count (Fig. 7.A.) and duration (Fig. 7.B.). Familiarity and vividness reflected both by stimulus-specific ratings and VVIQ-2 scores were found to have significant interactions with task and fixation duration difference scores (Table 8).

Linear mixed effects regressions accounting for subjects as random effects revealed no significant effect of VVIQ-2 score, participant age, gender, mean trial vividness, task, valence, or familiarity (as reported in the Post-Task survey) on either total fixation difference score measure (Table 9). A significant main effect of presentation sequence was identified for fixation count difference score, indicating smaller fixation count difference scores in Sequence 4 ($B = 1.783$, $p = 0.031$).

First fixations. Number of first fixations to Central and Outer AOIs (here referred to as first fixation count), latency, and duration of first fixations are summarized in Tables 10 and 11. Difference scores for these measures were calculated using the same method applied to total fixations.

Interactive ANOVAs for all three measures, VVIQ, valence, task, and mean vividness for Negative and Neutral Imagining trials (Vivid), indicated a significant main effect of task on first fixation count [$F(1,109) = 14.564$, $p = 0.0002$] and duration [$F(1,109) = 61.486$, $p < .0001$] difference scores, with the effect on latency difference score just above significance threshold at $F(1,109) = 3.846$, $p = .053$ (Table 12). Mean vividness during Imagining trials was significantly correlated with first fixation latency difference score [$F(1,109) = 3.992$, $p = 0.049$]. Overall, count and duration first fixation difference scores were significantly moderated by task (Fig. 8).

An interactive ANOVA including familiarity and vividness revealed a significant interaction of valence, mean vividness rating, and familiarity on first fixation count difference score [$F(1,25) = 12.366$, $p = 0.00123$], an interaction of mean vividness and familiarity [$F(1,25) = 5.072$, $p = 0.0333$] and a main effect of vividness [$F(1,83) = 4.427$, $p = 0.03841$] on first fixation latency difference score (Appendix F). A significant three-way interaction of valence, vividness, and familiarity [$F(1,83) = 4.440$, $p = 0.03813$], as well as a four-way interaction

including VVIQ [$F(1,83) = 7.012$, $p = .00969$] was identified for first fixation latency difference score. Together, these results suggest a significant interaction of vividness ratings and familiarity with stimulus valence that is unique to first fixation latency. Familiarity also had a significant interaction with task on first fixation duration difference score at $F(1,83) = 10.280$, $p = 0.00191$.

Linear mixed effects regressions revealed a significantly smaller first fixation difference score for all three measures during Imagining trials ($B = -1.324$, $p = .000$). Smaller first fixation latency ($B = -152.833$, $p = 0.023$) and greater first fixation duration difference scores ($B = 227.231$, $p = 0.045$) significantly predicted the experience of involuntary imagery reported in the Intrusive Imagery survey (Table 13). Similar to total fixations, interactive regression models (Appendix G) identified a significant effect of presentation sequence on first fixation measures. Specifically, an interaction between Sequence 4, Imagining task, and Neutral valence explained a significant amount of variance in first fixation count difference score ($B = 409.592$, $p = 0.043$). Increasing familiarity also predicted larger first fixation count difference score for Neutral Imagining tasks ($B = 128.198$, $p = 0.033$). Mean vividness significantly interacted with task, valence, and familiarity ($B = -36.592$, $p = 0.031$). Similar interactions between valence, task, vividness, and familiarity were significant for first fixation latency difference score, but not first fixation duration difference scores. Finally, there was a main effect of valence on first fixation latency difference score ($B = 42176.063$, $p = 0.023$).

Item AOIs. Descriptive statistics for discrete Item AOIs are provided in Table 14. Mean valid tracked time was high for all images (86.8% valid for Negative images; 86.5% for Neutral images). As previously noted, these AOIs surrounded regions that appeared to be cognitively salient, including human figures, weapons, faces, etc.; the term “item” here is used for convenience. Out of 161 total Item AOIs applied to the 40 experimental stimuli, 34 (21.1%)

contained a face, and 9 (5.6%) contained a weapon. Total number of Item AOIs applied to each image ranged from 2 – 7, with a nearly equivalent number of Central and Outer Item AOIs for both emotional categories (Table 15), which reflects the deliberately centralized composition of each image. Mean fixation count and duration to Item AOIs during Viewing trials were highly similar across valence. These measures were converted to difference scores as described previously, and further expressed as ratios relative to the number of Central AOIs for each image. A two-way ANOVA indicated no significant effect of valence on fixation count or duration ratio scores across image valence categories (Table 15).

Based on a large body of literature indicating the salient nature of human faces, particularly those portraying visible emotional expressions, Item AOIs containing human faces were identified. Within Neutral stimuli, 15 Item AOIs contained a complete face, 73.3% of which fell within the Central image region. Negative stimuli contained 20 face AOIs, 45% of which were centrally located. It should be noted that Negative stimuli differed from Neutral in that they also included salient items such as weapons (5 weapon AOIs total, 1 within the Outer region), as well as fire and vehicle wreckage. Figure 9 illustrates an example of the relationship between gaze to specific Item AOIs between Viewing and Imagining trials. Note that this example represents the relatively small sample of stimuli with noticeable overlap; similarity of performance varied significantly per image.

Hemodynamic Response

A total of 16 participants with less than 15% usable channels were discarded from fNIRS analyses. One participant was excluded for missing eye tracking data, and an additional participant was excluded due to incorrect cap configuration, resulting in a final *N* of 24 (11 females, 13 males). Mean age of this sample was 23.71 ± 8.68 years (range = 18 – 59). Average

percent of total usable channels was 50.6% (min = 16.7%, max = 95.2%, SD = 26.5%), with the majority of usable channels over occipital optode locations. Figure 10 illustrates the total number of usable observations for each channel.

Descriptive statistics for group mean HbO values (mM) per channel and condition are provided in Appendix H. Upon visual inspection, the character of the entire time course appears to vary among baseline, Viewing, and Imagining conditions (Fig. 11). Within-subjects, mean baseline occipital OxyHb values were not significantly associated with channel [$F(21,272) = 1.183$, $p = 0.265$]. An ANOVA accounting for subjects as random effects failed to provide evidence for a significant main effect of channel, task, valence, vividness, or familiarity on mean OxyHb concentration (Table 16).

A linear mixed effects regression accounting for subjects as random errors identified no significant effect of relevant experimental variables on mean occipital OxyHb concentration (Table 17). Mean OxyHb of participants who reported intrusive imagery experiences were significantly greater than those who did not [$B = 0.552\text{x}10^{-6}$, $t(1) = 2.207$, $p = 0.027$]. However, only 4 participants included in the fNIRS analysis reported intrusive imagery.

An interactive mixed effects regression revealed significant main effects of task ($B = 27.733\text{x}10^{-6}$, $p = .000$), valence ($B = 8.042\text{x}10^{-6}$, $p = 0.020$), familiarity ($B = 6.988\text{x}10^{-6}$, $p = .000$), and vividness ($B = 5.578\text{x}10^{-6}$, $p = .000$) on mean occipital OxyHb. Significant interactions between task and valence ($B = -22.536\ \text{x}10^{-6}$, $p = .000$) indicated lower OxyHb during Imagining of Neutral stimuli. Task also interacted with familiarity ($B = -9.076\text{x}10^{-6}$, $p = .000$) and Intrusive Imagery responses ($B = -116.807\text{x}10^{-6}$, $p = 0.018$), such that familiar content was associated with lower mean OxyHb during Imagining and lower OxyHb concentration during Imagining trials was associated with later involuntary imagery experiences. Imagery

vividness interacted with OxyHb concentration during Imagining (B = -7.357x10^{-6}, p = .000) and familiarity (B = -1.802x10^{-6}, p = .000). Relevant variables and their effects appear in Table 18; full results are provided in Appendix I.

Full time course comparison. The full time course of HDR spanning from 6 s before stimulus onset to 12 s after was investigated for differences between visual task and stimulus condition. Mean concentration values were averaged across all occipital channels. Overall HRF was similar within visual task, with moderate effects of valence (Fig. 12). Overall, peak amplitude had a later onset during Viewing than Imagining and Negative stimuli elicited greater amplitude of response in both conditions (Table 19).

Functional localization. Among 5 participants with optimal channel quality, an ANOVA and linear mixed effects regression revealed a significant main effect of recording region on mean OxyHb values (Tables 20 & 21). Probe plots of motor and occipital group HRF during Negative and Neutral stimulus valence are available in Appendix J.

Discussion

This study employed a novel combination of two behavioral measurements, eye tracking and fNIRS, to explore the relationship between eye gaze and occipital cortical blood flow during viewing of a negative scene and subsequent mental imagery of the scene as a reflection of internal visual representations. Given evidence for abnormal gaze and visual neural patterns in clinical individuals with visual intrusive imagery symptoms, fixations to suboptimal image regions, such as a narrow focus on centrally-located visual information, may serve as a mechanism for the creation of decontextualized (lacking peripheral content or overall scene gist) mental representations susceptible to involuntary and emotional re-experiencing. Although the current study deliberately tested individuals without clinical diagnoses, the data collected from

behavioral surveys, eye tracking, and hemodynamic response measures will be evaluated in terms of explaining the perceptual and cortical mechanisms involved in patients with disorders such as PTSD.

Behavioral Data

The high correlation between VVIQ-2 score and individual vividness ratings collected after each Imagining trial suggests that baseline mental imagery accurately reflects individual differences in imagery detail and supports previous studies demonstrating the VVIQ-2 is a reliable and valid measure of the mental imagery construct (Campos, 2011). However, vividness ratings reported during experimental Imagining trials failed to show a significant bias toward Negative or Neutral stimulus categories as first expected. This effect seems unlikely to originate from deficient image selection; the Post-Task familiarity survey indicated moderate familiarity with stimulus categories overall, with Negative categories rated slightly less familiar than Neutral. In addition, pleasantness ratings collected in the Post-Task survey corroborated the ratings provided during experimental trials as well as the original IAPS ratings, and therefore appear to support the intended valence manipulation.

Previous research has demonstrated that viewing traumatic videos influences involuntary imagery in a non-clinical sample up to 10 days following exposure (Holmes et al., 2010). Responses from the current Intrusive Imagery survey appear to agree with this finding, although the small number of positive responses limits the extent of their interpretation. It should be noted that, whereas Holmes et al. (2010) required participants to complete daily diary entries regarding the frequency and content of intrusive imagery experiences, the survey used in the current study was administered a single time, 7 days following study completion. In addition, the static images used in this experiment may not have elicited the same type or amount of emotional arousal as

the traffic accident video used by Holmes and colleagues. The responses from those who did report at least one involuntary imagery event varied in relative detail, but the majority of the descriptions contained enough information to distinguish the scene, or category of scene, to which they referred. Qualitative assessment of responses also revealed a possible bias for Negative imagery focused on human and animal violence subjects. Future extensions of this project may take advantage of a more standardized collection of responses that would allow for factors such as description accuracy to be better assessed. For example, a questionnaire administered multiple times following study completion featuring questions that prompt description of specific details such as events, people, objects, etc. could provide more objective and quantifiable data.

Eye Tracking

Overall, total fixations to Central and Outer image regions as operationalized in the current study were similar across stimulus valence (Hypothesis 1a). No significant effect of valence was identified for total fixation count or duration difference score, although Imagining tasks were significantly associated with greater fixation count and duration to the Central AOI relative to Outer AOI. Upon inspection of gaze plots, it is clear that there is overall less variability in fixations during Imagining tasks, as the majority of participants tended to retain fixation near the center of the screen. Both vividness and familiarity were found to interact with total fixation duration, such that greater vividness and familiarity predicted larger difference scores. This suggests that familiarity and baseline vividness predict increased variety of fixations directed toward Central and Outer AOIs. This finding partially supports Hypothesis 3.a, which predicted greater focus on Central AOIs in individuals with lower mental imagery vividness. However, the lack of significant effects and interactions with stimulus valence does not support

the additional predictions that this effect would only occur in Negative stimulus categories. Finally, the presence of task interactions fails to support the initial hypothesis that greater fixations to Central regions would be observed during Viewing as well as Imagining trials. These and other results indicating dissociations between Viewing and Imagining tasks support mental imagery as a uniquely informative process reflecting cognitive behaviors over and above those reflected by viewing gaze patterns.

Although total fixation measures were limited in their association with experimental variables, first fixations revealed more extensive relationships between eye gaze, cognitive factors, and stimulus features. After accounting for imagery vividness, familiarity, and sequence presentation, a significant effect of task was identified for difference scores for all three first fixation measures (number of first fixations that landed within Central or Outer AOI, latency to first fixation, and first fixation duration). First fixation latency and duration interacted with vividness and familiarity to predict positive responses to the Intrusive Imagery survey, suggesting that shorter latency and longer duration of first fixations to Central AOIs increase the likelihood of involuntary imagery following stimulus exposure. This finding is similar to, but does not exactly replicate, previous research showing that shorter fixation to fearful faces predicted PTSD symptoms in veterans with exposure to war zone stress (Beevers, Lee, Wells, Ellis, & Telch, 2011). Although previous work has demonstrated that emotional scenes correspond to eye gaze patterns (Nummenmaa, Hyönä, & Calvo, 2006), even to the degree that it is possible to decode emotional valence via fixation patterns with some accuracy (Tavakoli et al., 2015), valence explained a significant amount of variance in first fixation latency in the current study only when additional variables were taken into account (Hypothesis 1).

One possible reason that valence did not moderate eye gaze or cortical activity as expected may be due to the categorization criteria used to classify emotional content. Subjective responses from the Post-Task survey and visual task ratings indicate that participants did find Negative stimuli more unpleasant than Neutral stimuli. However, standard deviations of Negative familiarity ratings were higher than those for Neutral images, indicating greater between-subject variability. Although arousal ratings were included in selection criteria, arousal was not considered as a potential moderator of gaze or HDR. Yegiyan and Lang (2010), who influenced the central vs. peripheral manipulation used in the current study, found that memory performance for details in central and peripheral image regions was moderated by arousal as well as emotional tone. Other studies report similar effects of arousal over and above emotional valence (Calvo & Lang, 2004). Considering these findings, it may be useful to account for arousal in addition to valence when investigating the effect of scene content on observer behavior. Further categorizing negative valence as specific emotions (e.g., fear, sadness, etc.) may also improve precision of results, as well as hold meaningful significance for the content described in later mental imagery.

Overall, gaze patterns observed in the current study suggest that first fixation measures, specifically latency and duration, are more reflective of the influence of stimulus and cognitive variables on gaze patterns in the context of the current experiment. These findings also suggest that gaze patterns bear complex relationships with individual factors such as baseline mental imagery vividness and content familiarity – two factors that are important to consider when attempting to explain individual differences that lead to involuntary imagery events. Previous work suggests that fixation patterns indicate initial orientation bias as manipulated by stimulus

content (Calvo & Lang, 2004) and could possibly reflect perceptual vigilance, which research has shown is enhanced for threat-related stimuli in patients with PTSD (Hendler et al., 2003).

Contrary to the prediction stated in Hypothesis 1.b, no significant bias toward Central Item AOIs in Negative images was found for total fixation count or duration ratio. Although a similar number of Central Item AOIs (including a similar amount of faces) were identified within Negative and Neutral stimuli, Items did not appear to preferentially influence the number or duration of total fixations to Central AOIs in relation to stimulus valence. Though not significant, duration ratio was more strongly moderated by Item AOIs. Given the pattern of fixations to Central and Outer AOIs and evidence for object-moderated gaze such as the weapon focus effect (Flowe et al., 2013; Loftus et al., 1987), first fixations to Item AOIs may be more indicative of bias and would therefore be relevant to explore in future analyses.

The presence of faces did not appear to directly influence the number or duration of fixations to the Central or Outer visual regions in which they appeared. However, previous studies suggest that the mere presence of faces may not influence attention so much as the emotion they express. A study of the effect of fearful faces on visual processing and mental imagery found that presentation of fearful faces enhanced processing of subsequent low-level, low spatial frequency visual imagery, whereas processing of complex high spatial frequency imagery was impaired (Grégoire Borst & Kosslyn, 2010). These results suggest that the ability to process precise details is impaired following fearful facial cues and may indicate increased holistic processing of the relevant cue; amygdala activity is implicated in this and other effects of emotional stimuli on primary visual cortex (Chen, Li, Jin, Shou, & Yu, 2014). In light of the current study, the effects of valence may be limited to the processing of acute low-level details, rather than global spatial regions of a scene. If this is the case, it may explain why valence did

not have a stronger moderating effect on gaze patterns, as gross eye movement patterns would not adequately capture the effects on high- or low-level visual processing.

The similarity between number, AOI location, and duration of fixations during Viewing and Imagining tasks observed in the current study is notably weaker than that reported by previous studies using similar comparisons. The reason for attenuated variability in fixations during Imagining trials is unclear; instructions and trial length were comparable to previous studies (Beevers et al., 2011; Nummenmaa et al., 2006). However, previous mental imagery studies tend to involve simple geometric shapes or figures (Laeng et al., 2014; Laeng & Teodorescu, 2002), and viewing manipulations often use simultaneous presentation of competing stimuli (Beevers et al., 2011; Nummenmaa et al., 2006). The presentation of a single stimulus, deliberately manipulated to have a clear central focal region as used in the current study, may therefore attenuate the variety of observed fixation patterns. Predictability of trial progression and the frequent appearance of fixation crosses may also have encouraged participants to retain central fixation when not required. In addition, there is no clear explanation for the significant effect of Presentation Sequence 4 identified in several analyses of eye gaze. As described previously, an attempt was made to minimize variation in mean IAPS valence and arousal ratings within blocks. However, the final block in Sequence 4 did have the highest mean arousal rating out of all of the Negative blocks and contained a majority of human and animal violence content categories, which could be related to the observed effect.

Hemodynamic Response

In initial analyses, mean OxyHb concentration in occipital channels was not significantly moderated by task or valence conditions. Participants who reported at least one involuntary imagery experience at follow-up were found to have significantly greater mean OxyHb than

those who did not. When interactions between additional cognitive variables were included, mean OxyHb was found to be significantly moderated by task, valence, familiarity, and imagery vividness. Specifically, greater vividness reported during experimental trials, along with greater content familiarity, predicted smaller mean OxyHb values. This effect partially supports Hypothesis 3.b, which predicted vividness would correlate with greater moderation of mean OxyHb during both visual tasks, because lower mean OxyHb in participants with higher vividness potentially indicates less variability in amplitude of OxyHb in response to visual scenes. However, quantitative analysis of the full time course is necessary to confirm this conclusion.

Visual inspection of the full time course of OxyHb concentration during Imagining and Viewing tasks, averaged across all occipital channels, suggests similarity across tasks with moderate effects of valence, thereby failing to support the first prediction of Hypothesis 2. Overall, Imagining task OxyHb showed a shorter peak latency and lower peak amplitude than Viewing. This effect aligns with other neuroimaging findings suggesting greater activation of ventral visual areas during viewing as compared to mental imagery (Cattaneo, Bona, & Silvan to, 2012; Ganis, Thompson, & Kosslyn, 2004; Pearson et al., 2015; Slotnick et al., 2005), as well as evidence for increased OxyHb during active visual attention (Kojima & Suzuki, 2010) and visual search (Yang, Zhou, Liu, & Ruan, 2007). In addition, distinct differences appeared in the peak amplitude and latency to initial peak values between tasks. The full time course suggests that valence moderated the amplitude of HDR within tasks, which provides preliminary support for the second half of Hypothesis 2. Together, these results suggest that fNIRS was capable of capturing cortical blood flow responses that distinguish between visual perception and mental imagery tasks, similar to the type reported by previous studies using other techniques. If these

findings are accurate, they may be the first evidence for fNIRS as a reliable indicator of cortical activity associated specifically with visual mental imagery processes of this type (see below for limitations to be considered).

Although the functional localization analysis provided preliminary evidence that the observed changes in visual cortex HDR were not entirely determined by global changes in scalp or cortical blood flow, there are several limitations to fNIRS technology and its application in the current study that must be considered. The first concern is evident in the timing of the peak amplitude during Imagining tasks, which overlapped with the timing of stimulus onset. Due to the HDR lag, blood flow activity at this time point reflects cortical activity initiated several (~6) seconds prior (Xu, Graber, & Barbour, 2014). This, as well as the lack of a second peak, suggests that the rise in activity may be related to the "Imagine" word cue displayed immediately prior to the blank screen that constituted an Imagining trials. It is possible that this visual word cue prompted spontaneous imagery in participants earlier than intended. Alternatively, the observed change in blood flow may reflect an entirely different cognitive process, such as reading. Replacing this visual cue with an auditory one may better clarify this relationship and provide a more accurate reflection of imagery processes. In addition, a significant amount of participants were excluded from fNIRS analyses due to insufficient signal quality, and the average channel survival in the remaining sample was barely above 50%. Due to these reasons, conclusions regarding task-related HDR, particularly responses associated with visual mental imagery, are speculative and require further validation before confident inferences are made.

To further discuss the caveats of the current preliminary hemodynamic results, subject HRF in the current study was not manually corrected for baseline, which is a common and valuable practice (Chen et al., 2015; Putze et al., 2014; Shi et al., 2014; Tak & Ye, 2014). This

step was excluded in the current analyses in order to better understand how baseline correction affects results and provides a comparison measure for future analyses. However, this shortcoming may be compensated for by the high-pass filtering applied to the data (Tak & Ye, 2014), as well as the conservative effects of calculating the mean per channel for the entire time course (i.e., baseline effects are assumed to wash out between task and valence conditions). A variety of advanced analysis techniques exist that may provide more informative and accurate interpretations of these data (e.g., general linear modeling of the canonical HRF in comparison to task-related HRF; Scarpa, 2011) and will be explored in future analyses. In addition, studies indicate that differences in head size and brain anatomy resulting in variations in optical density support greatest reliability of HDR for within-subject comparisons (Minati, Visani, Dowell, Medford, & Critchley, 2011). One option to account for this in the current analysis could involve calculating a difference score in OxyHb between Viewing and Imagining tasks, similar to the kind used for fixation measures.

Memory and Mental Imagery

As discussed previously, the relationship between gaze patterns, mental representations, and subsequent intrusive imagery depends upon, and is intricately entangled with, visual memory processes. Research shows that, at a neural level, mental imagery recruits networks overlapping with visual working memory (Albers, Kok, Toni, Dijkerman, & de Lange, 2013), suggesting that mental imagery engages a perception-like process to recall stored information and bring it back into current consciousness for manipulation (Gregoire Borst, Ganis, Thompson, & Kosslyn, 2012; Gregoire Borst & Kosslyn, 2008). However, the processes of mental imagery and memory do appear to be at least partially distinct, including their reliance on sensory-based visual networks as correlated with the strength of baseline mental imagery (Keogh & Pearson, 2011;

see also Borst et al., 2012). Mental imagery can therefore be considered part of the output of memory, particularly in cases where the image being imagined has been previously viewed. A study of gaze patterns and memory for emotional film clips found that fixations to emotional film clips were more narrowly focused and associated with poorer object memory upon immediate recall (Subramanian, Shankar, Sebe, & Melcher, 2014). Results showed that fixations during emotional clips were not significantly correlated with memory for scene details, although the relationship held true for neutral film clips. Despite this, memory for scene gist as reflected by performance on an old/new memory test using static images selected from each clip was better for emotional scenes than for neutral ones. The authors of the study concluded that, although variability of fixations decreases for dynamic emotional scenes and does not correlate strongly with immediate memory, later memory performance reveals stronger holistic encoding for emotional scenes and weaker encoding of peripheral details. These results may inform the findings of the current study by suggesting that a lack of fixations to peripheral image regions does not accurately reflect a lack of holistic processing, as originally hypothesized. Instead, visual information encoded into memory via covert attention may facilitate a holistic memory representation independent of fixation region and accessible only by later memory recall.

In a similar vein, there is evidence that distinct neural systems support the formation of healthy, contextualized representations and inflexible, sensory-bound representations that are more susceptible to intrusive imagery (Brewin, Gregory, Lipton, & Burgess, 2010). The authors of this study propose that proper interaction of these systems within visuospatial working memory prevent the formation of intrusive representations. In their model, voluntary imagery is driven by top-down cognitive factors to activate contextualized representations, whereas intrusive imagery is activated by bottom-up sensory-bound representations triggered by

situational cues. Importantly, Brewin et al.'s (2010) inclusive model of intrusive imagery suggests that inflexible sensory-based representations lead to intrusive events, whereas the initial hypotheses of the current study proposed that excessively flexible and unbound sensory representations are more susceptible to involuntary re-experiencing.

Given these findings, it appears likely that encoding of holistic visual information or scene gist, which is poorly reflected by eye movement patterns but strongly reflected in memory processes, is modulated by emotional content (Subramanian et al., 2014). The effects of valence then alter amygdala activity to recruit distinct networks of visuospatial working memory that influence the formation of contextualized or sensory-bound representations. The vulnerability of these representations to re-activation by situational sensory cues then facilitates intrusive imagery following exposure. This network of intrusive symptoms may explain why the observed relationships between fixations, valence, and later imagining were less direct than originally predicted. In addition, this framework suggests that voluntary imagery as required in the current study may be altogether different from the networks involved in clinical flashback symptoms. In this case, it may be worthwhile to further explore reports of intrusive imagery following experimental exposure, as discussed in earlier sections, to better access the processes occurring in clinical populations.

Summary and Implications

The results of this study showed that gaze patterns and cortical hemodynamic response appear to share significant relationships with voluntary mental imagery as well as later involuntary re-imagining. Importantly, only specific measures reflected these relationships: during Viewing and Imagining, first fixation latency was uniquely influenced by cognitive factors such as familiarity and imagery vividness. Hemodynamic activity was more strongly

moderated by stimulus valence than gaze patterns and may better predict later involuntary imagery events, suggesting HDR as a more reliable indicator of mental representation formation. The distinction between eye gaze and cortical activity further indicates that fixation measures such as count and duration do not fully reflect visual cognitive processing, and may therefore be less well-suited to understanding the mechanisms involved in maladaptive visual processing. Instead, mental imagery processes indexed by first fixation latency and cortical blood flow appear to more accurately and descriptively capture the processes involved in voluntary imagery, with possible implications for intrusive imagery symptomatology. The current study also supports the influence of individual factors (e.g., baseline vividness of mental imagery and familiarity) on behavioral response to visual scenes and later re-experiencing.

Although the evidence reported here is not conclusive for possible treatment avenues for PTSD and other imagery-related disorders, these results add to a rich literature exploring the interactions between gaze, mental imagery, memory, and involuntary re-imagining to better explain the mechanisms involved in visual flashbacks. The value of the current findings will be most apparent if and when they can be compared to performance of patients diagnosed with relevant clinical disorders. Future studies could also investigate amygdala activity and/or physiological indicators of arousal to precisely categorize the emotional response of the observer (using technology in addition to or in place of fNIRS) and impose competition between central and peripheral details by varying the region of focus of the scene. A manipulation such as this may better capture fixations which facilitate the encoding of scene gist.

Characterizing the interaction between visual perceptual processes, mental imagery, and involuntary imagery events is an important endeavor for not only understanding the cognitive and physiological mechanisms underlying imagery-related disorders, but also to develop

treatments and interventions for its prevention. As the results of this study demonstrate, one of the initial challenges facing this goal is the identification of appropriate and informative measures by which to access these complex internal processes. By combining multiple modalities of behavioral assessment before, during, and after event exposure, future research can better target the methods and measurements that provide a holistic account of the relationship between perceptual behavior and mental imagery.

References

Adenauer, H., Catani, C., Gola, H., Keil, J., Ruf, M., Schauer, M., & Neuner, F. (2011). Narrative exposure therapy for PTSD increases top-down processing of aversive stimuli - evidence from a randomized controlled treatment trial. *BMC Neuroscience*, *12*(1), 127. https://doi.org/10.1186/1471-2202-12-127

Albers, A. M., Kok, P., Toni, I., Dijkerman, H. C., & de Lange, F. P. (2013). Shared Representations for Working Memory and Mental Imagery in Early Visual Cortex. *Current Biology*, *23*(15), 1427–1431. https://doi.org/10.1016/j.cub.2013.05.065

American Psychiatric Association. (2000). *Diagnostic and statistical manual of mental disorders: DSM-IV-TR* (4th ed., text revision.). Washington, DC: American Psychiatric Association.

American Psychiatric Association. (2013). *Diagnostic and Statistical Manual of Mental Disorders* (Fifth Edition). American Psychiatric Association. Retrieved from http://psychiatryonline.org/doi/book/10.1176/appi.books.9780890425596

Arntz, A., de Groot, C., & Kindt, M. (2005). Emotional memory is perceptual. *Journal of Behavior Therapy and Experimental Psychiatry*, *36*(1), 19–34. https://doi.org/10.1016/j.jbtep.2004.11.003

Ballesteros, S., & Mayas, J. (2015). Selective attention affects conceptual object priming and recognition: a study with young and older adults. *Frontiers in Psychology*, *5*. https://doi.org/10.3389/fpsyg.2014.01567

Baruch, O., Kimchi, R., & Goldsmith, M. (2014). Attention to distinguishing features in object recognition. *Visual Cognition*, *22*(9–10), 1184–1215. https://doi.org/10.1080/13506285.2014.987860

Becker, M. W., Pashler, H., & Lubin, J. (2007). Object-intrinsic oddities draw early saccades. *Journal of Experimental Psychology: Human Perception and Performance*, *33*(1), 20–30. https://doi.org/10.1037/0096-1523.33.1.20

Beevers, C. G., Lee, H.-J., Wells, T. T., Ellis, A. J., & Telch, M. J. (2011). Association of Predeployment Gaze Bias for Emotion Stimuli With Later Symptoms of PTSD and Depression in Soldiers Deployed in Iraq. *American Journal of Psychiatry*, *168*(7), 735–741. https://doi.org/10.1176/appi.ajp.2011.10091309

Blackwell, S. E., Browning, M., Mathews, A., Pictet, A., Welch, J., Davies, J., … Holmes, E. A. (2015). Positive Imagery-Based Cognitive Bias Modification as a Web-Based Treatment Tool for Depressed Adults A Randomized Controlled Trial. *Clinical Psychological Science*, *3*(1), 91–111. https://doi.org/10.1177/2167702614560746

Borst, G., Ganis, G., Thompson, W. L., & Kosslyn, S. M. (2012). Representations in mental imagery and working memory: Evidence from different types of visual masks. *Memory & Cognition*, *40*(2), 204–217. https://doi.org/10.3758/s13421-011-0143-7

Borst, G., & Kosslyn, S. M. (2008). Visual mental imagery and visual perception: Structural equivalence revealed by scanning processes. *Memory & Cognition*, *36*(4), 849–862. https://doi.org/10.3758/MC.36.4.849

Borst, G., & Kosslyn, S. M. (2010). Fear selectively modulates visual mental imagery and visual perception. *The Quarterly Journal of Experimental Psychology*, *63*(5), 833–839. https://doi.org/10.1080/17470211003602420

Brady, T. F., Konkle, T., Alvarez, G. A., & Oliva, A. (2013). Real-world objects are not represented as bound units: Independent forgetting of different object details from visual

memory. *Journal of Experimental Psychology: General*, *142*(3), 791–808. https://doi.org/10.1037/a0029649

Brewin, C. R., Gregory, J. D., Lipton, M., & Burgess, N. (2010). Intrusive images in psychological disorders: Characteristics, neural mechanisms, and treatment implications. *Psychological Review*, *117*(1), 210–232. https://doi.org/10.1037/a0018113

Broadbent, D. E., & Gregory, M. (1967). Perception of Emotionally Toned Words. *Nature*, *215*(5101), 581–584. https://doi.org/10.1038/215581a0

Calvo, M. G., & Lang, P. J. (2004). Gaze Patterns When Looking at Emotional Pictures: Motivationally Biased Attention. *Motivation and Emotion*, *28*(3), 221–243. https://doi.org/10.1023/B:MOEM.0000040153.26156.ed

Campos, A. (2011). Internal consistency and construct validity of two versions of the revised vividness of visual imagery questionnaire. *Perceptual and Motor Skills*, *113*(2), 454–460. https://doi.org/10.2466/04.22.PMS.113.5.454-460

Cattaneo, Z., Bona, S., & Silvan to, J. (2012). Cross-adaptation combined with TMS reveals a functional overlap between vision and imagery in the early visual cortex. *NeuroImage; Amsterdam*, *59*(3), 3015–3020. https://doi.org/http://dx.doi.org.ezproxy.lib.vt.edu/10.1016/j.neuroimage.2011.10.022

Chen, L.-C., Sandmann, P., Thorne, J. D., Herrmann, C. S., & Debener, S. (2015). Association of Concurrent fNIRS and EEG Signatures in Response to Auditory and Visual Stimuli. *Brain Topography*, *28*(5), 710–725. https://doi.org/10.1007/s10548-015-0424-8

Chen, M., Han, J., Hu, X., Jiang, X., Guo, L., & Liu, T. (2014). Survey of encoding and decoding of visual stimulus via FMRI: an image analysis perspective. *Brain Imaging and Behavior*, *8*(1), 7–23. https://doi.org/10.1007/s11682-013-9238-z

Chen, Y., Li, H., Jin, Z., Shou, T., & Yu, H. (2014). Feedback of the amygdala globally modulates visual response of primary visual cortex in the cat. *NeuroImage; Amsterdam*, *84*, 775–785. https://doi.org/http://dx.doi.org.ezproxy.lib.vt.edu/10.1016/j.neuroimage.2013.09.010

Diana, R. A., Yonelinas, A. P., & Ranganath, C. (2007). Imaging recollection and familiarity in the medial temporal lobe: a three-component model. *Trends in Cognitive Sciences*, *11*(9), 379–386. https://doi.org/10.1016/j.tics.2007.08.001

Flowe, H. D., Hope, L., & Hillstrom, A. P. (2013). Oculomotor Examination of the Weapon Focus Effect: Does a Gun Automatically Engage Visual Attention?: e81011. *PLoS One*, *8*(12), e81011. https://doi.org/http://dx.doi.org.ezproxy.lib.vt.edu/10.1371/journal.pone.0081011

Ganis, G., Thompson, W. L., & Kosslyn, S. M. (2004). Brain areas underlying visual mental imagery and visual perception: an fMRI study. *Cognitive Brain Research*, *20*(2), 226–241. https://doi.org/10.1016/j.cogbrainres.2004.02.012

Gilbert, D. T., & Wilson, T. D. (2007). Prospection: Experiencing the Future. *Science*, *317*(5843), 1351–1354.

Hendler, T., Rotshtein, P., & Hadar, U. (2001). Emotion–Perception Interplay in the Visual Cortex: "The Eyes Follow the Heart." *Cellular and Molecular Neurobiology*, *21*(6), 733–752. https://doi.org/10.1023/A:1015156222101

Hendler, T., Rotshtein, P., Yeshurun, Y., Weizmann, T., Kahn, I., Ben-Bashat, D., … Bleich, A. (2003). Sensing the invisible: differential sensitivity of visual cortex and amygdala to traumatic context. *NeuroImage*, *19*(3), 587–600. https://doi.org/http://dx.doi.org.ezproxy.lib.vt.edu/10.1016/S1053-8119(03)00141-1

Herwig, A., & Schneider, W. X. (2014). Predicting object features across saccades: Evidence from object recognition and visual search. *Journal of Experimental Psychology: General*, *143*(5), 1903–1922. https://doi.org/10.1037/a0036781

Holmes, E. A., James, E. L., Kilford, E. J., & Deeprose, C. (2010). Key Steps in Developing a Cognitive Vaccine against Traumatic Flashbacks: Visuospatial Tetris versus Verbal Pub Quiz. *PLOS ONE*, *5*(11), e13706. https://doi.org/10.1371/journal.pone.0013706

Holmes, E. A., & Mathews, A. (2010). Mental imagery in emotion and emotional disorders. *Clinical Psychology Review*, *30*(3), 349–362. https://doi.org/10.1016/j.cpr.2010.01.001

Johansson, R., & Johansson, M. (2014). Look Here, Eye Movements Play a Functional Role in Memory Retrieval. *Psychological Science*, *25*(1), 236–242. https://doi.org/10.1177/0956797613498260

Kamran, M. A., & Hong, K.-S. (2013). Indirect measurement of brain activation using fNIRS. In *2013 13th International Conference on Control, Automation and Systems (ICCAS)* (pp. 1633–1636). https://doi.org/10.1109/ICCAS.2013.6704193

Karatzias, T., Power, K., Brown, K., & McGoldrick, T. (2009). Vividness of mental imagery in Posttraumatic Stress Disorder (PTSD): The role of depression. *Journal of Behavior Therapy and Experimental Psychiatry*, *40*(2), 352–358. https://doi.org/10.1016/j.jbtep.2009.02.002

Keogh, R., & Pearson, J. (2011). Mental Imagery and Visual Working Memory. *PLOS ONE*, *6*(12), e29221. https://doi.org/10.1371/journal.pone.0029221

Kleim, B., Ehring, T., & Ehlers, A. (2012). Perceptual processing advantages for trauma-related visual cues in post-traumatic stress disorder. *PSYCHOLOGICAL MEDICINE*, *42*(1), 173–181. https://doi.org/10.1017/S0033291711001048

Kojima, H., & Suzuki, T. (2010). Hemodynamic change in occipital lobe during visual search: visual attention allocation measured with NIRS. *Neuropsychologia*, *48*(1), 349–352. https://doi.org/10.1016/j.neuropsychologia.2009.09.028

Laeng, B., Bloem, I. M., D'Ascenzo, S., & Tommasi, L. (2014). Scrutinizing visual images: The role of gaze in mental imagery and memory. *Cognition*, *131*(2), 263–283. https://doi.org/10.1016/j.cognition.2014.01.003

Laeng, B., & Teodorescu, D.-S. (2002). Eye scanpaths during visual imagery reenact those of perception of the same visual scene. *Cognitive Science*, *26*(2), 207–231. https://doi.org/10.1016/S0364-0213(01)00065-9

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1997). International affective picture system (IAPS): Technical manual and affective ratings. Gainesville, FL: The Center for Research in Psychophysiology, University of Florida.

Laor, N. M. D., Wolmer, L. M. A., Wiener, Z. M. D., Weizman, R. M. D., Toren, P. M. D., & Ron, S. (1999). Image Control and Symptom Expression in Posttraumatic Stress Disorder. *Journal of Nervous and Mental Disease*, *187*(11), 673–679.

Loftus, E. F., Loftus, G. R., & Messo, J. (1987). Some Facts about "Weapon Focus." *Law and Human Behavior*, *11*(1), 55–62.

Marks, D. F. (1995). New directions for mental imagery research. *Journal of Mental Imagery*, *19*(3–4), 153–167.

Meek, J. H., Firbank, M., Elwell, C. E., Atkinson, J., Braddick, O., & Wyatt, J. S. (1998). Regional Hemodynamic Responses to Visual Stimulation in Awake Infants. *Pediatric Research*, *43*(6), 840–843. https://doi.org/10.1203/00006450-199806000-00019

Minati, L., Visani, E., Dowell, N. G., Medford, N., & Critchley, H. D. (2011). Variability comparison of simultaneous brain near-infrared spectroscopy (NIRS) and functional MRI (fMRI) during visual stimulation. *Journal of Medical Engineering & Technology*, *35*(0), 370–376. https://doi.org/10.3109/03091902.2011.595533

Moulton, S. T., & Kosslyn, S. M. (2009). Imagining predictions: mental imagery as mental emulation. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1521), 1273–1280. https://doi.org/10.1098/rstb.2008.0314

Mueller-Pfeiffer, C., Schick, M., Schulte-Vels, T., O'Gorman, R., Michels, L., Martin-Soelch, C., … Hasler, G. (2013). Atypical visual processing in posttraumatic stress disorder. *NeuroImage: Clinical*, *3*, 531–538. https://doi.org/10.1016/j.nicl.2013.08.009

Naselaris, T., Olman, C. A., Stansbury, D. E., Ugurbil, K., & Gallant, J. L. (2015). A voxel-wise encoding model for early visual areas decodes mental images of remembered scenes. *NeuroImage*, *105*, 215–28. https://doi.org/http://dx.doi.org.ezproxy.lib.vt.edu/10.1016/j.neuroimage.2014.10.018

Nummenmaa, L., Hyönä, J., & Calvo, M. G. (2006). Eye movement assessment of selective attentional capture by emotional pictures. *Emotion*, *6*(2), 257. https://doi.org/10.1037/1528-3542.6.2.257

Nyberg, L., Habib, R., McIntosh, A. R., & Tulving, E. (2000). Reactivation of encoding-related brain activity during memory retrieval. *Proceedings of the National Academy of Sciences of the United States of America*, *97*(20), 11120.

Pearson, J., & Kosslyn, S. M. (2013). Mental imagery. *Perception Science*, 198. https://doi.org/10.3389/fpsyg.2013.00198

Pearson, J., Naselaris, T., Holmes, E. A., & Kosslyn, S. M. (2015). Mental Imagery: Functional Mechanisms and Clinical Applications. *Trends in Cognitive Sciences*, *19*(10), 590–602. https://doi.org/10.1016/j.tics.2015.08.003

Pearson, J., Rademaker, R. L., & Tong, F. (2011). Evaluating the Mind's Eye The Metacognition of Visual Imagery. *Psychological Science*, 956797611417134. https://doi.org/10.1177/0956797611417134

Putze, F., Hesslinger, S., Tse, C.-Y., Huang, Y., Herff, C., Guan, C., & Schultz, T. (2014). Hybrid fNIRS-EEG based classification of auditory and visual perception processes. *Frontiers in Neuroscience*, *8*. https://doi.org/10.3389/fnins.2014.00373

Richardson, D. C., & Spivey, M. J. (2000). Representation, space and Hollywood Squares: looking at things that aren't there anymore. *Cognition*, *76*(3), 269–295.

R-Tavakoli, H., Atyabi, A., Rantanen, A., Laukka, S. J., Nefti-Meziani, S., & Heikkilä, J. (2015). Predicting the Valence of a Scene from Observers' Eye Movements: e0138198. *PLoS One*, *10*(9). https://doi.org/http://dx.doi.org.ezproxy.lib.vt.edu/10.1371/journal.pone.0138198

Rubin, D. C., Berntsen, D., & Bohni, M. K. (2008). A memory-based model of posttraumatic stress disorder: Evaluating basic assumptions underlying the PTSD diagnosis. *Psychological Review*, *115*(4), 985–1011. https://doi.org/10.1037/a0013397

Sack, A. T., Ven, V. G. van de, Etschenberg, S., Schatz, D., & Linden, D. E. J. (2005). Enhanced vividness of mental imagery as a trait marker of schizophrenia? *Schizophrenia Bulletin*, *31*(1), 97–104. https://doi.org/10.1093/schbul/sbi011

Scarpa, F. (2011). A GLM-Based Approach to Estimate Stimulus-Evoked Hemodynamic Response from fNIRS Measurements. In *6th International Conference on Bioinformatics and Biomedical Engineering (iCBBE 2012)*.

Schlangen, D., & Barenholtz, E. (2015). Intrinsic and contextual features in object recognition. *Journal of Vision*, *15*(1), 28–28. https://doi.org/10.1167/15.1.28

Shang, J., Lui, S., Meng, Y., Zhu, H., Qiu, C., Gong, Q., … Zhang, W. (2014). Alterations in Low-Level Perceptual Networks Related to Clinical Severity in PTSD after an Earthquake: A Resting-State fMRI Study: e96834. *PLoS One*, *9*(5). https://doi.org/http://dx.doi.org.ezproxy.lib.vt.edu/10.1371/journal.pone.0096834

Shi, J., Sakatani, K., Okamoto, M., Yamaguchi, Y., & Zuo, H. (2014). Correlation between LIFG and autonomic activation during stressful tasks: A functional near-infrared spectroscopy (fNIRS) study. *Journal of Huazhong University of Science and Technology [Medical Sciences]*, *34*(5), 663–671. https://doi.org/10.1007/s11596-014-1334-9

Slotnick, S. D., Thompson, W. L., & Kosslyn, S. M. (2005). Visual Mental Imagery Induces Retinotopically Organized Activation of Early Visual Areas. *Cerebral Cortex*, *15*(10), 1570–1583. https://doi.org/10.1093/cercor/bhi035

Slotnick, S. D., Thompson, W. L., & Kosslyn, S. M. (2012). Visual memory and visual mental imagery recruit common control and sensory regions of the brain. *Cognitive Neuroscience*, *3*(1), 14–20. https://doi.org/10.1080/17588928.2011.578210

Subramanian, R., Shankar, D., Sebe, N., & Melcher, D. (2014). Emotion modulates eye movement patterns and subsequent memory for the gist and details of movie scenes. *Journal of Vision*, *14*(3), 31–31. https://doi.org/10.1167/14.3.31

Tak, S., & Ye, J. C. (2014). Statistical analysis of fNIRS data: A comprehensive review. *NeuroImage; Amsterdam*, *85*, 72–91. https://doi.org/http://dx.doi.org.ezproxy.lib.vt.edu/10.1016/j.neuroimage.2013.06.016

Takahashi, K., Ogata, S., Atsumi, Y., Yamamoto, R., Shiotsuka, S., Maki, A., … Igawa, M. (2000). Activation of the visual cortex imaged by 24-channel near-infrared spectroscopy. *Journal of Biomedical Optics*, *5*(1), 93–96. https://doi.org/10.1117/1.429973

Toronov, V. Y., Zhang, X., & Webb, A. G. (2007). A spatial and temporal comparison of hemodynamic signals measured using optical and functional magnetic resonance imaging during activation in the human primary visual cortex. *NeuroImage*, *34*(3), 1136–1148. https://doi.org/10.1016/j.neuroimage.2006.08.048

Ward, L. M., Morison, G., Simpson, W. A., Simmers, A. J., & Shahani, U. (2016). Using Functional Near Infrared Spectroscopy (fNIRS) to Study Dynamic Stereoscopic Depth Perception. *Brain Topography*, *29*, 515–523. https://doi.org/10.1007/s10548-016-0476-4

Wheeler, M. E., Petersen, S. E., & Buckner, R. L. (2000). Memory's echo: Vivid remembering reactivates sensory-specific cortex. *Proceedings of the National Academy of Sciences of the United States of America*, *97*(20), 11125.

Wijeakumar, S., Shahani, U., Simpson, W. A., & McCulloch, D. L. (2012). Localization of Hemodynamic Responses to Simple Visual Stimulation: An fNIRS StudyHemodynamic Responses to Simple Visual Stimulation. *Investigative Ophthalmology & Visual Science*, *53*(4), 2266–2273. https://doi.org/10.1167/iovs.11-8680

Wilcox, T., Bortfeld, H., Woods, R., Wruck, E., & Boas, D. A. (2005). Using near-infrared spectroscopy to assess neural activation during object processing in infants. *Journal of Biomedical Optics*, *10*(1), 011010–0110109. https://doi.org/10.1117/1.1852551

Xu, Y., Graber, H. L., & Barbour, R. L. (2014). nirsLAB: A Computing Environment for fNIRS Neuroimaging Data Analysis. In *Biomedical Optics 2014 (2014), paper BM3A.1* (p. BM3A.1). Optical Society of America. https://doi.org/10.1364/BIOMED.2014.BM3A.1

Yang, H.-Y., Zhou, Z.-Y., Liu, Y., & Ruan, Z.-C. (2007). Oxygenated Hemoglobin Responses in Prefrontal Area during Visual Search Tasks Measured with Near-infrared Spectroscopy. *Space Medicine & Medical Engineering*, *20*(3), 209–212.

Yegiyan, N. S., & Lang, A. (2010). Processing Central and Peripheral Detail: How Content Arousal and Emotional Tone Influence Encoding. *Media Psychology*, *13*(1), 77–99. https://doi.org/10.1080/15213260903563014

Table 1

General Category Descriptors for Negative and Neutral Stimuli

Negative ***Neutral***

Category Name	IAPS Image No.	No. of Images	Category Name	IAPS Image No.	No. of Images
Car accidents, automobile wreckage (fire)	9900 9908 9910	3	Portrait, indoor or outdoor	2002 2273 2305 2372 2495 2749 2850 2870 7493	9
Injury involving children and adults	2345.1	1			
Newborn infant (premature)	2661	1			
Riot	2691 9424	2			
Surgical procedures and bodily organs involving animals	3019	1			
Police, court, criminals	6838	1			
Gun violence/threats	3530 6571 6821	3	Store, shopping	2026 2745.1	2
Pistols, firearms, guns (not being used)	6220	1	Work or office scene	2383 9700	2
War, soldiers	9495	1	Ship, anchor	5395	1
Knife violence/threats	6313	1	Urban street scene including vehicles or people	7497 7595	2
Panic/sadness involving adults and children	2703 3022	2	Casino, gambling	7506	1
Animal injury/abuse	9183 9184	2	Chess	7512	1
			Athletic or sporting event	8121	1
Aircraft wreckage, fire	9622	1	Man urinating	2720	1

Table 2

Post-Task Survey Familiarity and Pleasantness Ratings

	Familiarity			**Pleasantness**		
Valence	*Mean*	*Median*	*SD*	*Mean*	*Median*	*SD*
Negative	2.91	2.81	0.92	1.76	1.65	0.57
Neutral	3.61	3.56	0.54	3.41	3.33	0.45

N = 38

Table 3

Qualitative Summary of Intrusive Imagery Survey Responses

Question	No. of Usable Responses	Relevant Descriptors		
"Since you completed the study, have you involuntarily thought about or been reminded of the images you viewed in the study?" "Please describe the visual content of these involuntarily thoughts. What did you see in your "mind's eye?"	8 = yes 23 = no	*Modal frequency of intrusions* 1-2 times *Avg. no. of distinct images described* 1.88	*Categories described (frequency)* Animal injury/abuse (5) Human violence (3) Medical (2) Man urinating (2) Human portrait (2) Vehicle accidents (1)	*Avg. rating of detail (out of 5)* 3.13
"If there are any images that you recall vividly from the experiment, please describe them here."	17	*Avg. no of distinct images described* 2.35	*Categories described (frequency)* Human violence (6) Animal injury/abuse (6) Human portrait (6) Vehicle accident (4) Man urinating (4) Medical (3)	*Avg. rating of detail (out of 5)* 3.35

Table 4

Average Pleasantness and Vividness Ratings for 37 Participants

	Pleasantness		**Vividness of Imagery**	
Valence	*Mean*	*SD*	*Mean*	*SD*
Negative	1.79	0.42	3.69	0.64
Neutral	3.37	0.43	3.39	0.58

N = 37

Table 5

Regression of Vividness of Mental Imagery and VVIQ Score

	Negative				***Neutral***			
	B	SE B	*t*	*p*	B	SE B	*t*	*p*
VVIQ	-0.014	0.005	-2.876	0.007 *	-0.013	0.004	-2.847	0.00734 *
R2			0.191				0.188	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 'o'

N = 37

Table 6

Summary of Total Fixations for Negative Stimuli

Viewing	**Central AOI**			**Outer AOI**			**Difference Score**
Negative	*Mean*	*Median*	*SD*	*Mean*	*Median*	*SD*	*Mean*
Count	10.36	10.55	2.39	3.67	3.61	1.15	6.69
Duration (ms)	2243.49	2315.28	664.29	700.37	685.32	245.56	1543.12

Imagining	**Central AOI**			**Outer AOI**			**Difference Score**
Negative	*Mean*	*Median*	*SD*	*Mean*	*Median*	*SD*	*Mean*
Count	7.66	7.76	2.40	0.57	0.31	0.73	7.09
Duration (ms)	3171.24	3314.55	976.97	134.38	63.90	184.27	3036.85

N = 37

Table 7

Summary of Total Fixations for Neutral Stimuli

Viewing	**Central AOI**			**Outer AOI**			**Difference Score**
Neutral	*Mean*	*Median*	*SD*	*Mean*	*Median*	*SD*	*Mean*
Count	9.84	9.70	2.22	4.05	3.85	1.45	5.79
Duration (ms)	2182.11	2157.93	585.77	771.05	721.81	306.59	1411.06

Imagining	**Central AOI**			**Outer AOI**			**Difference Score**
Neutral	*Mean*	*Median*	*SD*	*Mean*	*Median*	*SD*	*Mean*
Count	7.64	7.64	2.42	0.61	0.25	0.91	7.04
Duration (ms)	3165.99	3369.01	986.65	130.92	40.84	180.14	3035.07

N = 37

Table 8

ANOVA for Total Count and Duration Difference Scores

	Count			***Duration***	
Variable	DF	F value	*p*	F value	*p*
Error: Sub					
VVIQ	1	0.249	0.622	0.007	0.933
Vivid	1	0.798	0.380	0.310	0.583
Fam.	1	1.579	0.221	0.103	0.751
VVIQ:Vivid	1	0.715	0.406	0.000	0.997
Valence:Vivid	1	0.019	0.893	0.030	0.863
VVIQ:Fam.	1	1.420	0.245	1.882	0.182
Vivid:Fam.	1	2.574	0.121	1.792	0.193
VVIQ:Valence:Vivid	1	0.765	0.390	0.005	0.944
VVIQ:Vivid:Fam.	1	0.035	0.852	2.098	0.160
Valence:Vivid:Fam.	1	0.240	0.629	0.140	0.711
VVIQ:Valence:Vivid:Fam.	1	0.035	0.854	0.925	0.345
Residuals	25				
Error: Within					
Task	1	8.252	0.00517 *	404.904	<2e-16 **
Valence	1	2.801	0.098	0.746	0.390
Vivid	1	0.799	0.374	1.077	0.302
VVIQ:Task	1	0.630	0.430	0.075	0.785
VVIQ:Valence	1	0.166	0.685	0.250	0.618
Task:Valence	1	2.201	0.142	0.707	0.403
VVIQ:Vivid	1	0.332	0.566	0.107	0.745
Task:Vivid	1	2.268	0.136	1.225	0.272
Valence:Vivid	1	0.060	0.807	0.132	0.717
Task:Fam.	1	0.908	0.343	2.307	0.133
Valence:Fam.	1	0.698	0.406	1.950	0.166
Vivid:Fam.	1	0.716	0.400	0.698	0.406
VVIQ:Task:Valence	1	0.001	0.971	0.073	0.787
VVIQ:Task:Vivid	1	0.211	0.647	0.740	0.392
VVIQ:Valence:Vivid	1	1.239	0.269	2.713	0.103
Task:Valence:Vivid	1	1.193	0.278	1.040	0.311
VVIQ:Task:Fam.	1	1.708	0.195	8.333	0.00496 *
VVIQ:Valence:Fam.	1	0.502	0.481	1.150	0.287
Task:Valence:Fam.	1	0.041	0.841	0.191	0.663
VVIQ:Vivid:Fam.	1	1.491	0.226	1.997	0.161

Task:Vivid:Fam.	1	0.005	0.946	1.055	0.307
Valence:Vivid:Fam.	1	0.099	0.754	0.004	0.952
VVIQ:Task:Valence:Vivid	1	2.275	0.135	0.070	0.792
VVIQ:Task:Valence:Fam.	1	0.958	0.331	0.621	0.433
VVIQ:Task:Vivid:Fam.	1	0.083	0.779	6.665	0.01159 °
VVIQ:Valence:Vivid:Fam.	1	0.619	0.434	0.515	0.475
Task:Valence:Vivid:Fam.	1	0.534	0.467	0.004	0.953
VVIQ:Task:Valence:Vivid:Fam.	1	0.082	0.776	0.619	0.434
Residuals	83				

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘°’

N = 37

Table 9

Linear Mixed Effects Regression for Total Fixation Difference Scores

Count

Variable	B	SE B	*t*	*p*
VVIQ	0.011	0.016	0.660	0.509
Age	0.025	0.046	0.538	0.590
Gender2	0.476	0.642	0.742	0.458
Follow up1	0.342	0.716	-0.478	0.633
Sequence2	1.461	0.889	-1.643	0.100
Sequence3	0.890	0.786	-1.133	0.257
Sequence4	1.783	0.827	-2.157	0.031 °
Task2	1.444	13.016	-0.111	0.912
Valence2	2.778	13.112	0.212	0.832
Vivid	3.538	3.040	1.164	0.245
Fam.	4.038	3.817	1.058	0.290
Task2:Valence2	-1.912	18.155	-0.105	0.916
Task2:Vivid	-0.094	3.279	-0.029	0.977
Valence2:Vivid	-0.483	3.456	-0.140	0.889
Task2:Fam.	2.227	4.175	0.533	0.594
Valence2:Fam.	-0.319	4.230	-0.075	0.940
Vivid:Fam.	-0.951	0.946	-1.005	0.315
Task2:Valence2:Vivid	1.039	4.783	0.217	0.828
Task2:Valence2:Fam.	0.323	5.845	-0.055	0.956
Task2:Vivid:Fam.	-0.418	1.037	-0.403	0.687
Valence2:Vivid:Fam.	-0.080	1.101	-0.072	0.942
Task2:Valence2:Vivid:Fam.	-0.014	1.521	-0.009	0.993

Duration

Variable	B	SE B	*t*	*p*
VVIQ	4.528	7.167	0.632	0.528
Age	-13.071	20.275	-0.645	0.519
Gender2	-83.517	289.326	-0.289	0.773
Follow up1	209.959	323.739	0.649	0.517
Sequence2	98.019	402.803	0.243	0.808
Sequence3	346.960	352.945	0.983	0.326
Sequence4	484.684	373.584	1.297	0.195
Task2	-2142.463	3766.872	-0.569	0.570
Valence2	352.803	3809.457	0.093	0.926

Vivid	960.334	1018.296	0.943	0.346
Fam.	1124.186	1276.564	0.881	0.379
Task2:Valence2	1865.701	5254.034	0.355	0.723
Task2:Vivid	1002.708	949.068	1.057	0.291
Valence2:Vivid	64.246	1004.358	0.064	0.949
Task2:Fam.	1430.526	1208.373	1.184	0.236
Valence2:Fam.	-25.624	1229.248	-0.021	0.983
Vivid:Fam.	-258.822	314.547	-0.823	0.411
Task2:Valence2:Vivid	-245.838	1384.257	-0.178	0.859
Task2:Valence2:Fam.	-902.723	1691.600	-0.534	0.594
Task2:Vivid:Fam.	-389.404	300.036	-1.298	0.194
Valence2:Vivid:Fam.	-52.981	320.102	-0.166	0.869
Task2:Valence2:Vivid:Fam.	175.143	440.037	0.398	0.691

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘°’

N = 37

Table 10

Summary of First Fixations during Viewing Tasks

Viewing	**Central AOI**			**Outer AOI**			**Difference Score**
Negative	*Mean*	*Median*	*SD*	*Mean*	*Median*	*SD*	*Mean*
Count	16.05	17	4.17	0.14	0	0.35	15.92
Latency (ms)	84.40	45.12	132.75	730.15	166.70	985.25	-14.27
Duration (ms)	240.45	246.72	51.56	156.70	133.36	46.56	219.28

Viewing	**Central AOI**			**Outer AOI**			**Difference Score**
Neutral	*Mean*	*Median*	*SD*	*Mean*	*Median*	*SD*	*Mean*
Count	16.54	18	3.89	0.16	0	0.37	16.38
Latency (ms)	84.84	46.68	106.90	886.29	808.50	803.38	-58.88
Duration (ms)	252.80	237.77	62.34	230.60	208.38	95.13	215.40

N = 37

Table 11

Summary of First Fixations during Imagining Tasks

Imagining	**Central AOI**			**Outer AOI**			**Difference Score**
Negative	*Mean*	*Median*	*SD*	*Mean*	*Median*	*SD*	*Mean*
Count	14.81	16	4.72	0.11	0	0.31	14.70
Latency (ms)	81.00	35.72	131.25	125.03	116.69	112.65	67.48
Duration (ms)	651.97	480.49	558.60	175.04	166.70	61.63	633.05

Imagining	**Central AOI**			**Outer AOI**			**Difference Score**
Neutral	*Mean*	*Median*	*SD*	*Mean*	*Median*	*SD*	*Mean*
Count	15.08	16	4.26	0.14	0	0.35	14.95
Latency (ms)	107.61	37.26	236.54	280.06	266.72	200.53	69.76
Duration (ms)	705.72	602.08	538.26	296.73	233.38	290.27	665.62

N = 37

Table 12

ANOVA for Difference Scores of First Fixation Measures with Interaction Terms

	First Fixation Count			***Latency***		***Duration***	
Variable	DF	F value	*p*	F value	*p*	F value	*p*
Error: Sub							
VVIQ	1	0.525	0.474	0.966	0.333	0.307	0.584
Vivid	1	0.052	0.822	0.097	0.758	0.286	0.596
Valence:Vivid	1	0.742	0.396	0.469	0.498	0.010	0.923
VVIQ:Vivid	1	0.012	0.913	0.59	0.810	0.012	0.914
Valence:VVIQ: Vivid	1	2.527	0.122	0.016	0.900	0.720	0.403
Residuals	31						
Error: Within							
Valence	1	1.025	0.314	0.156	0.694	0.068	0.794
Task	1	14.564	0.0002 **	3.846	0.053	61.486	5.21e-12 **
Vivid	1	0.461	0.499	3.992	0.049 °	0.152	0.698
Valence:Task	1	0.097	0.756	0.191	0.663	0.110	0.741
Valence:VVIQ	1	0.148	0.701	1.683	0.198	0.006	0.937
Task:VVIQ	1	2.981	0.087	0.138	0.711	1.674	0.199
Valence:Vivid	1	1.835	0.179	0.031	0.861	0.469	0.495
Task:Vivid	1	0.180	0.672	0.848	0.359	0.767	0.383
VVIQ:Vivid	1	0.006	0.937	0.115	0.735	0.234	0.630
Valence:Task:VVIQ	1	0.165	0.686	0.639	0.426	0.013	0.910
Valence:Task:Vivid	1	1.073	0.303	0.115	0.736	0.034	0.855
Valence:VVIQ: Vivid	1	0.045	0.832	0.773	0.382	0.001	0.975
Task:VVIQ:Vivid	1	0.001	0.980	0.007	0.935	0.327	0.569
Valence:Task: VVIQ:Vivid	1	0.041	0.839	2.439	0.122	0.487	0.487
Residuals	109						

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘°’

N = 37

Table 13

Linear Mixed Effects Regression for First Fixation Difference Scores

First Fixation Count

Variable	B	SE B	*t*	*p*
VVIQ	0.023	0.036	0.640	0.522
Age	-0.029	0.104	-0.276	0.782
Gender2	0.322	1.492	0.216	0.829
Follow.up1	2.327	1.684	1.382	0.167
Sequence2	-2.343	2.102	-1.115	0.265
Sequence3	0.213	1.831	0.116	0.907
Sequence4	0.344	1.938	0.178	0.859
Task2	-1.324	0.339	-3.901	0.000 ***
Valence2	0.173	0.412	0.420	0.674
Vivid	-0.607	0.791	-0.767	0.443
Fam.	-0.941	1.180	-0.797	0.425

First Fixation Latency

Variable	B	SE B	*t*	*p*
VVIQ	-1.637	1.566	-1.045	0.296
Age	-0.219	4.366	-0.050	0.960
Gender 2	24.925	59.520	0.419	0.675
Follow up 1	-152.833	67.235	-2.273	0.023 °
Sequence 2	70.224	84.396	0.832	0.405
Sequence 3	-2.025	74.786	-0.027	0.978
Sequence 4	40.734	77.391	0.526	0.599
Task 2	105.195	52.630	1.999	0.046 °
Valence 2	-22.306	55.369	-0.403	0.687
Vivid	-3.888	58.487	-0.066	0.947
Fam.	23.106	48.433	0.477	0.633

First Fixation Duration

Variable	B	SE B	*t*	*p*
VVIQ	0.251	2.581	0.097	0.922
Age	-4.670	7.255	-0.644	0.520
Gender 2	-14.030	100.464	-0.140	0.889
Follow up 1	227.231	113.462	2.003	0.045 °
Sequence 2	101.313	142.153	0.713	0.476
Sequence 3	94.008	125.256	0.751	0.453
Sequence 4	248.667	130.586	1.904	0.057
Task 2	431.994	53.007	8.150	0.000 ***
Valence 2	38.677	58.757	0.658	0.510
Vivid	82.722	86.194	0.960	0.337
Fam.	-101.606	81.002123	-1.254	0.210

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '°'

N = 37

Table 14

Item AOIs Descriptive Statistics for 40 Images

		Emotional Category	
Mean Statistics		***Negative***	***Neutral***
Avg. No. of Item AOIs		4.5	4
Number of Central Item AOIs		1.7	1.5
Number of Outer Item AOIs		2.4	2.5
Central Items			
	Count	2.85	3.54
	Duration	735.65 ms	1029.34 ms
Outer Items			
	Count	1.62	1.42
	Duration	415.06 ms	338.60 ms
Difference Score			
	Count	1.23	2.20
	Duration	320.59 ms	690.74 ms
Central Item Ratio			
	Count	.88	1.92
	Duration	218.05 ms	630.66 ms

Table 15

ANOVA for Item Count and Duration Ratio

Variable	DF	F value	*p*
Count Ratio	1	2.336	0.135
Duration Ratio	1	3.709	0.062
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘○’			

N = 37

Table 16

ANOVA for Mean Occipital OxyHb

Variable	DF	F value	*p*
Error: Within			
Channel	21	0.528	0.960
Task	1	0.430	0.512
Valence	1	1.173	0.279
Fam.	1	1.548	0.214
Vivid	1	0.448	0.504
Residuals	1219		
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘°’			

N = 24

Table 17

Linear Mixed Effects Regression for Mean Occipital OxyHb

Variable	B	SE B	*t*	*p*
Age	0.002	0.012	0.168	0.866
Gender	0.275	0.216	1.271	0.204
Sequence2	-0.077	0.234	-0.329	0.742
Sequence3	-0.116	0.272	-0.426	0.670
Sequence4	-0.372	0.214	-1.736	0.083
Task2	-0.139	0.072	-1.943	0.052
Valence2	-0.031	0.111	-0.276	0.783
VVIQ	0.005	0.006	0.867	0.386
Fam.	0.040	0.083	0.481	0.631
Follow.up1	0.552	0.250	2.207	0.027 °
Vivid	0.123	0.182	0.674	0.500

Note: Beta values expressed as 10^{-6}

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘○’

N = 24

Table 18

Selected Effects Identified by Interactive Mixed Effects Regression of Mean Occipital OxyHb

Variable	B	SE B	*t*	*p*
Age	-0.002	0.013	-0.142	0.887
Gender	0.121	0.249	0.486	0.627
Sequence2	-0.335	0.283	-1.187	0.235
Sequence3	-0.149	0.314	-0.475	0.635
Sequence4	-0.229	0.269	-0.850	0.395
VVIQ	0.006	0.006	0.985	0.324
Task2	27.733	1.950	14.226	0.000 ***
Valence2	8.042	3.450	2.331	0.020 °
Fam.	6.988	0.708	9.870	0.000 ***
Follow.up1	-30.037	66.976	-0.448	0.654
Vivid	5.578	0.558	9.996	0.000 ***
Task2:Valence2	-22.536	4.204	-5.361	0.000 ***
Task2:Fam.	-9.076	0.751	-12.083	0.000 ***
Valence2:Fam.	-2.429	1.128	-2.154	0.031 °
Task2:Follow.up1	-116.807	49.356	-2.367	0.018 °
Valence2:Follow.up1	179.070	127.190	1.408	0.159
Fam.:Follow.up1	41.641	57.188	0.728	0.467
Task2:Vivid	-7.357	0.522	-14.102	0.000 ***
Valence2:Vivid	-2.212	0.961	-2.303	0.021 °
Fam.:Vivid	-1.802	0.182	-9.927	0.000 ***
Follow.up1:Vivid	8.064	17.594	0.458	0.647
Task2:Valence2:Fam.	6.241	1.379	4.526	0.000 ***
Task2:Valence2:Vivid	6.565	1.173	5.596	0.000 ***
Task2:Fam.:Vivid	2.329	0.192	12.106	0.000 ***
Task2:Follow.up1:Vivid	30.865	12.999	2.374	0.018 °
Task2:Valence2:Fam.:Vivid	-1.684	0.382	-4.408	0.000 ***

Note: Beta values expressed as 10^{-6}
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '°'

N = 24

Table 19

Peak and Latency to Initial Peak Values for Mean OxyHb

Viewing			***Imagining***	
Valence	*Peak HbO (mM)*	*Latency (s)*	*Peak HbO (mM)*	*Latency (s)*
Negative	$13.51x10^{-1}$	8.45	$5.38x10^{-1}$	0.58
Neutral	$6.24x10^{-1}$	8.64	$4.09x10^{-1}$	0.38

N = 24

Table 20

ANOVA for Mean OxyHb - Motor vs. Occipital Optodes

Variable	DF	F value	*p*
Error: Sub			
Optodes	1	0.657	0.477
Residuals	3		
Error: Within			
Optodes	1	6.500	0.0109 °
Valence	2	87.770	< 2e-16 ***
Task	1	0.053	0.818
Residuals	986		
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘°’			

N = 5

Table 21

Linear Mixed Effects Regression - Motor Regions

Variable	B	SE B	*t*	*p*
Region	-1.433	0.354	-4.051	0.000 ***
Task	0.291	0.646	0.450	0.652
Valence	0.347	0.646	0.536	0.592
Region:Task	0.893	0.418	2.135	0.033 °
Region:Valence	0.904	0.418	2.160	0.031 °
Task:Valence	-0.106	0.524	-0.203	0.839
Region:Task:Valence	-0.629	0.339	-1.855	0.064

Note: Beta values expressed as 10^{-6}

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '°'

N = 5

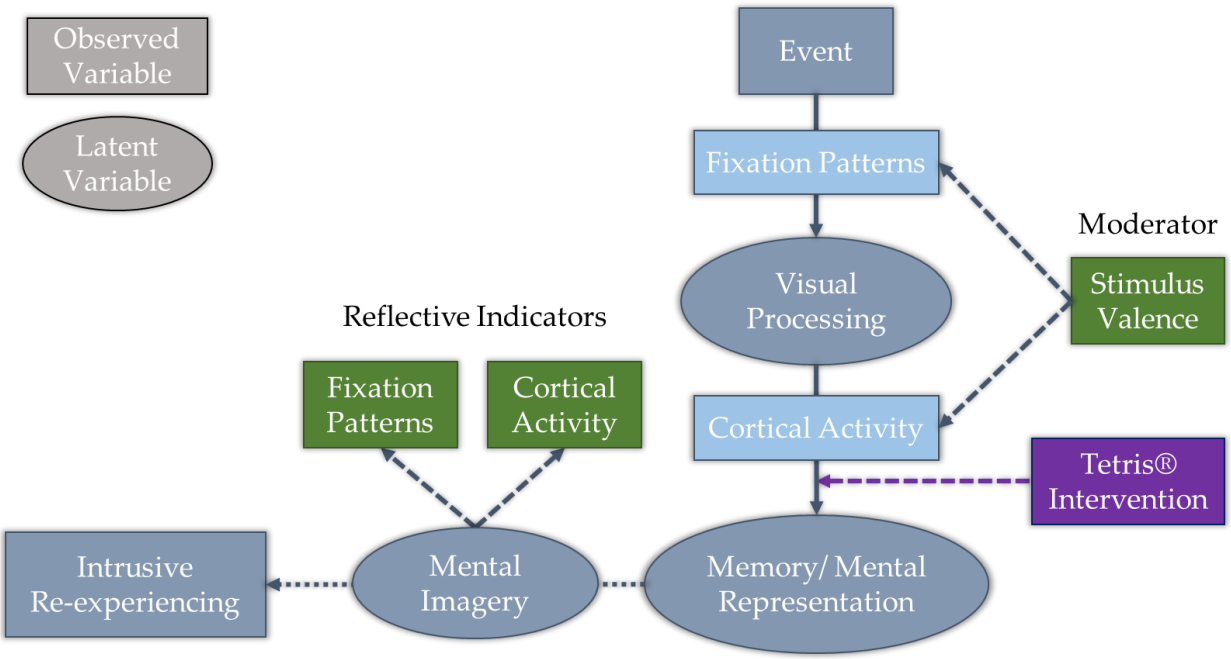


Figure 1. Schematic of the conceptual model tested in the current study.

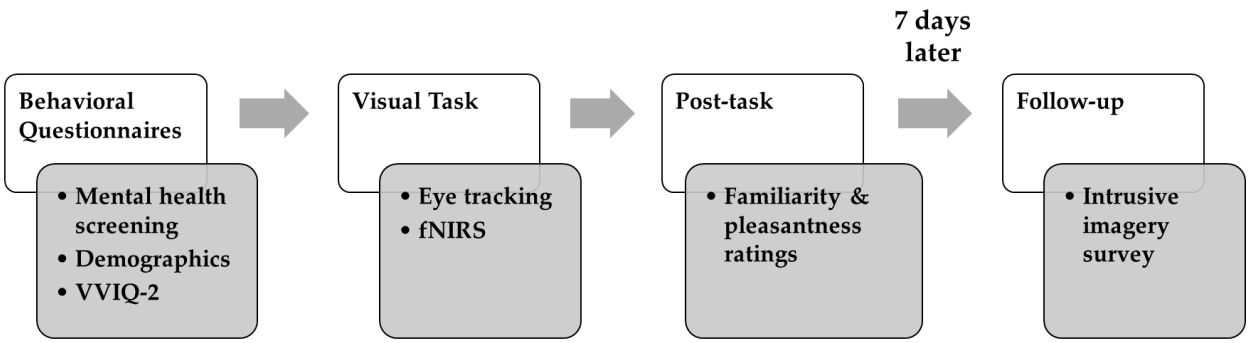


Figure 2. Progression of the experimental study.

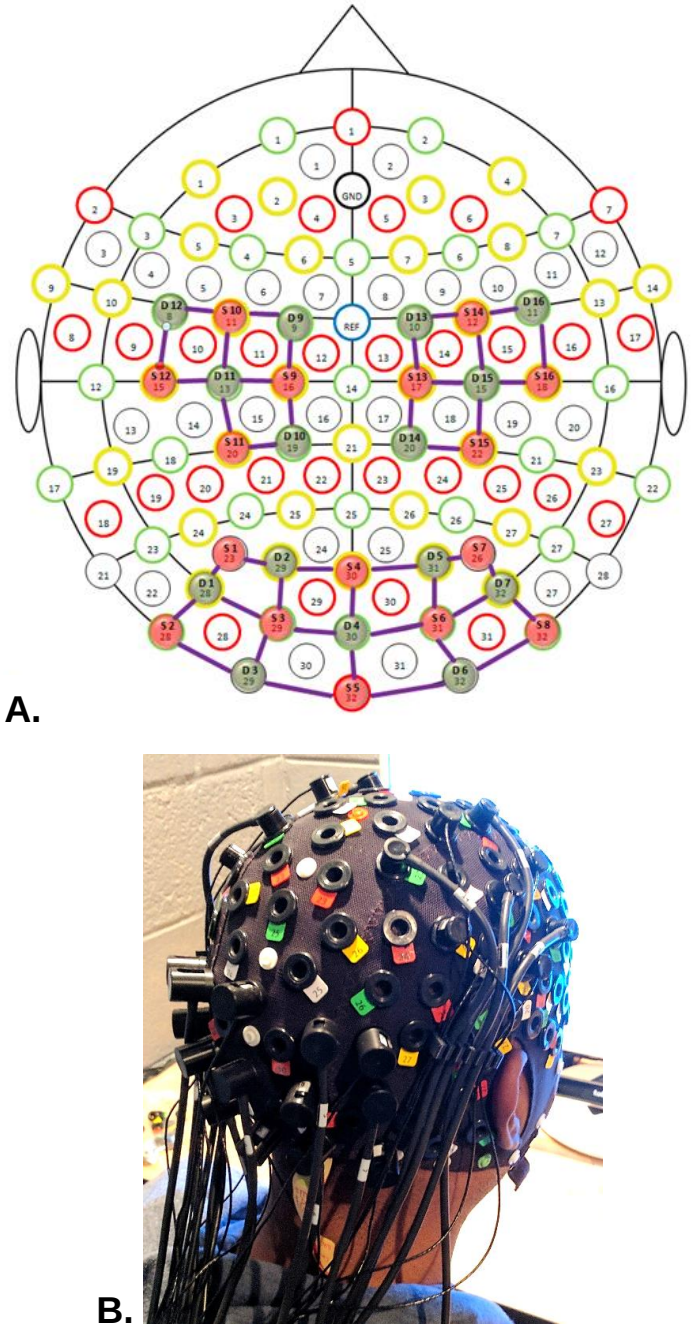


Figure 3. A.) 16x16 channel occipital motor optode layout as displayed in NIRStar software (NIRx Medical Technologies). Red circles denote sources; green circles represent detectors. Purple lines indicate channels. B.) Cap setup in the current study displaying the spring-loaded caps positioned over occipital optodes (image used with participant's permission).

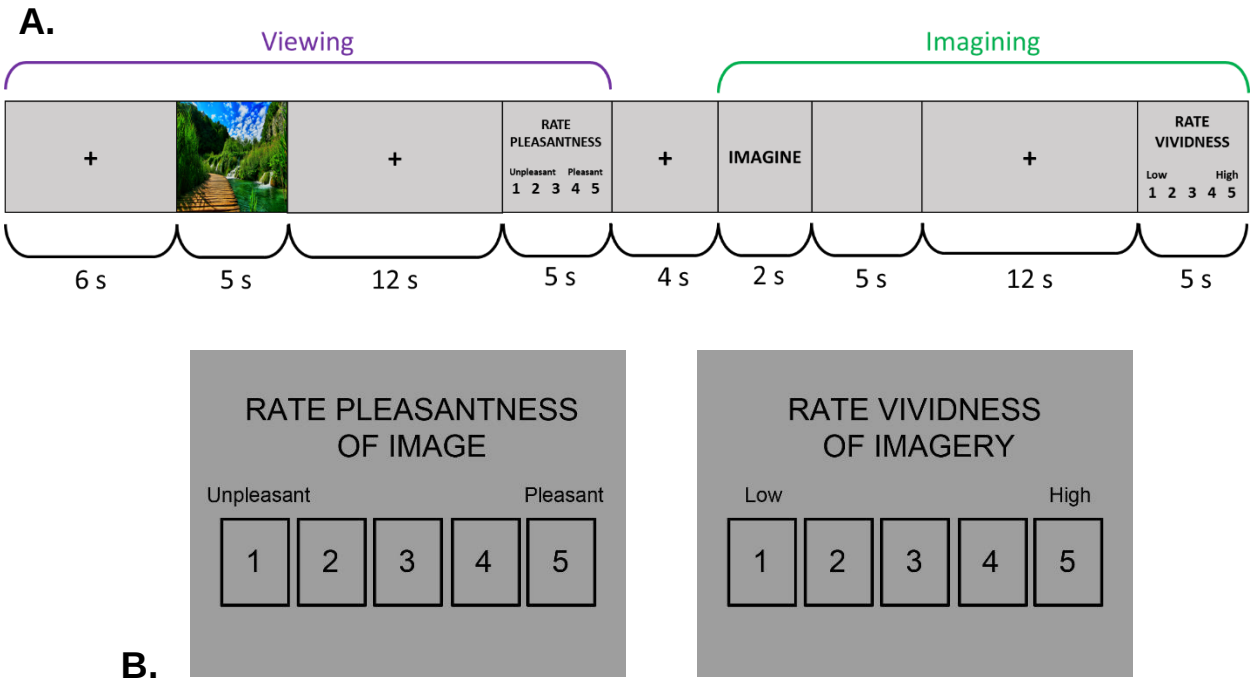


Figure 4. A.) Overall progression of task with alternating Viewing and Imagining trials. Example neutral stimulus acquired from Google image search. B.) Instruction screens used to collect valence and vividness ratings. Participants fixated on the chosen number score for the duration of the instruction screen.

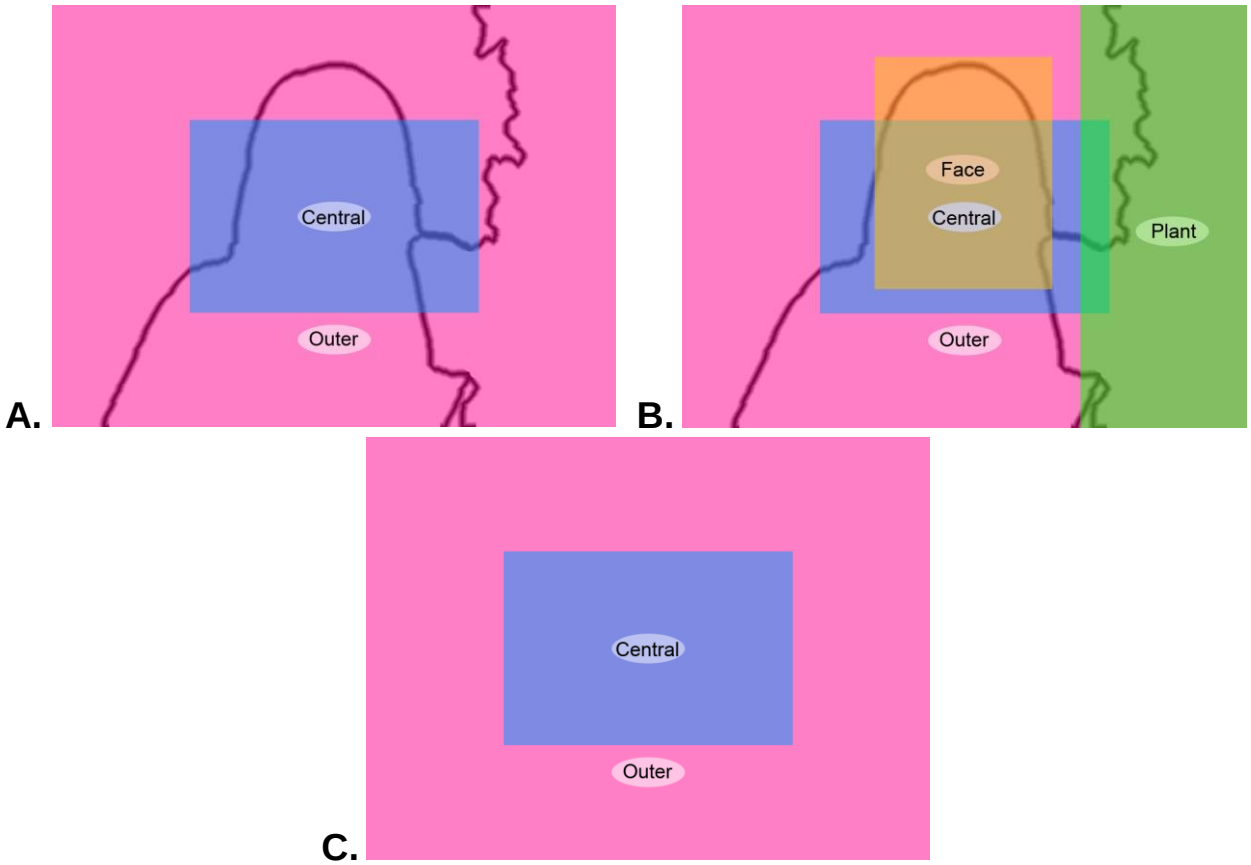


Figure 5. A.) AOI selection as applied to a masked Neutral scene used in the current study. B.) Item AOIs within the same scene. C.) AOIs recreated on a blank screen during Imagining trials.

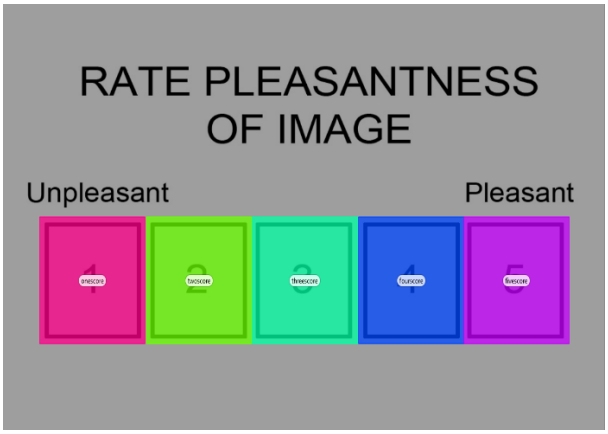


Figure 6. Example of unique AOIs used to identify fixations to rating scores.

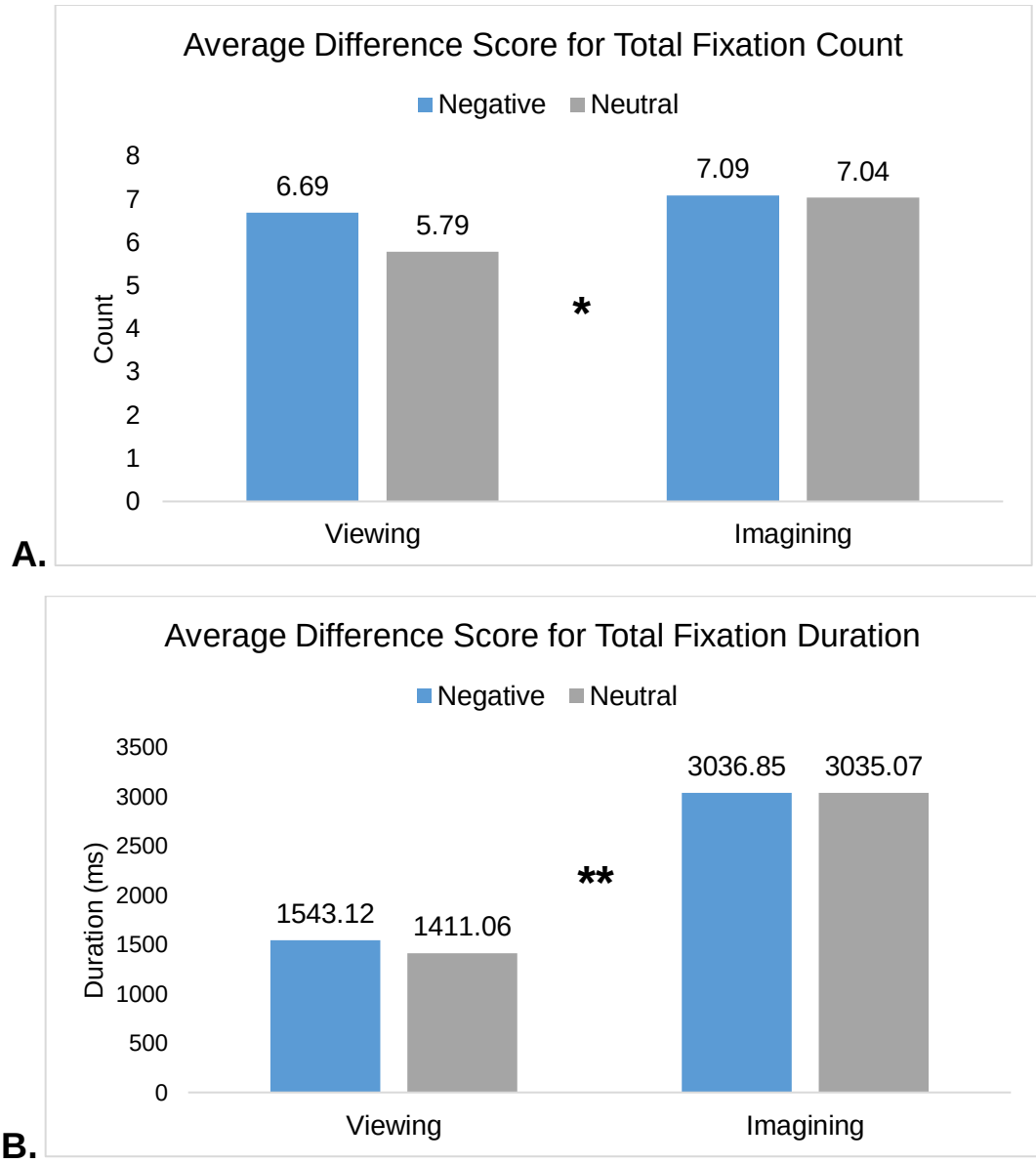
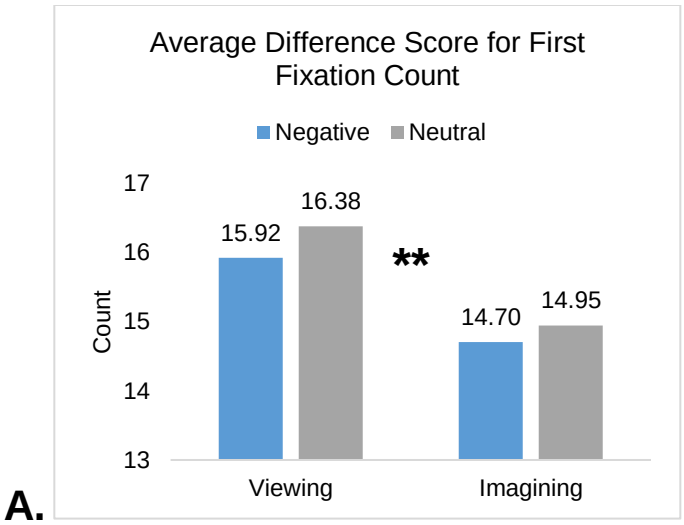
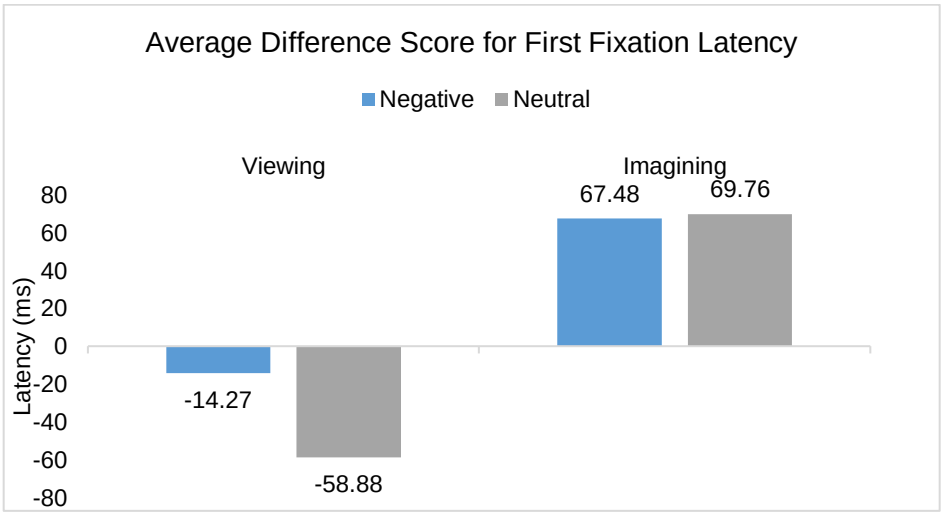


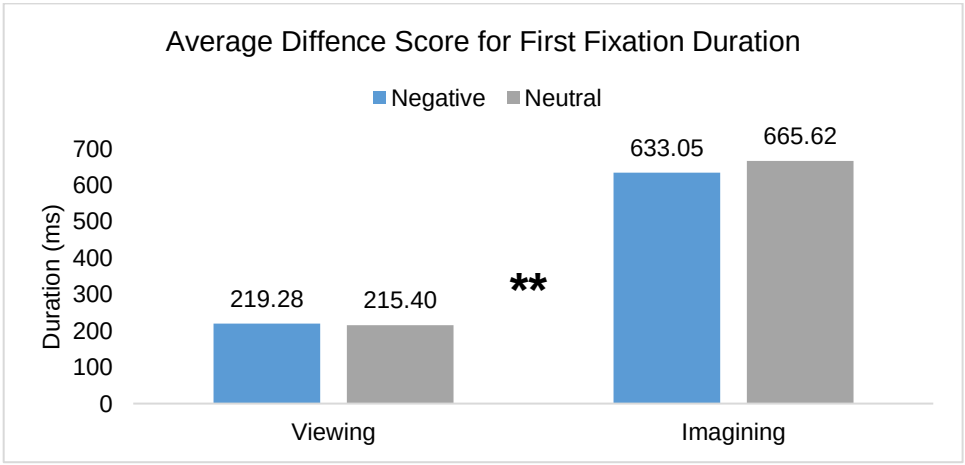
Figure 7. Mean difference score for A.) total fixation count and B.) fixation duration. Significant effect of task indicated by ANOVA results are denoted by asterisks.



A.



B.



C.

Figure 8. Graphs of mean difference scores for A.) first fixation count, B.) latency, and C.) duration across visual tasks and stimulus valence. Significant effect of task indicated by ANOVA results are denoted by asterisks.

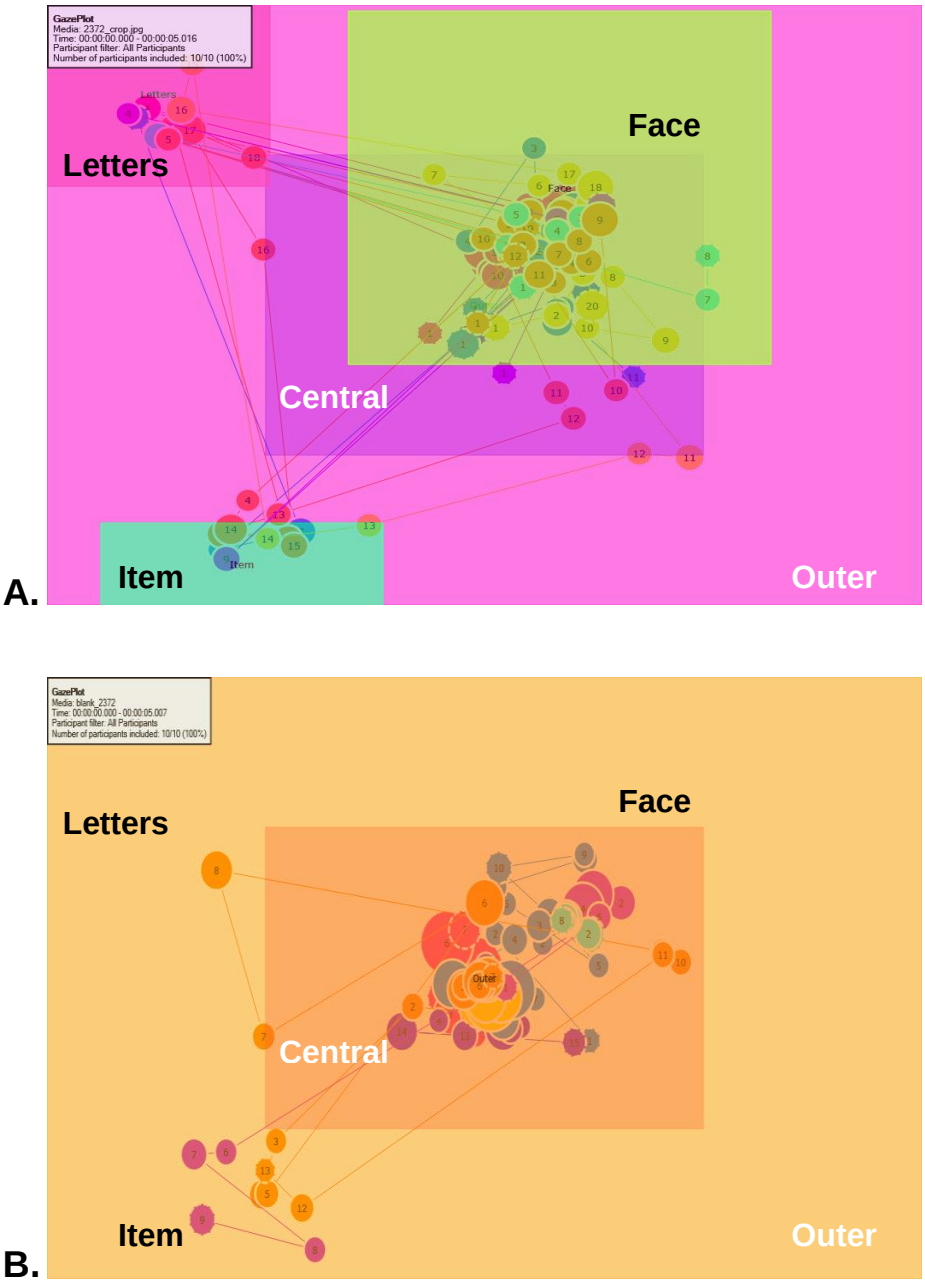


Figure 9. Sample gaze plot data produced by Tobii Studio illustrating moderate gaze overlap between A.) Viewing and B.) Imagining for a single Neutral stimulus. Item AOI names appear in both trials for clarity, but Item AOIs were applied only to Viewing trials. Colored circles and lines represent gaze data from 10 participants tested with Sequence 1. Circle size denotes fixation duration; numbers represent order of fixations.

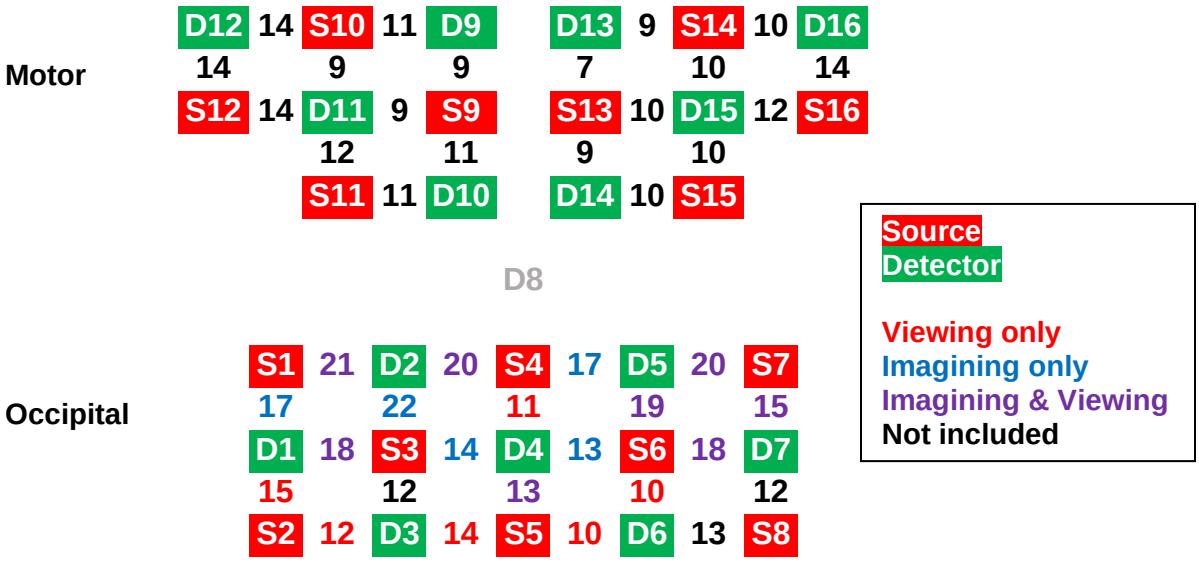
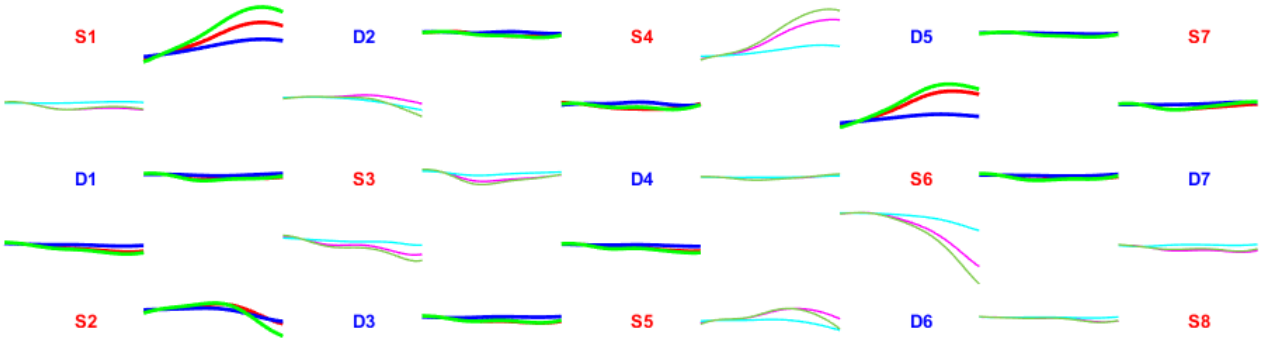
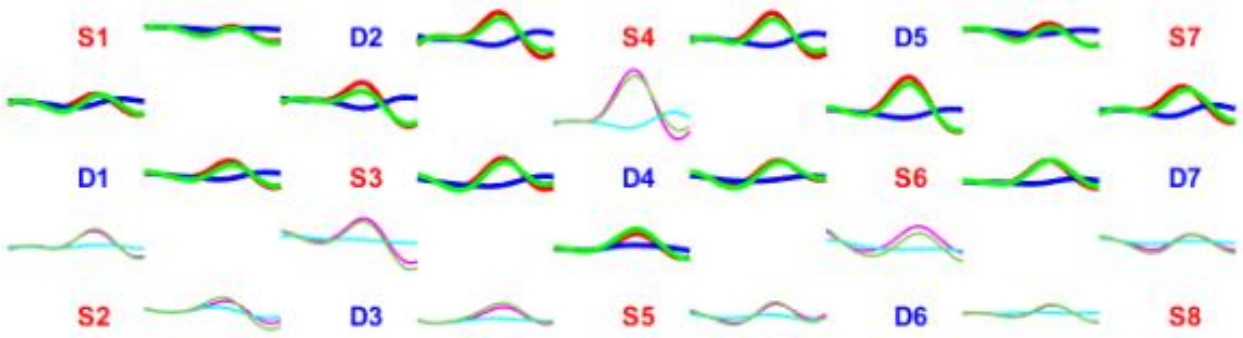


Figure 10. Graphical representation of the number of observations retained for each channel between source (red) and detector (green) pairs. Numbers between channels indicate number of observations included in analysis of Viewing (red), Imagining (blue) or both (purple) trials. Excluded channels appear in black.

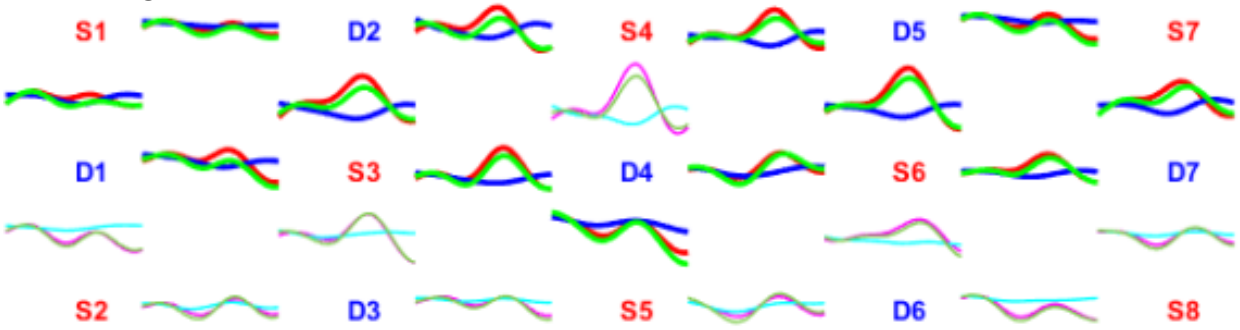
A. Baseline



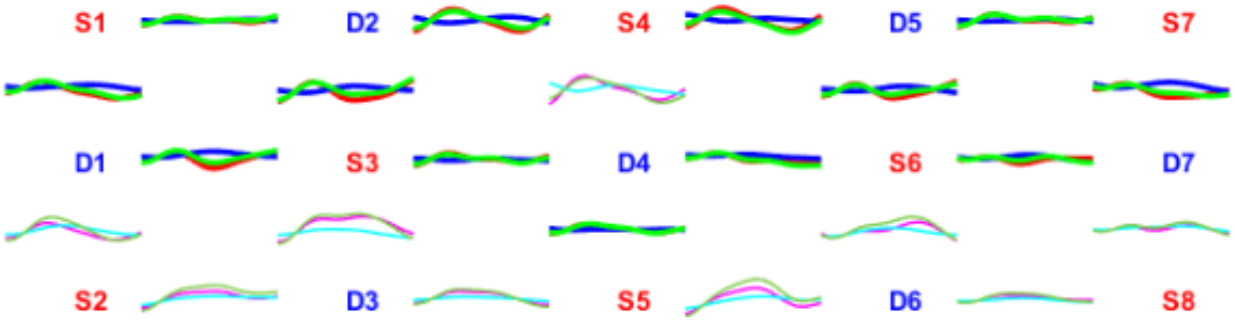
B. Viewing – Negative



C. Viewing – Neutral



D. Imagining – Negative



E. Imagining – Neutral

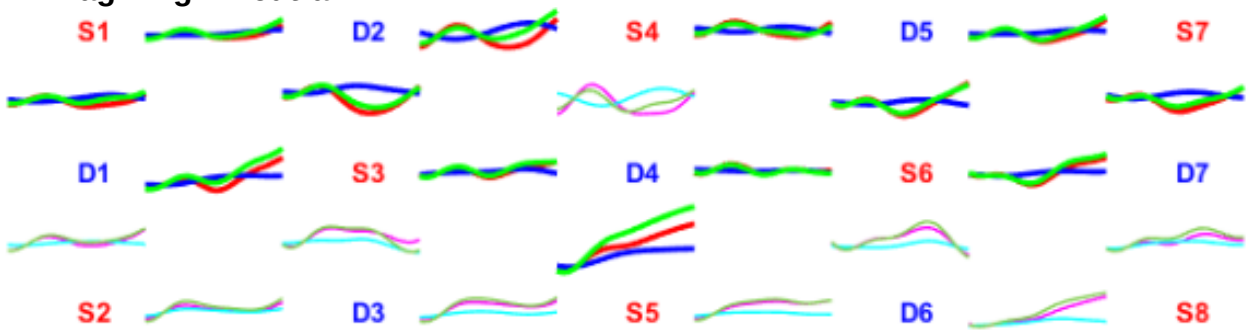


Figure 11. Probe plots for occipital optode locations illustrating block averaged HDR for A.) baseline, B.,C.) Viewing, and D.,E.) Imagining tasks. OxyHb appears in red, DeOxyHb in blue, and Total Hb in green.

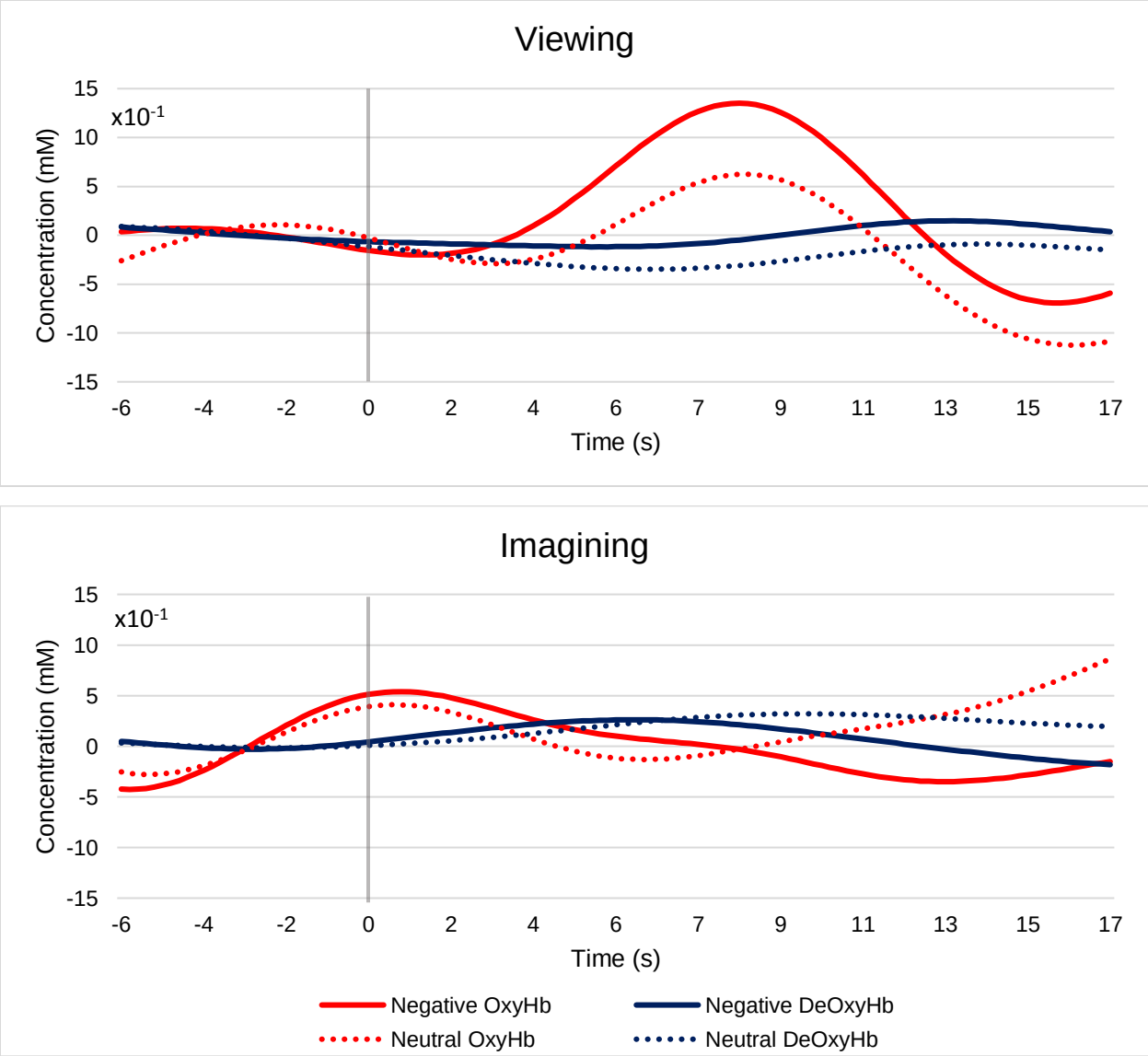


Figure 12. Group mean OxyHb concentration averaged across occipital channels. Gray bar denotes stimulus onset.

Appendix A

Mental Health Screening Form

This study involves viewing emotionally negative and arousing images that depict real and fictional scenes, including: car accidents, war, weapons, physical attack, and natural disasters. The violent nature of these images may be upsetting, offensive, or anxiety-inducing to some individuals. We are interested in the relationship between looking patterns and emotional image content and how it may influence visual "flashback" mental imagery experiences.

	Yes	No
Have you ever been diagnosed with, or suspect that you may have, a psychological or emotional disorder, such as depression, posttraumatic stress disorder (PTSD), anxiety, schizophrenia, etc.?	□	□
Have you experienced one or more severely upsetting or traumatic events in the past that have caused lasting psychological distress?	□	□
Are you able to tolerate viewing violent and/or graphic images and scenes, similar to those shown in newscasts or movies?	□	□
Have you ever experienced epileptic seizures related to light patterns or pulses?	□	□

Appendix B

VVIQ-2

Sample question from the VVIQ-2 as it appeared in the online version recreated for the current experiment. This question is selected from the “eyes closed” section.

Visualise the rising sun. Consider carefully the picture that comes before your mind’s eye.

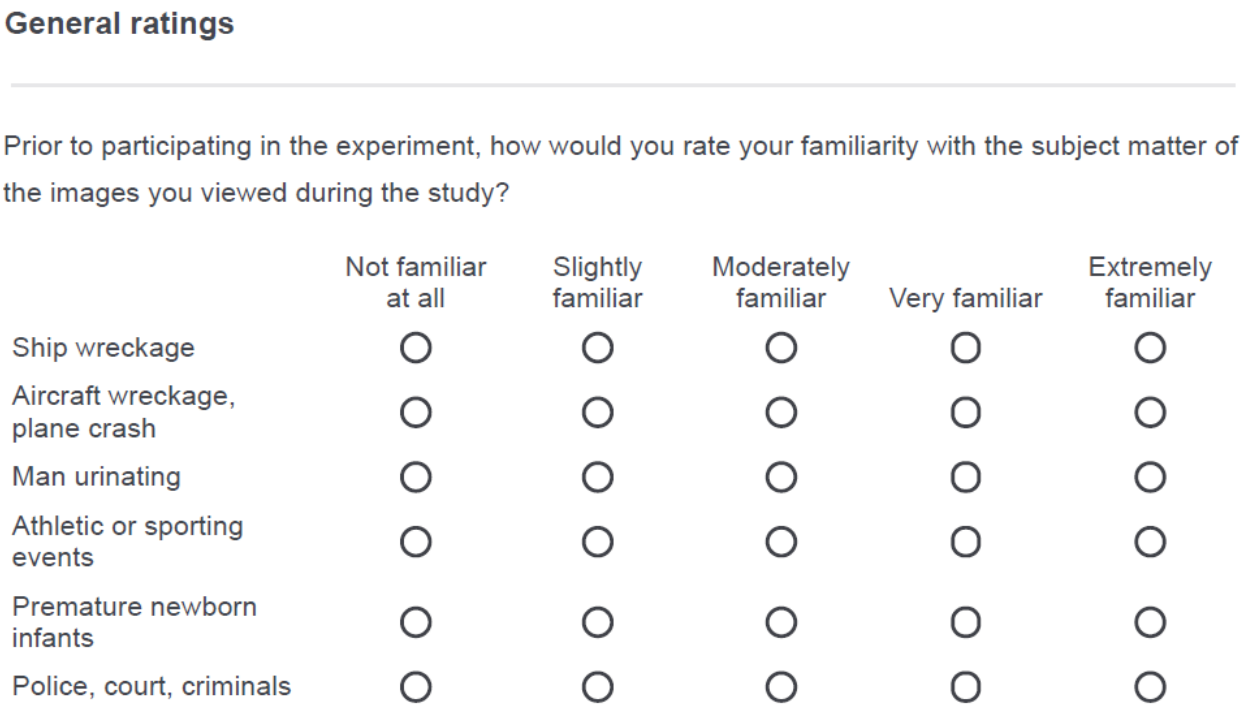
	Perfectly clear and as vivid as normal vision	Clear and reasonably vivid	Moderately clear and vivid	Vague and dim	No image at all, you only "know" that you are thinking of an object
	1	2	3	4	5
5- The sun is rising above the horizon into a hazy sky.					
6- The sky clears and surrounds the sun with blueness.					
7-Clouds. A storm blows up, with flashes of lightning.					
8- A rainbow appears.					

Figure B1. A question from the VVIQ-2, as presented in Qualtrics survey software.

Appendix C

Post-Task Survey

Portion of the post-task survey administered immediately following completion of the visual tasks. Note that order of categories was fully randomized for each participant.



General ratings

Prior to participating in the experiment, how would you rate your familiarity with the subject matter of the images you viewed during the study?

	Not familiar at all	Slightly familiar	Moderately familiar	Very familiar	Extremely familiar
Ship wreckage	○	○	○	○	○
Aircraft wreckage, plane crash	○	○	○	○	○
Man urinating	○	○	○	○	○
Athletic or sporting events	○	○	○	○	○
Premature newborn infants	○	○	○	○	○
Police, court, criminals	○	○	○	○	○

Figure C1. Sample familiarity rating questions, as presented in Qualtrics survey software.

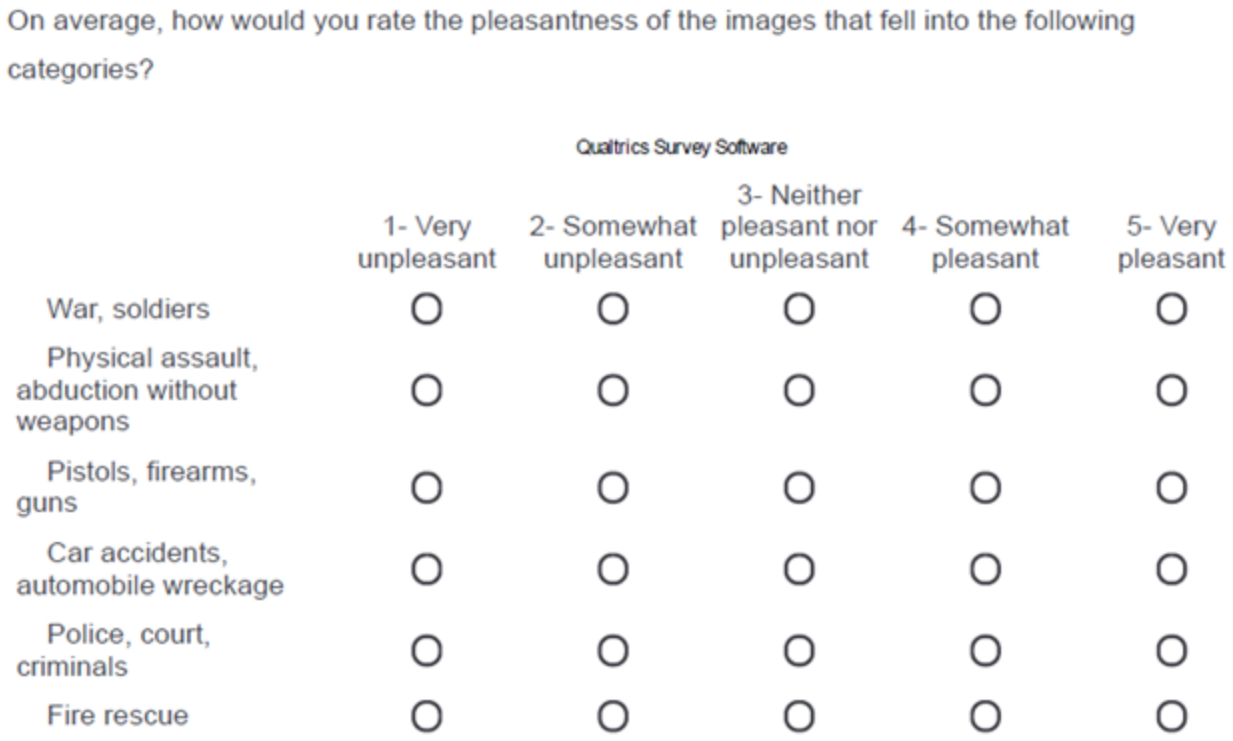


Figure C2. Sample pleasantness rating questions.

Appendix D

Presentation Sequence Statistics

Table D1

Mean IAPS Ratings for Negative Stimulus Blocks

Negative Stimuli	IAPS Number	Mean Valence	Mean Arousal
Block 1	9900	2.46	5.58
	9184	2.47	5.75
	6571	2.85	5.59
	2691	3.04	5.85
	9183	1.69	6.58
	Block average	2.502	5.87
Block 2	3019	2.99	6.3
	6313	1.98	6.94
	6220	3.1	5.89
	3530	1.8	6.82
	3022	3.7	5.88
	Block average	2.714	6.366
Block 3	9424	2.87	5.78
	9910	2.06	6.2
	6838	2.45	5.8
	9622	3.1	6.26
	6821	2.38	6.29
	Block average	2.572	6.066
Block 4	9908	2.34	6.63
	2661	3.9	5.76
	2703	1.91	5.78
	2345.1	2.26	5.5
	9495	3.34	5.57
	Block average	2.75	5.848

Table D2

Mean IAPS Ratings for Neutral Stimulus Blocks

Neutral Stimuli	IAPS Number	Mean Valence	Mean Arousal
Block 1	7493	5.35	3.39
	2720	5.43	3.43
	2002	4.95	3.35
	2273	5.41	3.52
	2026	4.82	3.4
	Block average	5.192	3.418
Block 2	2305	5.41	3.63
	2850	5.22	3
	5395	5.34	4.23
	7497	5.19	4.97
	2749	5.04	3.76
	Block average	5.24	3.918
Block 3	7506	5.34	4.25
	2372	5.48	4.09
	2870	5.31	3.01
	2383	4.72	3.41
	8121	4.63	4.14
	Block average	5.096	3.78
Block 4	2495	5.22	3.19
	9700	4.77	3.21
	2745.1	5.31	3.26
	7595	4.55	3.77
	7512	5.38	3.72
	Block average	5.046	3.43

Table D3

Final Presentation Sequences

Sequence 1:	**Neg 3**	Neut 3	**Neg 4**	Neut 2	**Neg 2**	Neut 4	**Neg 1**	Neut 1
Sequence 2:	**Neg 2**	Neut 4	**Neg 4**	Neut 1	**Neg 1**	Neut 2	**Neg 3**	Neut 3
Sequence 3:	Neut 4	**Neg 1**	Neut 2	**Neg 2**	Neut 3	**Neg 4**	Neut 1	**Neg 3**
Sequence 4:	Neut 1	**Neg 4**	Neut 3	**Neg 3**	Neut 2	**Neg 1**	Neut 4	**Neg 2**

Table D4

Distribution of Presentation Sequences

Sequence	***No. of Participants***
Sequence 1	10
Sequence 2	9
Sequence 3	12
Sequence 4	9

Appendix E

Intrusive Imagery Survey

Table E1

Intrusive Imagery Survey Responses

Since you completed the study, have you involuntarily thought about or been reminded of the images you viewed in the study?	How many times have you involuntarily thought about or been reminded of the images?	Please describe the visual content of these involuntarily thoughts. What did you see in your "mind's eye?" Separate different images by describing only one per line.	Were any of these thoughts accompanied by an emotional response or feeling?	Select the top 5 emotions that you experienced during these involuntary thoughts.	If needed, please list any additional emotions that you experienced during these involuntarily thoughts.	Please rate the strength of the emotions you experienced during these thoughts, on average:	If there are any images that you recall vividly from the experiment, please describe them here. Please separate images by describing only one per line.
No							
No							The image of the dog who had been abused is the main one I can recall.
No							
Yes	7-8 times	I thought of the image of the man assaulting the woman (grabbing her from behind) I saw the neglected dogs	Yes	Sad, Anxious		Somewhat weak	The vivid one is the one of the man assaulting the woman. He is grabbing her from behind and she looks very frightened.

No							
No							
Yes	1-2 times	I thought about the one image of the African American female standing in front of a wired fence.	No				The image of the African American woman standing in front of a wired fence. The image of the man peeing in the toilet in an old fashioned styled bathroom.
No							The most disturbing and vivid image from the experiment was the one with the airplane crash with a guy falling out of the plane.
No							I can't say that I really remember them well at all. The one of the fighter jet exploding and the pilot ejecting is remembered by what it was, but not in great detail.
No							The plane exploding in the air
No							Man peeing boy with black eye army in the streets person being held by gun point
Yes	3-4 times	I mostly remembered the premature infant covered in blood	Yes	Sad, Anxious, Frightened, Shocked		Neither strong nor weak	I can remember the premature infant, because it was so small and covered in blood. It

		and being held by hands in surgical gloves, the plane crash with the explosion of fire, and the dog in a cast next to the stairs.					looked like it was sitting in a dish and being held by a doctor's hands, which were covered by surgical gloves.
No							There was a body in a bag Car crash Individual sitting in a chair
No							
No							The plane crashing The inside of an animal A riot in another country A white guy gettting jumped
No							none
No							I remember the riot picture with people crowding around a building that had steps, the one with the man peeing, and the picture of the African American lady close up picture.
No							eyeless dog with flies man urinating car crash into pole man standing in street with graffitied wall
No							Premature baby Tied up dog Injured dog

No							
No							Dog on collar/leash attached to a pole with a cast on. Supermarket scene with a lot of colors. Crying little girl next to a car with an open door with a police yelling. Dog with an injury on his face tied to a pole. Scene of a riot with a man throwing a smoke grenade towards a political building. Picture of an old man with a grumpy look on his face.
Yes	1-2 times	When discussing the study with friends about the study I would visualize some of the more disturbing images.	No				I remember the premature baby image where the baby was crying. I remember the photo of the two young boys holding guns and smiling.
No							
Yes	3-4 times	I've thought about the male peeing, some rioting scenes, as well as the bald man sitting on on a deck with his chest hair out.	No				

No							
No							There was no image that I recalled vividly.
No							I remember some, but not very vividly
No							There are none that I recall vividly
Yes	1-2 times	I thought about the one with the dog chained up with maggots or something on its face. I mostly just saw the dog and the chain.	Yes	Angry,Sad, Anxious, Frightened, Disgusted		Somewhat weak	Chained up dog with maggots/flies on face Kid on hood of car with radio
Yes	1-2 times	Remembered viewing the pants and urine of the peeing man. Remembered viewing the orangeness of one of the boat pictures.	No				
Yes	Not sure/can't remember	The image of the child with the black eye. The image of the dog being abused. The fish being cut open to view it's guts.	Yes	Angry,Sad, Aggressive, Disgusted, Shocked		Neither strong nor weak	The image of the child with a black eye. The image of the fish being cut open. The image of the dog being abused.

Appendix F

First Fixation Interactive ANOVAs

Table F1

First Fixation Count Difference Scores

First Fixation Count

Variable	DF	F value	*p*
Error: Sub			
VVIQ	1	0.787	0.384
Vivid	1	0.077	0.783
Fam	1	1.337	0.259
Valence:Vivid	1	0.955	0.338
VVIQ:Vivid	1	0.028	0.869
VVIQ:Fam	1	0.137	0.714
Vivid:Fam	1	2.744	0.110
Valence:VVIQ:Vivid	1	3.665	0.067
Valence:Vivid:Fam	1	13.266	0.00123 *
VVIQ:Vivid:Fam	1	3.440	0.07545
Valence:VVIQ:Vivid:Fam	1	0.215	0.647
Residuals	25		
Error: Within			
Valence	1	0.966	0.329
Task	1	13.726	0.00038 **
Vivid	1	0.434	0.512
Valence:Task	1	0.091	0.763
Valence:VVIQ	1	0.139	0.710
Task:VVIQ	1	2.810	0.098
Valence:Vivid	1	1.729	0.192
Task:Vivid	1	0.169	0.682
VVIQ:Vivid	1	0.006	0.939
Valence:Fam	1	0.031	0.861
Task:Fam	1	2.314	0.132
Vivid:Fam	1	1.421	0.237
Valence:Task:VVIQ	1	0.161	0.689
Valence:Task:Vivid	1	1.054	0.308
Valence:VVIQ:Vivid	1	0.002	0.968
Task:VVIQ:Vivid	1	0.007	0.935
Valence:Task:Fam	1	0.026	0.872
Valence:VVIQ:Fam	1	1.220	0.273

Task:VVIQ:Fam	1	0.559	0.457
Valence:Vivid:Fam	1	0.329	0.568
Task:Vivid:Fam	1	0.681	0.412
VVIQ:Vivid:Fam	1	0.059	0.808
Valence:Task:VVIQ:Vivid	1	0.012	0.913
Valence:Task:VVIQ:Fam	1	0.033	0.857
Valence:Task:Vivid:Fam	1	0.041	0.840
Valence:VVIQ:Vivid:Fam	1	0.138	0.711
Task:VVIQ:Vivid:Fam	1	0.019	0.891
Valence:Task:VVIQ:Vivid:Fam	1	1.563	0.215
Residuals	83		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘°’

N = 37

Table F2

First Fixation Latency Difference Scores

First Fixation Latency

Variable	DF	F value	*p*
Error: Sub			
VVIQ	1	0.997	0.328
Vivid	1	0.100	0.754
Fam	1	0.850	0.365
Valence:Vivid	1	0.408	0.529
VVIQ:Vivid	1	0.048	0.828
VVIQ:Fam	1	0.052	0.821
Vivid:Fam	1	5.072	0.0333 °
Valence:VVIQ:Vivid	1	0.045	0.833
Valence:Vivid:Fam	1	0.095	0.760
VVIQ:Vivid:Fam	1	0.103	0.751
Valence:VVIQ:Vivid:Fam	1	0.892	0.354
Residuals	25		
Error: Within			
Valence	1	0.173	0.679
Task	1	4.265	0.04204 *
Vivid	1	4.427	0.03841 *
Valence:Task	1	0.212	0.647
Valence:VVIQ	1	1.866	0.176
Task:VVIQ	1	0.153	0.697
Valence:Vivid	1	0.034	0.854
Task:Vivid	1	0.940	0.335
VVIQ:Vivid	1	0.128	0.722
Valence:Fam	1	0.660	0.419
Task:Fam	1	0.166	0.685
Vivid:Fam	1	0.016	0.899
Valence:Task:VVIQ	1	0.705	0.404
Valence:Task:Vivid	1	0.131	0.718
Valence:VVIQ:Vivid	1	1.056	0.307
Task:VVIQ:Vivid	1	0.005	0.943
Valence:Task:Fam	1	3.922	0.05098
Valence:VVIQ:Fam	1	0.042	0.839
Task:VVIQ:Fam	1	0.029	0.865
Valence:Vivid:Fam	1	4.440	0.03813 °
Task:Vivid:Fam	1	1.784	0.185
VVIQ:Vivid:Fam	1	0.231	0.632
Valence:Task:VVIQ:Vivid	1	3.010	0.08644

Valence:Task:VVIQ:Fam	1	0.760	0.386
Valence:Task:Vivid:Fam	1	1.937	0.168
Valence:VVIQ:Vivid:Fam	1	2.400	0.125
Task:VVIQ:Vivid:Fam	1	7.012	0.00969 *
Valence:Task:VVIQ:Vivid:Fam.	1	0.648	0.423
Residuals	83		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘°’

N = 37

Table F3

First Fixation Duration Difference Scores

First Fixation Duration

Variable	DF	F value	*p*	
Error: Sub				
VVIQ	1	0.303	0.587	
Vivid	1	0.283	0.600	
Fam	1	2.832	0.105	
Valence:Vivid	1	0.042	0.840	
VVIQ:Vivid	1	0.025	0.875	
VVIQ:Fam	1	0.407	0.529	
Vivid:Fam	1	0.050	0.824	
Valence:VVIQ:Vivid	1	0.465	0.501	
Valence:Vivid:Fam	1	1.092	0.306	
VVIQ:Vivid:Fam	1	0.097	0.758	
Valence:VVIQ:Vivid:Fam	1	1.324	0.261	
Residuals	25			
Error: Within				
Valence	1	0.067	0.796	
Task	1	61.038	1.53e-11	**
Vivid	1	0.150	0.700	
Valence:Task	1	0.109	0.743	
Valence:VVIQ	1	0.006	0.937	
Task:VVIQ	1	1.652	0.202	
Valence:Vivid	1	0.463	0.498	
Task:Vivid	1	0.757	0.387	
VVIQ:Vivid	1	0.231	0.632	
Valence:Fam	1	0.010	0.922	
Task:Fam	1	10.280	0.00191	*
Vivid:Fam	1	0.084	0.773	
Valence:Task:VVIQ	1	0.009	0.923	
Valence:Task:Vivid	1	0.019	0.890	
Valence:VVIQ:Vivid	1	0.003	0.956	
Task:VVIQ:Vivid	1	0.471	0.494	
Valence:Task:Fam	1	0.106	0.746	
Valence:VVIQ:Fam	1	0.087	0.768	
Task:VVIQ:Fam	1	1.230	0.271	
Valence:Vivid:Fam	1	0.000	0.993	
Task:Vivid:Fam	1	0.296	0.588	
VVIQ:Vivid:Fam	1	0.011	0.916	
Valence:Task:VVIQ:Vivid	1	0.605	0.439	

Valence:Task:VVIQ:Fam	1	0.176	0.676
Valence:Task:Vivid:Fam	1	0.069	0.794
Valence:VVIQ:Vivid:Fam	1	0.004	0.951
Task:VVIQ:Vivid:Fam	1	0.110	0.741
Valence:Task:VVIQ:Vivid:Fam	1	0.013	0.909
Residuals	83		
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘○’			

N = 37

Appendix G

First Fixations Interactive Linear Mixed Effects Regressions

Table G1

First Fixation Count Difference Scores

First Fixation Count

Variable	B	SE B	*t*	*p*
VVIQ	0.015	0.05	0.302	0.762
Age	0.028	0.108	0.26	0.795
Gender2	-0.428	1.55	-0.276	0.782
Follow.up1	0.802	1.784	0.45	0.653
Sequence2	-162.244	232.234	-0.699	0.485
Sequence3	62.792	100.778	0.623	0.533
Sequence4	37.216	89.824	0.414	0.679
Task2	14.039	86.444	0.162	0.871
Valence2	312.116	185.035	1.687	0.092
Vivid	17.472	23.038	0.758	0.448
Fam	15.689	22.177	0.707	0.479
Sequence2:Task2	-213.082	242.3	-0.879	0.379
Sequence3:Task2	48.356	101.211	0.478	0.633
Sequence4:Task2	-55.744	90.912	-0.613	0.54
Sequence2:Valence2	-27.348	325.463	-0.084	0.933
Sequence3:Valence2	-291.531	192.746	-1.513	0.13
Sequence4:Valence2	-310.575	187.161	-1.659	0.097
Task2:Valence2	-406.987	198.841	-2.047	0.041 °
Sequence2:Vivid	53.487	70.479	0.759	0.448
Sequence3:Vivid	-20.651	26.472	-0.78	0.435
Sequence4:Vivid	-8.385	23.671	-0.354	0.723
Task2:Vivid	-5.517	22.87	-0.241	0.809
Valence2:Vivid	-87.911	52.082	-1.688	0.091
Sequence2:Fam	73.872	82.458	0.896	0.37
Sequence3:Fam	-15.711	27.366	-0.574	0.566
Sequence4:Fam	-5.807	24.771	-0.234	0.815
Task2:Fam	-3.267	23.145	-0.141	0.888
Valence2:Fam	-96.667	56.622	-1.707	0.088
Vivid:Fam	-4.636	5.77	-0.803	0.422
Sequence2:Task2:Valence2	591.113	324.626	1.821	0.069
Sequence3:Task2:Valence2	374.52	211.092	1.774	0.076
Sequence4:Task2:Valence2	409.592	202.689	2.021	0.043 °
Sequence2:Task2:Vivid	61.564	73.966	0.832	0.405

Sequence3:Task2:Vivid	-10.56	26.491	-0.399	0.69
Sequence4:Task2:Vivid	13.965	23.789	0.587	0.557
Sequence2:Valence2:Vivid	-7.595	100.161	-0.076	0.94
Sequence3:Valence2:Vivid	84.641	53.864	1.571	0.116
Sequence4:Valence2:Vivid	87.759	52.69	1.666	0.096
Task2:Valence2:Vivid	115.452	55.766	2.07	0.038 °
Sequence2:Task2:Fam	64.065	86.333	0.742	0.458
Sequence3:Task2:Fam	-15.084	28.317	-0.533	0.594
Sequence4:Task2:Fam	18.157	25.374	0.716	0.474
Sequence2:Valence2:Fam	-11.875	112.897	-0.105	0.916
Sequence3:Valence2:Fam	90.431	59.001	1.533	0.125
Sequence4:Valence2:Fam	96.095	57.532	1.67	0.095
Task2:Valence2:Fam	128.198	60.26	2.127	0.033 °
Sequence2:Vivid:Fam	-24.063	25.368	-0.949	0.343
Sequence3:Vivid:Fam	5.334	7.028	0.759	0.448
Sequence4:Vivid:Fam	1.046	6.332	0.165	0.869
Task2:Vivid:Fam	1.335	6.025	0.222	0.825
Valence2:Vivid:Fam	27.318	16.019	1.705	0.088
Sequence2:Task2:Valence2:Vivid	-167.737	98.914	-1.696	0.09
Sequence3:Task2:Valence2:Vivid	-107.308	58.607	-1.831	0.067
Sequence4:Task2:Valence2:Vivid	-114.668	56.628	-2.025	0.043 °
Sequence2:Task2:Valence2:Fam	-188.415	110.066	-1.712	0.087
Sequence3:Task2:Valence2:Fam	-120.638	64.06	-1.883	0.06
Sequence4:Task2:Valence2:Fam	-129.115	61.967	-2.084	0.037 °
Sequence2:Task2:Vivid:Fam	-18.612	26.656	-0.698	0.485
Sequence3:Task2:Vivid:Fam	3.142	7.276	0.432	0.666
Sequence4:Task2:Vivid:Fam	-4.447	6.491	-0.685	0.493
Sequence2:Valence2:Vivid:Fam	8.657	35.055	0.247	0.805
Sequence3:Valence2:Vivid:Fam	-26.299	16.551	-1.589	0.112
Sequence4:Valence2:Vivid:Fam	-27.313	16.257	-1.68	0.093
Task2:Valence2:Vivid:Fam	-36.592	16.96	-2.158	0.031 °
Sequence2:Task2:Valence2:Vivid:Fam	53.833	33.836	1.591	0.112

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘°’

N = 37

Table G2

First Fixation Latency Difference Scores

First Fixation Latency

Variable	B	SE B	*t*	*p*
VVIQ	-1.166	2.321	-0.502	0.615
Age	1.514	5.490	0.276	0.783
Gender2	9.045	65.689	0.138	0.890
Follow.up1	-122.463	75.482	-1.622	0.105
Sequence2	8282.816	23160.563	0.358	0.721
Sequence3	-645.804	9973.999	-0.065	0.948
Sequence4	-11644.896	8753.377	-1.330	0.183
Task2	-4051.762	11407.599	-0.355	0.722
Valence2	42176.063	18619.007	2.265	0.023 °
Vivid	-760.804	2269.367	-0.335	0.737
Fam	-764.768	2277.894	-0.336	0.737
Sequence2:Task2	-3530.522	31975.195	-0.110	0.912
Sequence3:Task2	2861.865	13356.329	0.214	0.830
Sequence4:Task2	16785.588	11997.263	1.399	0.162
Sequence2:Valence2	-67767.677	30886.549	-2.194	0.028 °
Sequence3:Valence2	-44773.996	19806.797	-2.261	0.024 °
Sequence4:Valence2	-31956.333	18966.180	-1.685	0.092
Task2:Valence2	-34409.107	26240.164	-1.311	0.190
Sequence2:Vivid	-2593.915	7038.880	-0.369	0.712
Sequence3:Vivid	77.274	2611.580	0.030	0.976
Sequence4:Vivid	2964.302	2299.598	1.289	0.197
Task2:Vivid	1037.873	3018.053	0.344	0.731
Valence2:Vivid	-12024.188	5219.574	-2.304	0.021 °
Sequence2:Fam	-2808.950	8209.066	-0.342	0.732
Sequence3:Fam	-107.114	2772.740	-0.039	0.969
Sequence4:Fam	4182.089	2419.416	1.729	0.084
Task2:Fam	1059.684	3054.357	0.347	0.729
Valence2:Fam	-14185.394	5642.227	-2.514	0.012 °
Vivid:Fam	187.110	592.108	0.316	0.752
Sequence2:Task2:Valence2	58617.942	42839.454	1.368	0.171
Sequence3:Task2:Valence2	34887.426	27856.924	1.252	0.210
Sequence4:Task2:Valence2	22860.544	26747.986	0.855	0.393
Sequence2:Task2:Vivid	1350.392	9760.923	0.138	0.890
Sequence3:Task2:Vivid	-688.622	3495.949	-0.197	0.844
Sequence4:Task2:Vivid	-4332.957	3139.393	-1.380	0.168
Sequence2:Valence2:Vivid	20321.707	9427.582	2.156	0.031 °
Sequence3:Valence2:Vivid	12244.515	5495.019	2.228	0.026 °

Sequence4:Valence2:Vivid	9316.023	5298.244	1.758	0.079
Task2:Valence2:Vivid	9981.426	7359.207	1.356	0.175
Sequence2:Task2:Fam	1726.520	11392.923	0.152	0.880
Sequence3:Task2:Fam	-552.129	3736.911	-0.148	0.883
Sequence4:Task2:Fam	-6073.459	3348.558	-1.814	0.070
Sequence2:Valence2:Fam	22979.620	10501.550	2.188	0.029 °
Sequence3:Valence2:Fam	15332.704	6011.595	2.551	0.011 °
Sequence4:Valence2:Fam	10107.684	5796.153	1.744	0.081
Task2:Valence2:Fam	12121.623	7952.189	1.524	0.127
Sequence2:Vivid:Fam	879.569	2526.607	0.348	0.728
Sequence3:Vivid:Fam	48.046	712.723	0.067	0.946
Sequence4:Vivid:Fam	-1066.360	621.340	-1.716	0.086
Task2:Vivid:Fam	-268.830	795.053	-0.338	0.735
Valence2:Vivid:Fam	4051.042	1587.350	2.552	0.011 °
Sequence2:Task2:Valence2:Vivid	-17654.547	13053.210	-1.353	0.176
Sequence3:Task2:Valence2:Vivid	-9682.215	7734.133	-1.252	0.211
Sequence4:Task2:Valence2:Vivid	-6997.932	7472.930	-0.936	0.349
Sequence2:Task2:Valence2:Fam	-21068.341	14524.858	-1.451	0.147
Sequence3:Task2:Valence2:Fam	-12773.220	8453.650	-1.511	0.131
Sequence4:Task2:Valence2:Fam	-7745.939	8177.542	-0.947	0.344
Sequence2:Task2:Vivid:Fam	-609.446	3517.608	-0.173	0.862
Sequence3:Task2:Vivid:Fam	135.081	960.241	0.141	0.888
Sequence4:Task2:Vivid:Fam	1563.739	856.602	1.826	0.068
Sequence2:Valence2:Vivid:Fam	-6938.891	3234.146	-2.146	0.032 °
Sequence3:Valence2:Vivid:Fam	-4212.131	1670.535	-2.521	0.012 °
Sequence4:Valence2:Vivid:Fam	-2966.327	1621.683	-1.829	0.067
Task2:Valence2:Vivid:Fam	-3514.538	2238.072	-1.570	0.116
Sequence2:Task2:Valence2:Vivid:Fam	6400.999	4465.242	1.434	0.152
Sequence3:Task2:Valence2:Vivid:Fam	3552.142	2350.846	1.511	0.131
Sequence4:Task2:Valence2:Vivid:Fam	2391.723	2288.066	1.045	0.296

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘°’

N = 37

Table G3

First Fixation Duration Difference Scores

First Fixation Duration

Variable	B	SE B	*t*	*p*
VVIQ	0.900	4.191	0.215	0.830
Age	-7.020	9.634	-0.729	0.466
Gender2	-38.545	123.111	-0.313	0.754
Follow.up1	236.916	141.485	1.674	0.094
Sequence2	22001.720	31374.926	0.701	0.483
Sequence3	3000.762	13434.190	0.223	0.823
Sequence4	2022.145	11755.739	0.172	0.863
Task2	-2174.810	13559.275	-0.160	0.873
Valence2	11720.670	24668.126	0.475	0.635
Vivid	794.790	3065.040	0.259	0.795
Fam	813.105	3049.095	0.267	0.790
Sequence2:Task2	-18816.820	38006.284	-0.495	0.621
Sequence3:Task2	4642.353	15875.569	0.292	0.770
Sequence4:Task2	2518.417	14260.160	0.177	0.860
Sequence2:Valence2	-42458.750	42723.998	-0.994	0.320
Sequence3:Valence2	-13460.780	26029.554	-0.517	0.605
Sequence4:Valence2	-11025.520	25045.705	-0.440	0.660
Task2:Valence2	-14793.090	31189.525	-0.474	0.635
Sequence2:Vivid	-6527.648	9528.360	-0.685	0.493
Sequence3:Vivid	-681.477	3520.735	-0.194	0.847
Sequence4:Vivid	-546.919	3093.180	-0.177	0.860
Task2:Vivid	689.433	3587.311	0.192	0.848
Valence2:Vivid	-3279.468	6926.971	-0.473	0.636
Sequence2:Fam	-7354.439	11125.608	-0.661	0.509
Sequence3:Fam	-908.803	3715.775	-0.245	0.807
Sequence4:Fam	-312.865	3242.436	-0.096	0.923
Task2:Fam	543.626	3630.463	0.150	0.881
Valence2:Fam	-3862.032	7493.537	-0.515	0.606
Vivid:Fam	-197.517	792.462	-0.249	0.803
Sequence2:Task2:Valence2	73830.170	50919.736	1.450	0.147
Sequence3:Task2:Valence2	15370.740	33111.234	0.464	0.642
Sequence4:Task2:Valence2	12670.350	31793.131	0.399	0.690
Sequence2:Task2:Vivid	5626.802	11602.006	0.485	0.628
Sequence3:Task2:Vivid	-1168.935	4155.347	-0.281	0.778
Sequence4:Task2:Vivid	-197.627	3731.538	-0.053	0.958
Sequence2:Valence2:Vivid	13119.500	13108.089	1.001	0.317
Sequence3:Valence2:Vivid	3598.552	7242.760	0.497	0.619

Sequence4:Valence2:Vivid	3127.550	7017.129	0.446	0.656
Task2:Valence2:Vivid	4186.088	8747.284	0.479	0.632
Sequence2:Task2:Fam	5446.244	13541.831	0.402	0.688
Sequence3:Task2:Fam	-1192.391	4441.758	-0.268	0.788
Sequence4:Task2:Fam	-591.300	3980.156	-0.149	0.882
Sequence2:Valence2:Fam	14345.600	14667.159	0.978	0.328
Sequence3:Valence2:Fam	4548.455	7915.808	0.575	0.566
Sequence4:Valence2:Fam	3631.989	7659.573	0.474	0.635
Task2:Valence2:Fam	5043.602	9452.113	0.534	0.594
Sequence2:Vivid:Fam	2200.198	3422.649	0.643	0.520
Sequence3:Vivid:Fam	201.895	955.225	0.211	0.833
Sequence4:Vivid:Fam	87.990	832.823	0.106	0.916
Task2:Vivid:Fam	-158.410	945.015	-0.168	0.867
Valence2:Vivid:Fam	1086.402	2112.668	0.514	0.607
Sequence2:Task2:Valence2:Vivid	-23487.350	15515.277	-1.514	0.130
Sequence3:Task2:Valence2:Vivid	-3944.467	9192.928	-0.429	0.668
Sequence4:Task2:Valence2:Vivid	-3714.314	8882.457	-0.418	0.676
Sequence2:Task2:Valence2:Fam	-22119.280	17264.504	-1.281	0.200
Sequence3:Task2:Valence2:Fam	-5639.124	10048.159	-0.561	0.575
Sequence4:Task2:Valence2:Fam	-4470.196	9719.971	-0.460	0.646
Sequence2:Task2:Vivid:Fam	-1615.546	4181.091	-0.386	0.699
Sequence3:Task2:Vivid:Fam	303.732	1141.359	0.266	0.790
Sequence4:Task2:Vivid:Fam	52.334	1018.173	0.051	0.959
Sequence2:Valence2:Vivid:Fam	-4451.500	4539.558	-0.981	0.327
Sequence3:Valence2:Vivid:Fam	-1220.759	2207.718	-0.553	0.580
Sequence4:Valence2:Vivid:Fam	-1036.535	2150.953	-0.482	0.630
Task2:Valence2:Vivid:Fam	-1439.495	2660.212	-0.541	0.588
Sequence2:Task2:Valence2:Vivid:Fam	7050.847	5307.466	1.328	0.184
Sequence3:Task2:Valence2:Vivid:Fam	1491.196	2794.258	0.534	0.594
Sequence4:Task2:Valence2:Vivid:Fam	1308.824	2719.635	0.481	0.630

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘°’

N = 37

Appendix H

Group Mean HbO Descriptive Statistics

Table H1

Baseline Condition Group Mean HbO

Baseline			
Channel	*Mean HbO*	*Median*	*SD*
HbO,1,1	-2.591	-2.285	4.309
HbO,1,2	7.576	-1.195	38.454
HbO,2,1	-1.956	-1.764	3.255
HbO,2,3	2.325	-1.480	16.973
HbO,3,1	1.029	-1.120	11.289
HbO,3,2	0.297	-0.328	5.303
HbO,3,3	-2.534	-1.875	5.195
HbO,3,4	-2.129	-0.569	4.335
HbO,4,2	1.466	-0.749	10.811
HbO,4,4	-0.992	-0.963	3.027
HbO,4,5	8.447	-1.120	39.134
HbO,5,3	-1.926	-1.990	2.229
HbO,5,4	1.873	-1.445	8.346
HbO,5,6	2.789	-1.280	10.490
HbO,6,4	-0.211	-0.784	2.456
HbO,6,5	10.158	-0.405	37.562
HbO,6,6	-7.426	-2.390	15.737
HbO,6,7	1.693	-0.590	11.290
HbO,7,5	1.499	-0.412	9.377
HbO,7,7	-4.467	-1.130	13.046
HbO,8,6	-3.697	-1.720	8.752
HbO,8,7	-1.023	-1.500	3.396

Note: All values expressed as 10^{-6}

$N = 24$

Table H2

Viewing Task Group Mean HbO

Viewing						
Negative				***Neutral***		
Channel	*Mean HbO*	*Median*	*SD*	*Mean HbO*	*Median*	*SD*
HbO,1,1	-2.591	-2.285	4.309	-0.135	-0.275	2.041
HbO,1,2	7.576	-1.195	38.454	-0.333	0.015	1.262
HbO,2,1	-1.956	-1.764	3.255	0.201	0.105	1.154
HbO,2,3	2.325	-1.480	16.973	0.221	0.261	0.812
HbO,3,1	1.029	-1.120	11.289	0.065	0.419	1.691
HbO,3,2	0.297	-0.328	5.303	-0.167	0.014	1.562
HbO,3,3	-2.534	-1.875	5.195	0.290	0.236	2.195
HbO,3,4	-2.129	-0.569	4.335	0.372	0.485	1.778
HbO,4,2	1.466	-0.749	10.811	0.201	0.042	1.425
HbO,4,4	-0.992	-0.963	3.027	0.909	0.548	1.348
HbO,4,5	8.447	-1.120	39.134	0.119	-0.428	1.495
HbO,5,3	-1.926	-1.990	2.229	0.559	0.490	0.813
HbO,5,4	1.873	-1.445	8.346	0.465	0.313	1.631
HbO,5,6	2.789	-1.280	10.490	0.135	0.822	1.291
HbO,6,4	-0.211	-0.784	2.456	0.354	0.630	1.691
HbO,6,5	10.158	-0.405	37.562	0.246	0.632	1.426
HbO,6,6	-7.426	-2.390	15.737	0.454	1.560	2.243
HbO,6,7	1.693	-0.590	11.290	0.386	0.665	1.582
HbO,7,5	1.499	-0.412	9.377	-0.290	-0.064	1.107
HbO,7,7	-4.467	-1.130	13.046	0.265	0.865	1.748
HbO,8,6	-3.697	-1.720	8.752	0.141	-0.011	0.853
HbO,8,7	-1.023	-1.500	3.396	0.040	0.638	1.412

Note: All values expressed as 10^{-6}

$N = 24$

Table H3

Imagining Task Group Mean HbO

Imagining						
Negative				***Neutral***		
Channel	*Mean HbO*	*Median*	*SD*	*Mean HbO*	*Median*	*SD*
HbO,1,1	-0.271	-0.157	0.891	-0.035	-0.283	1.563
HbO,1,2	0.065	-0.145	0.840	0.101	-0.011	1.073
HbO,2,1	0.037	-0.005	0.870	0.201	-0.119	1.100
HbO,2,3	0.362	0.410	1.034	0.174	0.069	1.091
HbO,3,1	-0.207	-0.412	0.910	0.311	-0.024	1.483
HbO,3,2	-0.024	-0.111	1.143	-0.382	-0.424	0.947
HbO,3,3	0.486	0.189	1.798	0.278	-0.045	1.461
HbO,3,4	-0.072	-0.288	0.990	0.091	-0.073	0.689
HbO,4,2	0.016	-0.203	1.275	0.035	-0.006	1.408
HbO,4,4	-0.148	-0.518	1.463	-0.354	-0.221	0.675
HbO,4,5	-0.175	-0.033	1.064	-0.067	-0.194	1.057
HbO,5,3	0.076	0.075	0.736	0.526	0.148	0.860
HbO,5,4	-0.052	-0.122	1.290	1.060	0.314	1.609
HbO,5,6	0.524	0.489	1.000	0.214	0.018	0.603
HbO,6,4	-0.385	-0.340	0.945	-0.069	-0.127	1.016
HbO,6,5	-0.047	-0.115	0.958	0.028	0.369	1.108
HbO,6,6	0.179	-0.178	1.683	0.296	0.253	1.343
HbO,6,7	-0.091	-0.304	1.090	0.180	-0.180	1.176
HbO,7,5	0.111	0.016	0.980	0.055	0.121	0.843
HbO,7,7	-0.380	-0.275	1.053	-0.077	-0.036	1.535
HbO,8,6	0.039	0.467	0.996	0.500	0.374	0.992
HbO,8,7	-0.046	-0.037	0.739	0.389	-0.076	1.242

Note: All values expressed as 10^{-6}

$N = 24$

Appendix I

Interactive Random Effects Regression for Occipital OxyHb

Table I1

Random Effects Model for Group Mean Occipital OxyHb

Variable	B	SE B	*t*	*p*
Age	-0.002	0.013	-0.142	0.887
Gender	0.121	0.249	0.486	0.627
Sequence2	-0.335	0.283	-1.187	0.235
Sequence3	-0.149	0.314	-0.475	0.635
Sequence4	-0.229	0.269	-0.850	0.395
VVIQ	0.006	0.006	0.985	0.324
Task2	27.733	1.950	14.226	0.000 ***
Valence2	8.042	3.450	2.331	0.020 °
Fam.	6.988	0.708	9.870	0.000 ***
Follow.up1	-30.037	66.976	-0.448	0.654
Vivid	5.578	0.558	9.996	0.000 ***
Task2:Valence2	-22.536	4.204	-5.361	0.000 ***
Task2:Fam.	-9.076	0.751	-12.083	0.000 ***
Valence2:Fam.	-2.429	1.128	-2.154	0.031 °
Task2:Follow.up1	-116.807	49.356	-2.367	0.018 °
Valence2:Follow.up1	179.070	127.190	1.408	0.159
Fam.:Follow.up1	41.641	57.188	0.728	0.467
Task2:Vivid	-7.357	0.522	-14.102	0.000 ***
Valence2:Vivid	-2.212	0.961	-2.303	0.021 °
Fam.:Vivid	-1.802	0.182	-9.927	0.000 ***
Follow.up1:Vivid	8.064	17.594	0.458	0.647
Task2:Valence2:Fam.	6.241	1.379	4.526	0.000 ***
Task2:Valence2:Follow.up1	7.878	74.788	0.105	0.916
Task2:Fam.:Follow.up1	75.098	42.204	1.779	0.075
Valence2:Fam.:Follow.up1	-87.485	73.646	-1.188	0.235
Task2:Valence2:Vivid	6.565	1.173	5.596	0.000 ***
Task2:Fam.:Vivid	2.329	0.192	12.106	0.000 ***
Valence2:Fam.:Vivid	0.571	0.313	1.823	0.068
Task2:Follow.up1:Vivid	30.865	12.999	2.374	0.018 °
Valence2:Follow.up1:Vivid	-47.228	33.834	-1.396	0.163
Fam.:Follow.up1:Vivid	-10.956	15.065	-0.727	0.467
Task2:Valence2:Fam.:Follow.up1	-41.329	45.633	-0.906	0.365
Task2:Valence2:Fam.:Vivid	-1.684	0.382	-4.408	0.000 ***
Task2:Valence2:Follow.up1:Vivid	-3.876	19.946	-0.194	0.846

Task2:Fam.:Follow.up1:Vivid	-19.998	11.137	-1.796	0.073
Valence2:Fam.:Follow.up1:Vivid	23.156	19.545	1.185	0.236
Task2:Valence2:Fam.:Follow.up1:Vivid	11.560	12.103	0.955	0.340

Note: Beta values expressed as 10^{-6}
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '°'

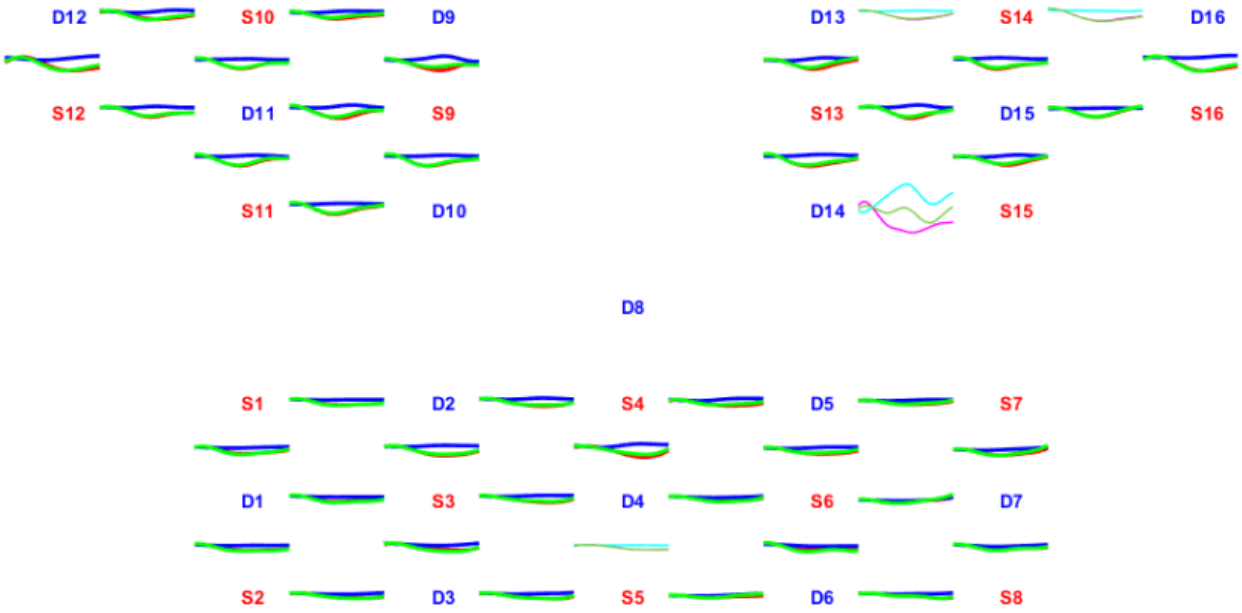
N = 24

Appendix J

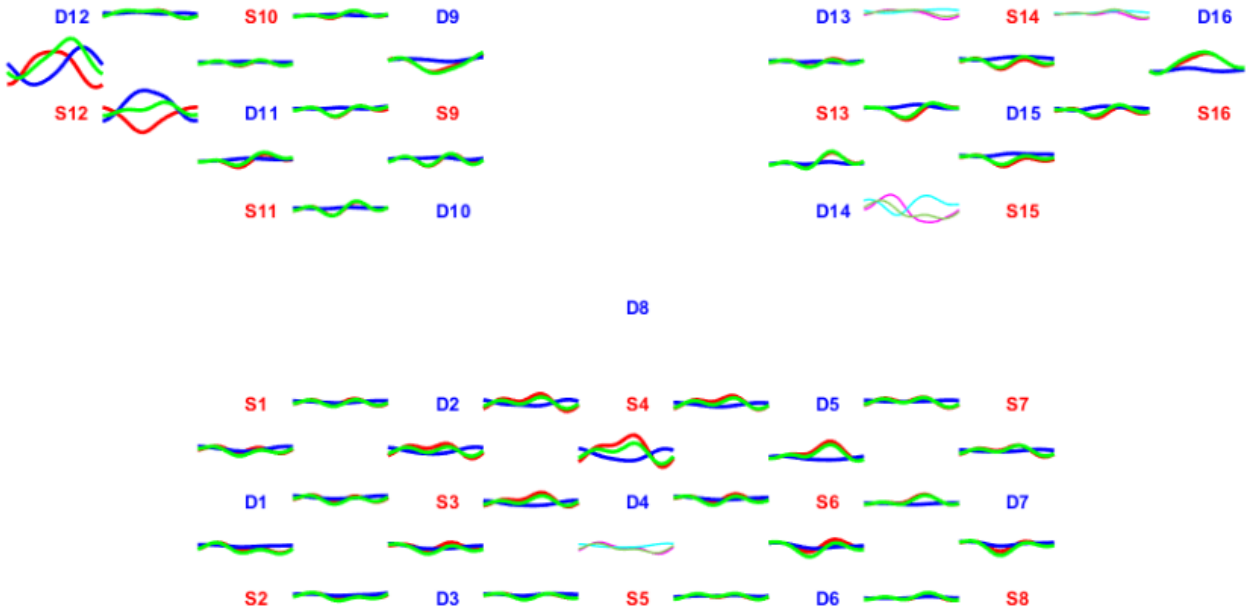
Functional Localization Probe Plots

Probe plots for motor and occipital channels in five participants used for the functional localization analysis.

A. Baseline



B. All Tasks – Negative



C. All Tasks – Neutral

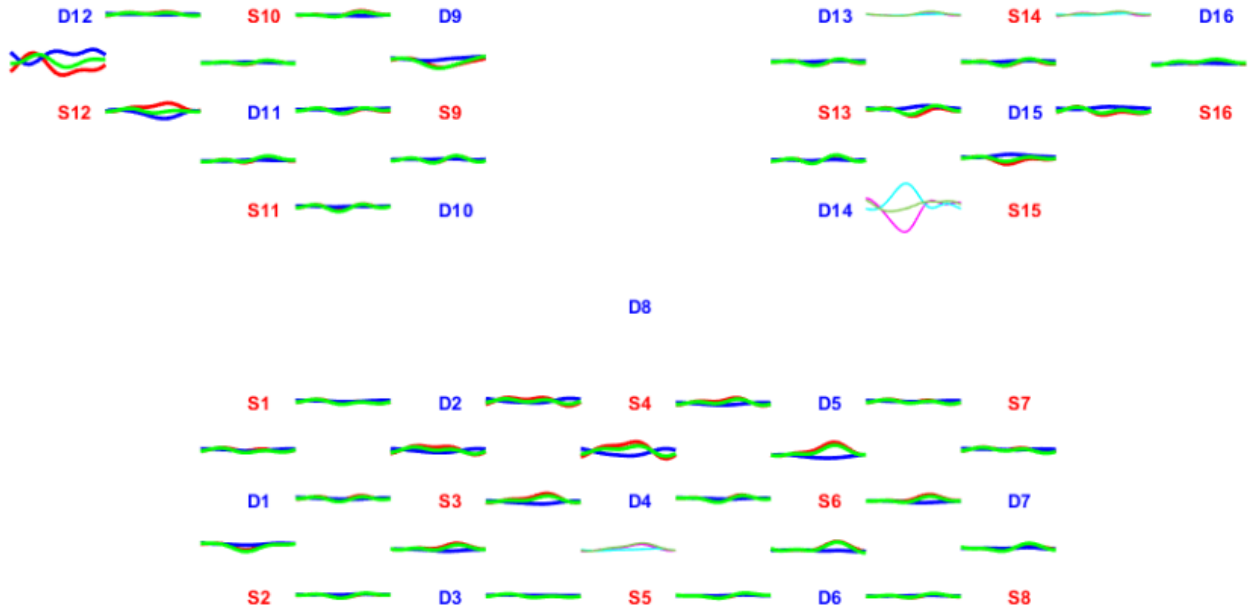


Figure J1. Probe plots for motor and occipital group HRF in five subjects, displaying OxyHb (red), DeOxyHb (blue), and Total Hb (green) concentrations.