Hemispheric Contributions to Visuospatial Attention and Emotional Processing

by

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Summary

The human brain comprises the right and left hemisphere, which increase its capacity by allowing simultaneous processing of information. The right and left hemispheres have functional asymmetries, defined as differences in behaviour or neural activation resulting from specialisations located in each hemisphere. This thesis focuses on asymmetries for visuospatial attention and emotional processing. Few studies have investigated the *combined* influence of visuospatial attention and emotional processing asymmetries on behavioural responses (e.g., attention, memory) to naturalistic scenes, despite knowing they are largely automatic and do not function in isolation. I seek to address this gap by investigating the influence of visuospatial attention and emotional processing asymmetries on three behavioural outcomes; attention, recognition memory, involuntary memory. More specifically, the broad objective of this thesis is to understand how functional asymmetries influence attention to and memory for emotional stimuli, primarily images. I achieved this objective by establishing whether these asymmetries influence (1) attending to and disengaging from emotional stimuli, (2) recognition memory for emotional (negative and positive) compared to neutral images, and (3) involuntary memory for negative images. I also investigated (4) increasing hemispheric activation to perform unilateral contractions (i.e., squeezing a ball with one hand), by measuring whether these contractions alter biases in visuospatial attention.

My findings suggest that hemispheric asymmetries for visuospatial attention and emotional processing influence some behavioural outcomes, primarily recognition memory for emotional images. I found a left hemisphere memory deficit for emotional (positive and negative) compared to neutral images. Thus, it is not right hemisphere superiority for processing emotion, but left hemisphere inferiority, that appears to influence memory. However, task demands (e.g., making recognition memory judgments after viewing image pairs for 500 ms vs. viewing a single image for 3000 ms) and the type of memory measured (voluntary vs. involuntary) influenced whether or not this left hemisphere memory deficit occurred. I also examined whether hemispheric asymmetries influence attention; specifically, the emotion induced blindness effect (Most, Chun, Widders, & Zald, 2005)—where an emotional distractor impairs people's ability to notice a neutral target presented shortly afterwards. I found limited evidence that hemispheric asymmetries influence people's ability to disengage from emotional (vs. neutral) stimuli, in this case to detect a neutral target. Although right hemisphere processing improved target detection overall, right and left hemisphere processing led to a similar impairment in target detection following emotional distractors. Finally, I found that unilateral contractions did not influence visuospatial attention, suggesting they may be an ineffective method of increasing hemispheric activation and visuospatial attention asymmetries.

These findings add to the view that we can no longer see responsibilities of the right and left hemisphere as single dichotomous units; the processes within *and* the interaction between the right and left hemispheres leads to our experience of emotion. This thesis has practical implications for understanding how hemispheric asymmetries contribute to emotional processing in general and speculating how hemispheric asymmetries may lead to problematic emotional processing. Future research should directly test the influence of hemispheric asymmetries in the development and maintenance of psychological disorders.

Declaration

I certify that this thesis does not incorporate without my acknowledgement any material previously submitted for a degree or diploma in any university; and to the best of my knowledge and belief, does not contain any material previously published or written by another person except where due reference is made in the text.

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Now let the celebrations continue; we made it!

1 Visuospatial Attention and Emotional Processing Asymmetries: Literature Review

"Hemispheric asymmetries are a central principle of nervous system architecture and shape the functional organisation of most cognitive systems" (Ocklenburg, Friedrich, Güntürkün, & Genc, 2016, p. 465). Hemispheric asymmetries (also termed lateralisation) are defined as relative differences in function and activation resulting from specialisations in the right and left hemisphere (Ocklenburg et al., 2016), or the various functional roles played by each side of the brain (Frasnelli & Vallortigara, 2018). Hemispheric asymmetries affect several cognitive functions, including language (e.g., Ocklenburg, Beste, Arning, Peterburs, & Güntürkün, 2014), motor control of the hands (Volkmann, Schnitzler, Witte, & Freund, 1998), emotional processing (e.g., Gainotti, 2012), and visuospatial attention (e.g., Bowers & Heilman, 1980). For example, most people show left hemisphere (LH) predominance for language and right hemisphere (RH) predominance for visuospatial attention[1], though it is important to note that no cognitive function is determined by a single neural region. In addition to differences in activation whilst performing tasks, like producing language, hemispheric asymmetries influence our behaviour. Perhaps the most well-known demonstration of the connection between asymmetries and behaviour is handedness; around 90% of the population show a preference for performing manual tasks with their right hand, due to LH predominance for motor control (Corballis, 2010). Similarly, we pay slightly more attention to the left side of space, due to RH predominance for visuospatial attention—termed pseudoneglect (Bowers & Heilman, 1980).

Despite the ubiquity of hemispheric asymmetries amongst humans and animals alike

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[1] The terms visuospatial attention and spatial attention will be used interchangeably.

(Rogers, Vallortigara, & Andrews, 2013), they remain one of the brain's least understood organisational principles (Güntürkün & Ocklenburg, 2017). This thesis seeks to advance our understanding of two hemispheric asymmetries—visuospatial attention and emotional processing—by establishing their influence on behaviour; namely, attention, recognition memory, and involuntary memory for emotional images. As an important improvement on prior research, I investigate the *combined* influence of visuospatial attention and emotional processing asymmetries because they do not occur in isolation. Limited research has investigated how asymmetries might affect one another (Hartikainen, Ogawa, & Knight, 2000).

I focused on visuospatial attention and emotional processing because of the connection between these two processes. Our automatic attention to threatening (or potentially threatening) stimuli in our environment clearly demonstrates this connection. This automatic attention toward emotion occurs so that—evoluntionarily—we can adequately respond to such threats (see Carretie, 2014 for review). But it biases our behaviour in several ways. The following three biases underlie my thesis experiments. First, emotional stimuli impair our ability to notice other, neutral, stimuli appearing directly after—an effect known as emotion induced blindness (e.g., Most et al., 2005). Second, emotion facilitates encoding (e.g., Anderson, 2005), leading to enhanced memory—an effect known as the emotional enhancement of memory. Third, we are likely to develop involuntary memories in the days and weeks after a highly emotional event (e.g., witnessing a car crash; Galatzer-Levy et al., 2013). When these involuntary memories persist, they can lead to psychological disorders including Post Traumatic Stress Disorder (PTSD). We know that RH predominance for visuospatial attention biases attention toward the left side of space. Therefore, if attention affects how we respond in the presence of emotion, or how we remember emotional scenarios, then it follows that hemispheric asymmetries could also influence those behaviours. To our knowledge, only one study has directly investigated this possibility (Kensinger & Choi, 2009, in the context of memory). Therefore, in eight experiments presented across five chapters I established how hemispheric asymmetries influenced attention to and memory for emotional images.

In most neurotypical people, visuospatial attention is a RH asymmetry (e.g., de Schotten et al., 2011) leading people to pay slightly more attention to the left side of space. Over several decades, theorists have attempted to account for hemispheric asymmetries in emotional processing. Initially, emotional processing was also thought to be a RH asymmetry (e.g., Gainotti, 1972), followed by the emergence of a valence-specific view, which posited that the RH processes negative emotions and the LH processes positive emotions (Davidson & Fox, 1982). But these views of emotional processing as a dichotomous asymmetry are no longer viable (e.g., Miller, Crocker, Spielberg, Infantolino, & Heller, 2013). The current consensus is that the RH and LH make unique contributions to emotional processing depending on processing stage and task type. For example, the RH may control the processing of emotion upon first perception (e.g., identify its valence, Gainotti, 2012), termed initial processing, while the LH may be predominant in the later processing of emotion (e.g., regulating emotional responses; Shobe, 2014). Emotional processing theories were primarily informed by clinical populations or differences in neural activation between the hemispheres at rest or while people performed various tasks. As Grimshaw and Carmel (2014), and Shobe (2014) echo, we lack understanding of the relationship between *emotional* asymmetries and performance on *behavioural* measures, termed asymmetry performance relationships.

There are several known asymmetry performance relationships in areas other than emotional processing. For example, as a result of LH dominance for verbal processing, people are better at detecting stimuli presented to the right than the left ear in a dichotic listening task (e.g., Jerger & Martin, 2004), and faster at naming words that appear in the right than the left visual field (Scott & Hellige, 1998). Of more interest to the current thesis are behavioural biases from RH dominance for visuospatial attention. We know that people show a leftward bias in line bisection (see Jewell & McCourt, 2000 for review), picture scanning (e.g., Foulsham, Gray, Nasiopolous, & Livingstone, 2013; Ossandón, Onat, & König, 2014), remembering items located within pictures (Dickinson & Intraub, 2009), and even responses on Likert scales (e.g., Nicholls, Orr, Okubo, & Loftus, 2006). The RH dominance for visuospatial attention also biases *involuntary* responses to stimuli, for example through attention capture. Du and Abrams (2010) found that participants were more impaired by visual distractors when they appeared in the left than the right visual field, due to heightened attention (and therefore susceptibility) to the left side. But few studies have investigated behavioural biases as a result of emotional processing asymmetries, nor the interaction between emotional and visuospatial attention asymmetries.

There are three primary reasons why I focus on differences in behaviour, rather than just focusing on differences in neural activation, as a result of hemispheric asymmetries for emotional processing. First, neural 'fingerprints' of emotion differ across studies, labs, induction techniques, and participants (Barrett, 2018). For example, hemispheric differences in the frontal cortex are supported by electroencephalogram (EEG) studies, but not by functional magnetic resonance imaging (fMRI) studies (Grimshaw & Carmel, 2014). Second, imaging studies are inherently noisy and the results can only ever be correlated with responses on behavioural tasks. Therefore, we need experiments to infer causality. Third, recent evidence suggests that neural activation and behavioural responses on the same task may diverge. Prete, Capotosto, Zappasodi, and Tommasi (2018) investigated neural activation and behavioural responses to facial expressions presented in a divided visual field paradigm—where stimuli are presented on the left and the right of a central fixation cross (Bourne, 2006). Their results were measure-dependent; for positive facial expressions they found RH superiority in neural activation, yet LH superiority in behaviour—i.e., naming the expressed emotion. This discrepancy highlights the need to study both neural processes *and* behaviour, the latter of which has received less empirical attention (Caeyenberghs & Leemans, 2014; Krakauer, Ghazanfar, Gomez-Marin, MacIver, & Peoppel, 2017). Investigating how hemispheric asymmetries influence behavioural responses to emotional stimuli may be particularly worthwhile for informing discrepant models of emotion, which are primarily informed by neuroimaging (Kragel, Koban, Barrett, & Wager, 2018).

Due to the contralateral innervation of the visual cortex (Figure 1.1), my thesis makes two key assumptions. First, the RH controls attention to the left visual field and the LH controls attention to the right visual field—termed contralateral attention. I use contralateral attention to infer top-down processing, defined as an endogenous process where cognitive factors, including knowledge, expectation and goals, direct visual attention (Corbetta & Shulman, 2002). Second, superior performance in the left visual field indicates RH involvement, whereas superior performance in the right visual field indicates LH involvement—termed contralateral processing. I use contralateral processing to infer bottom-up processing, defined as an exogenous process where sensory stimulation or environmental cues direct visual attention (Corbetta & Shulman, 2002).

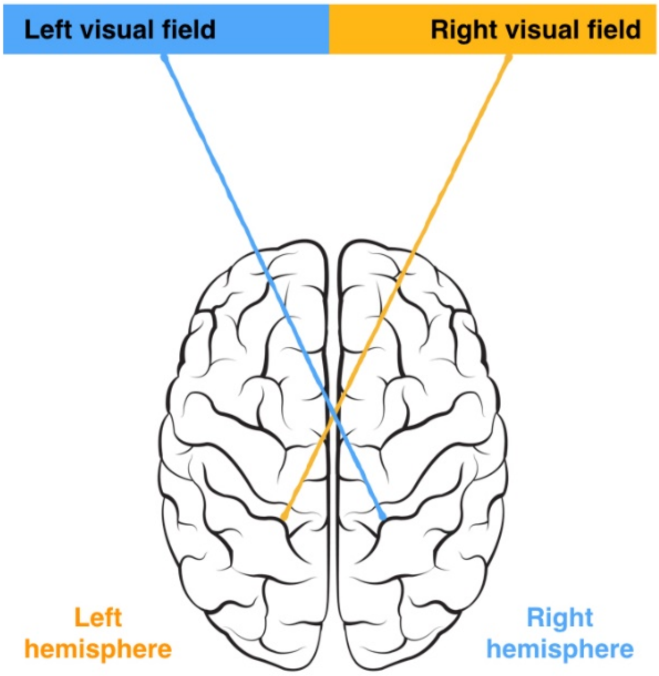

Figure 1.1. A simplified diagram of contralateral innervation.

1.1 Visuospatial attention asymmetries

The RH is dominant for visuospatial attention in approximately 90% of the population (de Schotten et al., 2011; Hervé, Zago, Petit, Mazoyer, & Tzourio-Mazoyer, 2013). According to Bavelier, Achtman, Mani, and Föcker (2012):

> *"Visuospatial attention is the process by which different components, originating from a variety of sensory and cognitive processes such as proprioception, vision, spatial memory, and movement are focused upon, and ultimately attended to, allowing for efficient interaction with the environment."*

There is convergent evidence from patient (hemispatial neglect) and non-patient (pseudoneglect) data for RH predominance in visuospatial attention. Hemispatial neglect—defined as failure to explore the side of space contralateral to a brain lesion (Heilman & Valenstein, 1979; Heilman & Van Den Abell, 1980)—was first documented in the early 20th century by Riddoch (1935). This condition most commonly occurs following RH lesions in the superior temporal lobe (Karnath, Ferber, & Himmelbach, 2001)—leading patients to neglect the left side of space—due to the dominance of this hemisphere in visuospatial attention. In neurotypical people, RH predominance for visuospatial attention is demonstrated by pseudoneglect—defined as increased attention *toward* the left side of space, leading to slight neglect of the right side (Bowers & Heilman, 1980). From here on, I focus on pseudoneglect rather than hemispatial neglect, because my thesis experiments investigate visuospatial attention asymmetries in a neurotypical population.

Bowers and Heilman (1980) first demonstrated pseudoneglect using a tactile line bisection task. When asked to estimate the midpoint of a wooden stick using their index finger, blindfolded participants pointed to the left of centre. This leftward bisection bias has been widely replicated, most typically by asking participants to manually bisect the centre of a horizontal line (see Jewell & McCourt, 2000 for review). The bias occurs because RH dominance for visuospatial attention leads people to over-attend to the left and perceive the left side as longer than the right side of the line. Thus, to make the right and left side of the line look equal in length, people bisect to the left of true centre. The estimated effect size of this leftward line bisection bias—based on meta-analysis of 73 studies (Jewell & McCourt, 2000)—is $d = -0.37$ to -0.44.

People display pseudoneglect on other simple tasks, including the landmark task—where they choose which side of a pre-bisected line looks longer (e.g., McCourt & Jewell, 1999; Thomas, Loetscher, & Nicholls, 2012)—and the greyscales task—where people choose which of two equiluminant bars looks darker (e.g., Nicholls, Bradshaw, & Mattingley, 1999). In both these tasks, people favour the left when searching for the relevant feature—they perceive the left side as longer than the right in the landmark task and choose the rectangle where the dark half is on the left in the greyscales task. People also display pseudoneglect in more complex, real life, tasks. For example, when searching for a target in a visual display, people more rapidly and (sometimes) more accurately detect left than right side targets (e.g., Nicholls, Hobson, Petty, Churches, & Thomas, 2017), and when walking through doors people more often bump into the left than the right side of the doorframe (e.g., Nicholls, Loftus, Mayer, & Mattingley, 2007). Pseudoneglect also influences how well people are able to mentally bring a familiar scene to mind, termed representational pseudoneglect (see Brooks, Della Sala, & Darling, 2014 for review). In this instance, people recall more details on the left than the right side of the imagined scene, regardless of viewpoint (McGeorge, Beschin, Colnaghi, Rusconi, & Della Sala, 2007). Taken together, these leftward biases across a wide variety of stimuli show that asymmetries in visuospatial attention influence several behavioural outcomes which, in turn, demonstrates the underlying RH asymmetry in visuospatial attention.

Despite hemispatial neglect first being documented in the early 20th century (e.g., Riddoch, 1935), and pseudoneglect almost 40 years ago (e.g., Bowers & Heilman, 1980), only recently did researchers find confirmatory neuroanatomical evidence of exactly how parietal, temporal, and frontal areas are involved in spatial attention. Using fMRI, Gotts, Jo, Wallace, Saad, Cox, & Martin (2013) identified two clusters of RH brain regions (at rest) that were strongly associated with high-level visuospatial attention. The connectivity of one of these clusters (i.e., ventral temporal cortex, including fusiform gyrus, transverse collateral sulcus, and inferior temporal gyrus) to areas in the opposite hemisphere significantly correlated with block design score, a behavioural measure of visuospatial attention (partial $r = .40$, $p < 0.01$). De Schotten et al. (2011) also emphasised the importance of connectivity in the neuroanatomy of visuospatial attention. They used diffusion imaging tractography to identify if the volume of white matter—i.e., nerve fibres within the brain—in parieto-frontal regions predicted visuospatial attention asymmetries. The volume of white matter connectivity in *middle* parieto-frontal regions—specifically the middle Superior Longitudinal Fasciculus (SLF-II)—predicted the degree of hemispheric lateralisation for visuospatial attention. Seventeen participants who showed pseudoneglect (indexed by a leftward line bisection bias) had larger volumes of white matter in their right than their left SLF-II. Conversely, three people who did not show pseudoneglect (indexed by a rightward line bisection bias) had larger volumes of white matter in their left than their right SLF-II. The authors replicated these results using a different visuospatial task—a modified Posner paradigm (Posner, 1980)—where participants detect targets that appear in the left or right visual field as quickly as possible. Larger right than left SLF-II volumes correlated with faster detection of left than right side targets. These results led De Schotten et al. to conclude that differences in the volume of white matter occur due to visuospatial attention speed, because the SLF-II (middle tract) represents communication between the dorsal (upper tract) and ventral (lower tract) networks of spatial attention.

Dorsal and ventral networks in fronto-parietal regions work together to direct spatial attention (Corbetta & Shulman, 2002). The dorsal network is bilateral and comprises the intraparietal sulcus and the frontal eye fields of each hemisphere. It directs the voluntary allocation of attention, or top-down processes, and is primarily recruited when stimuli relate to a task goal, e.g., searching for a target stimulus. The ventral network comprises the temporoparietal junction and the ventral frontal cortex. This network is lateralised to the RH for several functions—though there is some evidence for bilateral elements of the temporoparietal junction (e.g., Doricchi, Macci, Silvetti, & Macaluso, 2010)—and responds to bottom-up processes, including shifting attention after detecting unexpected environmental stimuli, e.g., when a stimulus changes colour. The dorsal and ventral networks do not operate in isolation (Vossel, Geng, & Fink, 2014); the ventral system may detect relevant environmental stimuli, but the dorsal system identifies the precise location of the environmental stimuli (Corbetta & Shulman, 2002). This between-system interaction is also demonstrated by the ventral system being suppressed when a task relies on the dorsal system's top-down attention processes (e.g., Shulman et al., 2003). According to Vossel et al. (2014), the hemispheric specialisation of the dorsal and ventral systems requires further research.

Two models account for how spatial attention is lateralised; the *Activation-Orientation Account* (Kinsbourne, 1970) and the *Hemispatial Theory* (Heilman & Van Den Abell, 1980). Kinsbourne's *Activation-Orientation Account* (1970) posits that two opposing attentional gradients govern spatial attention; the contralateral hemisphere controls each gradient. As cortical activation increases, the slope of the gradient increases, leading to an attentional bias in the opposite hemispace. Hence, with increased activity in the RH, attention is biased to the left. This account was slightly revised by Siman-Tov et al. (2007) to explain stronger transfer of information from the RH-to-LH than vice versa, contributing to a leftward bias of spatial attention. Several studies support this account, including Loftus and Nicholls (2012), where twenty minutes of transcranial direct current stimulation over the LH significantly reduced participants' leftward bias on the greyscales task. This finding was attributed to rebalancing activation—or the slope of the gradients—between the RH and LH, thus reducing RH dominance. The *Activation-Orientation Account* led to the development of unilateral contractions as a proposed method for increasing hemispheric activation—the focus of Chapter 6.

Heilman and Van Den Abell's (1980) *Hemispatial Theor*y states the RH is dominant for spatial attention *and* controlling shifts of attention to the left and right side of space. By contrast, the LH can only control shifts of attention to the right side of space. Work by Duecker, Formisano, and Sack (2013) supports this theory; they found stimulating the RH impaired participants' ability to shift spatial attention to the RH and LH, whilst stimulating the LH only impaired participants ability to shift spatial attention to the RH. However, Duecker et al. (2013) concluded that both the Activation Orientation Account and the Hemispatial Theory apply to different aspects of the dorsal network and are not mutually exclusive. They emphasise the importance of considering RH dominance, as well as interhemispheric connectivity, as a predictor of spatial attention.

Dual stream attentional blink research (i.e., a stream on the left and the right side) highlights RH dominance and interhemispheric connectivity in shifting spatial attention (Asanowicz, Kruse, Smigasiewicz, & Verleger, 2017). In attentional blink tasks, participants must detect two targets (e.g., a letter [T1] and a number [T2]), which appear within 500 ms of each other in a rapid serial visual presentation (RSVP; Broadbent & Broadbent, 1987) stream. Participants display a consistent impairment[2] in detecting the second target in single (e.g., Shapiro, Arnell, & Raymond, 1997) and dual stream (e.g., Holländer, Corballis, & Hamm, 2005) experiments. Although single stream attentional blink experiments allow us to study the time-course of attention and memory consolidation (Martens & Wyble, 2010), dual stream experiments allow us to study *spatial* attention (Asanowicz et al., 2017). In dual stream experiments the two targets can appear in the same (e.g., both on the left) stream as one another; the attentional blink is smaller in the left-side stream (i.e., with RH processing) and larger in the right-side stream (i.e., with LH processing, see Verleger & Smigasiewicz,

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[2] Because participants can accurately report T2 when they are instructed to ignore T1, attentional blink is not considered to be perceptual (see Martens & Wyble, 2010 for review).

2015 for review). However, the targets can also appear in opposite streams from one another (e.g., T1 on the left, T2 on the right). Because of RH superiority in shifting attention, the attentional blink is at its lowest when T1 appears on the right and T2 on the left.

There is an abundance of behavioural research that demonstrates RH superiority in visuospatial attention. But most of these studies focus on basic attention processes, neglecting whether the tendency to attend more to the left side of space influences other behavioural outcomes that we know are affected by attention, including memory (Bradley, 2014). We may be aware of several inputs of visual stimuli in our environment, but unless we attend to those stimuli, we will not remember them.

1.2 Attention and Memory

We typically remember elements of an event that we paid attention to—a selective process where some information is processed faster, better, or deeper than other information (Lamme, 2003)—during encoding. For example, when remembering objects within a scene, memory accuracy is higher for fixated than non-fixated objects, where fixating indicates attention (e.g., Hollingworth & Henderson, 2002; Irwin & Zelinsky, 2002). More complex scenarios than scene viewing also demonstrate the link between attention and memory. For example, in the first real-world demonstration of change blindness (Simons & Levin, 1998), an experimenter conversed with a participant by asking them for directions. Mid-way through the conversation, something unusual and distracting occurred; people holding a door walked between the experimenter and the participant. The door shielded the experimenter, so that a new experimenter could replace the first experimenter. The authors inferred that participants who detected this change were those who paid attention to the details of the experimenters. Importantly, in a follow-up experiment, participants who detected the change—i.e., those who paid attention to the experimenter—were better able to identify the original experimenter in a subsequent memory test than participants who missed the change (Levin, Simons, Angelone, & Chabris, 2002). This finding again demonstrates that people tend to remember the elements of an event (e.g., the face of the experimenter) they attended to during encoding.

The link between attention and memory prompted Dickinson and Intraub (2009) to investigate whether attending more toward the left side of space enhances memory for objects on the left side of neutral scenes. They found a left side memory bias; participants' memory accuracy was 5% better for objects that appeared on the left than objects that appeared on the right side. This finding is attributed to participants' increased allocation of attention to the left side (i.e., pseudoneglect). But Dickinson and Intraub (2009) used neutral scenes, failing to consider how emotional scenes might alter this leftward bias. Studies on visuospatial attention asymmetries share this limitation, typically using simple, neutral stimuli including numbers, letters, and coloured shapes. Although these types of stimuli isolate basic attention processes, they shed no light on the combined influence of visuospatial attention and emotional processing asymmetries on people's attention to, and memory for, aspects of their environment. It is important to address this limitation, which prompted my thesis experiments, because we know that people generally remember emotional stimuli better than neutral stimuli—termed the emotional enhancement of memory effect.

People typically remember emotional stimuli (including events, words, and images) more vividly (e.g., Todd, Talmi, Schmitz, Susskind, & Anderson, 2012) and accurately (see LaBar & Cabeza, 2006 for review) than neutral stimuli encoded under the same conditions. One explanation for this effect is that memory consolidation is better for emotional than neutral stimuli, due to the activation of the amygdala, which occurs when viewing something emotionally arousing (McGaugh, 2004). A second explanation is that attention is enhanced, and often automatically directed, toward emotional over neutral stimuli (Talmi, Schimmack, Paterson, & Moscovitch, 2007). Based on this second explanation, other processes that influence where attention is directed, like RH dominance for visuospatial attention, could alter this effect. Therefore, it is important to establish how any influence of hemispheric asymmetries on memory for images may change depending on whether the images are emotional or not. Below I review theories on emotional processing asymmetries.

1.3 Hemispheric asymmetries for emotional processing

"Emotions are one of the most apparent and important aspects of our lives, yet have remained one of the most enigmatic to explain scientifically" (Adolphs & Anderson, 2018). The RH and LH differ in their contribution to emotional processing, though the direction of these asymmetries remains debated. Jules Bernard Lyus (as cited in Harrington, 1995) first argued that the RH plays a pivotal role in emotional processing in 1881, when he suggested there is an 'emotion centre' in the RH to accompany the LH's 'intellectual centre'. Despite the attempts to account for emotional processing using a single dichotomous model, emotional processing is highly complex and likely requires multiple models (Grimshaw & Carmel, 2014; Miller, Crocker, Spielberg, Infantolino, & Heller, 2013). Indeed, there is mixed support for all traditional theories of lateralised emotional processing; leading Miller et al. (2013) to suggest these accounts are no longer viable.

Traditional theories. Traditionally, theorists searched for a basic dichotomy to account for hemispheric differences in emotional processing. Three influential theories followed this approach: the *right-hemisphere hypothesis* (Gainotti, 1972), the *valence-specific hypothesis* (Davidson & Fox, 1982; modified by Harmon-Jones, 2003 to a withdrawal related *approach/avoidance hypothesis*), and the *circumplex model* (Heller, 1993). According to the right-hemisphere hypothesis, the RH is responsible for processing *all* emotions, regardless of valence. The valence-specific hypothesis was developed after accumulating evidence that the LH plays some role in emotional processing. According to the valence hypothesis, the RH is specialised for negative emotion, whereas the LH primarily processes positive emotion. Both the right-hemisphere and valence hypotheses were initially informed by research with patients with damage in the RH or LH. For example, patients with RH damage have difficulty comprehending emotional tone of voice (e.g., Tucker, Watson, & Heilman, 1977), naming emotional scenes (e.g., DeKosky, Heilman, Bowers, & Valenstein, 1980), and interpreting affective aspects of cartoons, films, and stories (e.g., Wapner, Hamby & Gardner, 1981). RH damage also significantly impairs face perception; a recent meta-analysis concluded RH damage is more detrimental to emotional face perception than LH damage (Abbott, Cumming, Fidler, & Lindell, 2013). These studies highlight the importance of the RH in emotional processing, particularly negative emotions, upon which the two theories converge.

But studies using healthy populations and the divided visual field paradigm support both the valence (e.g., Jansari, Rodway, & Goncalves, 2011; Prete, Laeng, & Tommasi, 2014) and the right-hemisphere hypotheses (e.g., Prete, Capotosto, Zappasodi, Laeng, & Tommasi, 2015). For example, the RH plays an important role in *expressing* emotions; in a review of 15 emotional expression studies 80% of observations indicated a left-side bias regardless of emotional valence (Borod, Bloom, Brickman, Nakhutina, & Curko, 2002). By contrast, the RH and LH may make unique contributions to *perceiving* emotional expressions, depending on their valence or how they are presented. One methodological factor that influences whether results support the right-hemisphere or the valence hypothesis is unilateral or bilateral presentation of stimuli (Prete et al., 2018). When hybrid faces are presented unilaterally—i.e., as a single stimulus in the left *or* right visual field—judgments typically support the valence hypothesis (e.g., Prete, Laeng, Fabri, Foschi, & Tommasi, 2015; Prete et al., 2014). With bilateral presentation—two stimuli simultaneously in the left *and* right visual field—judgments generally support the right-hemisphere hypothesis in non-clinical (Prete, Laeng, et al., 2015) and split-brain patients (Prete, D'Ascenzo, Laeng, Fabri, Foschi, & Tommasi, 2015). However, Jansari et al. (2011) found support for the valence hypothesis with bilateral presentation. They had participants select which of two faces, one on the left and one on the right, depicted a labelled emotion. The faces were morphs of emotional facial expressions—half the face was neutral and half the face depicted a positive (happiness, surprise) or negative (fear, sadness, disgust, anger) expression. Participants more accurately identified morphs containing negative expressions when the morphs appeared in the left (65%) vs. the right (58%) visual field, and morphs containing positive expressions when they appeared in the right (72%) than the left (60%) visual field; an interaction between valence and visual field. This interaction occurred despite participants fixating more on the face that appeared in the left than the right visual field.

In general, evidence for the role of the LH in perceiving positive emotions is less consistent than evidence for the role of the RH in perceiving negative emotions. Indeed, for emotional images, some studies find no hemispheric difference in processing positive emotions, e.g., equal speed of motor responses to positive images regardless of hemispheric processing (Önal-Hartmann, Pauli, Ocklenburg, & Güntürkün, 2012). Other studies suggest that the LH structures activated during emotional processing are largely related to language—consistent with the LH's dominance for language (e.g., Vallortigara & Rogers, 2005).

In contrast to the valence specific hypothesis which focuses on activation differences relating to emotional valence only, the *circumplex model* (Heller, 1993) focuses on activation differences relating to autonomic arousal, as well as emotional valence. Autonomic arousal refers to changes in heart rate, blood pressure, and skin temperature in response to emotional stimuli (Heller, 1993). Heller suggests the RH is particularly implicated in the arousal component of emotion and that greater right than left posterior activity occurs when viewing highly arousing material (Heller, Koven, & Miller, 2003). She also posits that differences in activation in frontal cortices relate to valence, where—in line with the valence hypothesis—viewing pleasant stimuli leads to greater left than right frontal activity (Heller et al., 2003). This model is grounded by clinical work; it predicts that people with rightward frontal asymmetry are vulnerable to psychological disorders. Specifically, low levels of right parietal activity predict depression and high levels of right parietal activity predict anxiety.

Despite their differences, traditional theories largely converge on RH superiority for processing negative emotion, particularly highly arousing negative emotion (e.g., Borod et al., 1998; Demaree, Everhart, Youngstrom, & Harrison, 2005; Heller, Nitschke, & Miller, 1998). However, there is an expanding view that a number of cortical areas in both the RH and LH contribute to our experience of emotion. This view is reflected in contemporary models of emotional processing asymmetries.

Contemporary models. Contemporary models have shifted from attempting to identify a basic dichotomy to identifying which hemisphere may be dominant for certain emotional processing tasks. Below, I review two influential contemporary models of hemispheric contributions to emotional processing.

First, the *Hemispheric Independence and Collaboration Model* (Shobe, 2014) posits that both the RH and LH process emotions, but at different levels. The RH is dominant for the initial detection of all emotions (positive and negative). Initially, the LH is restricted to processing positive or neutral stimuli. Because both the RH and LH can process positive emotions on first perception, they are processed faster than negative emotions (Jansari et al., 2011). Only the RH can "identify, comprehend, and feel negative emotions" (Shobe, 2014, p. 9) leading O'Hare, Atchley, and Young (2017) to term the RH an emotional "reactor". For the LH to contribute to processing negative emotions, the information must be transferred cross-collosally from the RH to the LH. After the information is transferred from the RH to the LH, the LH may provide a 'secondary interpretation' that is positively biased and contributes to executive functioning, emotional regulation, and well-being. This view of the LH fits with research on split-brain patients, which suggests the LH is an emotional "interpreter" (see Volz & Gazzaniga, 2017, for review).

The *Asymmetric Inhibition Model* (Grimshaw & Carmel, 2014) posits that the prefrontal cortex plays a critical role in the inhibition of emotional distractors. The left prefrontal cortex inhibits negative distractors while the right prefrontal cortex inhibits positive distractors. Critically, the model refers to distractors as items that are contrary to current goals. Evidence for this model, like the circumplex model, stems primarily from clinical populations. For example, people with depression and anxiety have low levels of activity in their left frontal cortex, which is associated with difficulty disengaging from negative information (Eysenck, Derakshan, Santos, & Calvo, 2007; Cisler & Koster, 2010; De Raedt & Koster, 2010; Gotlib & Joormann, 2010). People with poor self-regulation and who are vulnerable to addiction have low levels of activity in their right frontal cortex, which is associated with difficulty inhibiting positive distractors, e.g., drugs (Bechara, 2005; Garavan & Hester, 2007; Goldstein & Volkow, 2011). At present, the relationship between left frontal activity and difficulty disengaging from negative distractors is better supported than the relationship between right frontal activity and difficulty disengaging from positive distractors. For example, Grimshaw, Foster, and Corballis (2014) used EEG and a dot-probe task to examine attentional biases to emotional (angry, happy) relative to neutral faces. In the dot-probe task, two cues are presented—in this case, one of the cues is an emotional face and the other is a neutral face—followed by a simple probe (e.g., a white square) in the same location as one of the cues. Faster responses to probes that appear in the same place as the emotional cue indicates attentional bias toward emotion. In Grimshaw et al. (2014), participants with leftward frontal asymmetry showed no attentional bias on the dot probe task, i.e., healthy processing. Participants with rightward (or balanced) frontal asymmetry showed attentional biases toward threat (i.e., angry faces) that were predicted by their parietal asymmetry; low levels of right parietal activity were associated with hypervigilance to the angry faces (shorter reaction times) and high levels of right parietal activity were associated with avoidance of angry faces (longer reaction times). However, a limitation of this study, and several others, is the use of facial expressions, which only represent the communicative and social aspect of emotional processing (e.g., Mavratzakis, Herbert, & Walla, 2016). Another limitation is that most facial expressions research only includes few basic emotions, often only two (e.g., angry, happy).

This limitation occurs frequently; in fact, most models of emotional process have been informed by how people perceive facial expressions. To advance understanding of hemispheric contributions to emotional processing, we need to use complex stimuli, like emotional scenes, because they are more ecologically valid than isolated facial expressions. For example, context (e.g., body language and surrounding environment) can change the judgments of facial expressions, particularly negative expressions (Calbi et al., 2017). Although emotional facial expressions lead to faster attentional orienting than emotional scenes, scenes lead to stronger and more stable affective neural activity and behavioural responses (e.g., spontaneous facial reactions of the viewer) than faces (Mavratzakis et al., 2016). Scenes have a robust effect on neural activity and behavioural responses because they activate stronger functional connectivity between visual areas and amygdala than socially relevant stimuli, like faces (Sakaki, Niki, & Mather, 2012). Emotional scenes also promote more intense self-reported emotions than objects or faces (Thom et al., 2014) and provide a larger range of stimulus variation than faces. For example, there is greater similarity between different facial expressions than between different emotional scenes (Mavratzakis et al., 2016). Therefore, I used scenes rather than facial expressions, but ensured several images in the image sets contained people and/or faces to account for the specialised effect of faces on attentional orienting.

Extensive research has attempted to identify the exact contributions of the RH and LH in emotional processing, though the neural underpinnings of RH and LH contributions to emotional processing remain unclear. Perhaps more unclear, however, is the combined influence of any hemispheric specialisations on behavioural outcomes, meaning: what happens when multiple asymmetries are elicited simultaneously[3]—for example, when spatially orienting to emotional stimuli? Interestingly, in her pivotal 1993 paper, Heller discusses the possibility of a conjoint visuospatial and emotional processing system in the RH, due to the superiority of this hemisphere in detecting and responding to environmental threats. Yet, this possibility has received little empirical attention. My thesis begins to address this gap by investigating the combined influence of asymmetries for visuospatial attention and emotional processing in attending to and disengaging from emotional distractors (using an Emotion Induced Blindness paradigm; Experiments 1a & 1b), recognition memory of

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[3] Limited research has investigated what happens when multiple asymmetries are elicited simultaneously, though see Hausmann, Hodgetts, and Eerola (2016) and Innes, Burt, Birch, and Hausmann (2016) for exceptions which are beyond the focus of this thesis.

emotional and neutral scenes (Experiments 2a, 2b, 3a, & 3b), and involuntary memory for negative scenes (Experiment 5).

2 Overview of Methods and Research Objectives

The overarching objective of my thesis is to determine how asymmetries for visuospatial attention and emotional processing influence three behavioural outcomes; visuospatial attention (Experiments 1a, 1b, & 4a-4e), recognition memory (Experiments 2a, 2b, 3a, & 3b), and involuntary memory (Experiment 5). Using a rigorous experimental approach, this thesis seeks to understand how automatic lateralised brain processes, like paying slightly more attention to the left than the right side of space (Bowers & Heilman, 1980), influences attention to and memory for emotional stimuli. As outlined in Chapter 1, few studies have investigated whether asymmetries for visuospatial attention and emotional processing have a *combined* influence on behaviour. My thesis seeks to address this gap and, in turn, considers the contribution of the RH and LH in emotional processing (see Shobe, 2014). I primarily used null hypothesis significance testing but have accompanied this technique with Bayesian statistics (e.g., in Experiments 4a-4e) when trying to establish evidence for the null hypothesis (Wetzels et al., 2011). My stimuli were complex scenes sourced from well-known image databases. These databases provide normed valence and arousal ratings, allowing the development of positive, negative, and neutral image sets[4]. The following sections provide a brief overview of the thesis structure and each chapter's objective.

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[4] I opted for broad emotion categories (positive vs. negative) rather than discrete categories such as "fear" to remain consistent with hemispheric emotional processing theories. Note, however, that normed images elicit single and blended discrete categories (e.g., positive: awe, excitement, contentment, amusement; negative: fear, sadness, disgust, anger; Mikels et al., 2005) demonstrating their utility for studying complex emotional processing.

2.1 Chapter 3 - Experiments 1a and 1b

This chapter aims to determine hemispheric contributions in attending to and disengaging from emotional distractors, using an emotion induced blindness paradigm. To achieve this aim, I determined whether hemispheric processing influences emotion induced blindness (e.g., Most et al., 2005)—where something emotional stops you from noticing something neutral appearing directly afterwards. Emotion induced blindness is demonstrated using a rapid serial visual presentation stream of landscape images. Each trial comprised 10 images, one of which is rotated 90° to the left or the right—the neutral target—and another that is a negative or neutral (non-landscape) image—the distractor. The distractor appeared before the target (usually two to four items before) and participants' task was to detect the rotation (left, right) of the neutral target image embedded in the stream. Accuracy in detecting the rotation of the neutral target was significantly worse following a negative than a neutral distractor. This emotion induced blindness effect is attributed to the emotional distractor automatically capturing and holding attention, which the neutral distractor does not.

To establish whether hemispheric processing influences emotion induced blindness, I adapted a dual stream paradigm—where two image streams are simultaneously presented on the top and the bottom of the screen (e.g., Most & Wang, 2011)—by placing the streams horizontally rather than vertically. Thus, I ensured lateral presentation, which should result in predominantly contralateral processing, because I placed an image stream in the left and right visual field, used a short presentation time for each image (100 ms), and asked participants to maintain central fixation (Bourne, 2006). In Experiment 1a, a negative or neutral distractor appeared either two or four items before the target. The distractor and target only ever appeared in the same location as one another and were therefore both processed by the same hemisphere. In Experiment 1b, the distractor and target appeared in the same, as well as the opposite, location from one another and therefore, on the opposite stream trials, were processed by *opposite* hemispheres. By manipulating the distractor-target relationship, I can infer the isolated—on trials where the distractor and target appear in the same visual field—and collaborative—on trials where the distractor and target appear in the opposite visual field—contributions of the RH and LH (Verleger & Smigasiewicz, 2015) to emotion induced blindness. Differences in the extent of emotion induced blindness depending on visual field and distractor-target relationship would suggest differences in the capacity of the RH and LH to disengage from emotion. These findings have important practical applications. For example, imagine you are driving along a highway and your attention is drawn to a graphic billboard on the side of the road. Does the extent to which this billboard stops you from noticing something neutral—like the car in front of you braking—depend on which side of the road the billboard appears?

2.2 Chapter 4 – Experiments 2a and 2b

We pay slightly more attention to the left than the right side of space (Bowers & Heilman, 1980), which enhances our memory for stimuli that appear in the left visual field (Dickinson & Intraub, 2009). Given the potential interaction between visuospatial attention and emotional processing asymmetries, the primary objective of this chapter is to determine if this left visual field memory advantage is greater for emotional stimuli. I adapted a divided visual field paradigm and presented valence-matched image pairs (Experiment 2a: negative vs. neutral, Experiment 2b: negative vs. positive) for 500 ms in the left and right visual fields. To increase the likelihood of predominantly contralateral processing, participants maintained central fixation on encoding trials—confirmed via eye-tracking. I tested recognition memory using forced-choice test items integrated within encoding, and measured confidence and response time for each memory judgment. By presenting two images simultaneously to the left and right visual fields, these experiments isolate the *independent* contributions of the RH and LH (respectively) upon first perception, at which stage both hemispheres have to process an image each. Thus, the results contribute to emotional processing theories, which have been primarily informed by experiments using less naturalistic stimuli (e.g., facial expressions; Jansari et al., 2011, and isolated objects; Kensinger & Choi, 2009).

2.3 **Chapter 5 – Experiments 3a and 3b**

Does hemispheric processing continue to influence recognition memory for emotional stimuli when people freely view scenes? This chapter aims to increase the ecological validity of Chapter 4. Because visuospatial attention is predominantly a RH function, most people (60-70%, Foulsham et al., 2013) show an initial leftward bias in their eye movements, even when they are required to look for a stimulus located in the right visual field (Nuttham & Matthias, 2013). The objective of this chapter is to determine whether this leftward attentional bias enhances subsequent memory for stimuli located in the left visual field and establish the role of image valence on this effect. In two online experiments, I used a free viewing paradigm—defined as presenting the stimuli for at least two seconds (Voyer, Voyer, & Tramonte, 2012). Participants saw positive, negative, and neutral scenes (for three seconds each) with a target stimulus clearly located in the left and right visual fields. Participants did not know their memory would be tested until after encoding, when we presented segments of the scenes containing the target stimuli and asked ‘have you seen this stimulus before?’. This chapter has practical implications for understanding how RH asymmetries for visuospatial attention and emotional processing may influence our memory in everyday life, where we generally choose where to look.

2.4 Chapter 6 – Experiments 4a-4e

Given my interest in how hemispheric asymmetries for visuospatial attention and emotional processing influence behaviour, a subsidiary aim of this thesis is to find appropriate methods of increasing hemispheric activation. According to existing literature (e.g., Beckmann, Gröpel, & Ehrlenspiel, 2013), the motor cortex in one hemisphere activates to perform unilateral contractions—squeezing a ball with the opposite hand. This activation then spreads to surrounding brain areas and enhances any specialisations of that hemisphere, suggesting unilateral contractions were a promising method for increasing activation in one hemisphere over the other. In light of psychology's replication crisis and high rate of false positives (Lindsay, 2015), I first tested that unilateral contractions were an appropriate manipulation of hemispheric activation using a reliable a measure of visuospatial attention, the landmark task (adapted by Thomas et al., 2012). Thus, the main objective of this chapter is to empirically test whether we can observe increased hemispheric activation following unilateral contractions using the Landmark Task (Thomas et al., 2012). According to the rationale of unilateral contractions research, we should be able to 'move' visuospatial attention more leftward or rightward using unilateral contractions. Across five experiments, participants squeezed a ball with their right or left hand and then completed the landmark task. Due to the small sample size within each experiment, I pooled the data for a meta-analysis. The results of this meta-analysis have important implications for knowing whether unilateral contractions are a useful method for increasing hemispheric activation and shed light on potentially misleading published research. I found unilateral contractions did not move landmark task responses, suggesting this method would be an inappropriate way to manipulate hemispheric activation in Chapter 7. However, I have included Chapter 6 in this thesis because demonstrating the ineffectiveness of unilateral contractions in manipulating hemispheric activation makes an important empirical contribution.

2.5 Chapter 7 – Experiment 5

After exposure to a traumatic event, people often experience intrusions—i.e., involuntary memories of the trauma, or trauma-related thoughts about the future (Galatzer-Levy et al., 2013; Marks, Franklin, & Zoellner, 2018). In a small proportion of people, these intrusions will persist and may become distressing and unwanted. These persistent intrusions can become problematic, as demonstrated by intrusions being a primary symptom of Post Traumatic Stress Disorder (PTSD). Visuospatial attention may be one factor that predicts whether intrusions will become problematic (e.g., Meyer, Krans, van Ast, & Smeets, 2017). Until now, research on the role of visuospatial attention in the development and maintenance of intrusions has not considered the dominance of the RH for visuospatial attention. Interestingly, RH abnormalities have been linked with PTSD symptoms (e.g., Engdahl et al., 2010), though the direction of this link is unknown. Thus, the primary objective of my final empirical chapter is to determine whether hemispheric processing influences involuntary memory for traumatic images.

Because Chapter 6 determined unilateral contractions were an ineffective way of increasing hemispheric activation, I manipulated hemispheric activation by biasing how many images were processed by the RH vs. the LH. I adapted a divided visual field paradigm but, different to Experiments 2a and 2b, presented 100 negative images *singly* for 250 ms in the left *or* right visual field. I varied whether the majority of the images were processed by the RH, the LH, or equally between the two hemispheres. In the leftward presentation bias (RH processing bias) condition, 80 images were presented to the left visual field and 20 to the right visual field. This ratio reversed for the rightward presentation bias (LH processing bias) condition. In the no presentation bias condition, images appeared equally often in the left and right visual fields. I measured the frequency, duration, and characteristics of intrusions for the images in a thought-monitoring phase directly after encoding, and in a three-day thought diary. This experiment comprehensively tested whether hemispheric processing contributes to the development (immediate intrusions), persistence (three-day diary), and characteristics of traumatic intrusions. I took a number of intrusion measures across several time points. Therefore, this chapter contributes not only to emotional processing theories, but also to PTSD theories (e.g., Rubin, Berntsen, & Johansen, 2008) by understanding how the quality of initial intrusions (e.g., distress, vividness) may predict whether intrusions persist, which in turn may predict the development of PTSD (Marks et al., 2018).

3 Does Hemispheric Processing Influence Emotion Induced Blindness?

Emotion induced blindness (EIB) is a consistent and reliable effect where an emotional distractor impairs people's ability to notice a subsequent neutral target in a rapidly presented image stream (Most, Chun, Widders, & Zald, 2005). We know that EIB occurs because attention is automatically drawn to emotional stimuli (Anderson, 2005), allowing us to detect and respond to potential threats. We also know that people pay slightly more attention to the left than the right side of space (Brooks, Sala, & Darling, 2014; de Schotten et al., 2011; Hervé, Zago, Petit, Mazoyer, & Tzourio-Mazoyer, 2013), due to right hemisphere (RH) dominance for visuospatial attention. But this increased attention to the left may come at a cost, by making people more susceptible to having attention captured by left than right side distractors (Du & Abrams, 2010). But what happens when these distractors are *emotional,* as in EIB? In addition to being dominant for spatial attention, the RH is dominant for processing emotion upon first perception, particularly negative emotions (e.g., Gainotti, 2012; Shobe, 2014). Given these specialisations, it may be more difficult for people to ignore briefly presented (100 ms) emotional distractors processed by the RH than those processed by the left hemisphere (LH), leading us to wonder: does RH processing enhance emotion-induced blindness? To test this possibility, we presented two image streams in the right and left visual field, building on existing EIB work that has only used vertical streams.

In most EIB experiments, images are presented for 100 ms each in a single, centrally located rapid serial visual presentation (RSVP) stream (Choisdealbha, Piech, Fuller, & Zald, 2017; Kennedy & Most, 2012; Kennedy & Most, 2015; Kennedy, Newman, & Most, 2018; Most, Chun, Johnson, & Kiehl, 2006; Most et al., 2005; Most & Jungé, 2008; Most, Smith, Cooter, Levy, & Zald, 2007; Singh & Sunny, 2017; Smith, Most, Newsome, & Zald, 2006;

Zhao & Most, 2018). The participant's task is to identify the rotation of a neutral target image—a landscape photograph rotated 90° left or right—embedded in the stream. The target is preceded by a neutral or emotional distractor. Accuracy in detecting the rotation of the target image is reliably impaired when an emotional (compared to a neutral) distractor appears one or two items prior (i.e., at lag 1 and 2), with a weaker effect four items (lag 4) and no effect eight items prior (lag 8) (e.g., Kennedy & Most, 2015). Importantly, this impairment is *not* due to an inability to remember the target rotation by the time participants respond; participants show similar EIB when they respond immediately after seeing the target *and* when they respond after the last image in the RSVP stream (Kennedy & Most, 2012). Thus, EIB is a perceptual impairment, rather than a result of reaching working memory capacity.

EIB also occurs when participants simultaneously monitor *two* image streams (Kennedy, Pearson, Sutton, Beasley, & Most, 2018; Most & Wang, 2011; Wang & Most, 2017). In these dual stream experiments, image streams appear vertically on the top and the bottom of the screen while participants fixate centrally. Because there are two streams, the distractor (emotional or neutral) and target can appear in the same or the opposite location to one another. EIB generally occurs only when the emotional distractor appears in the same stream as the neutral target (Kennedy et al., 2018; Most & Wang, 2011; Wang & Most, 2017), suggesting EIB is spatially localised (Wang, Kennedy, & Most, 2012). With vertically placed image streams, both the RH and LH can contribute to processing both images; though note the RH contributes slightly more than the LH for processing upper visual field stimuli (e.g., Verleger, Dittmer, & Smigasiewicz, 2013). Therefore, because existing dual stream EIB research has only placed streams vertically, it is difficult to infer hemispheric contributions to EIB from existing work. But why might the RH and LH independently contribute to EIB?

EIB occurs due to *spatiotemporal* competition between the emotional distractor and the neutral target, where the emotional distractor is prioritised (Wang et al., 2012). EIB relies on temporal—i.e., selecting relevant events from a continuous stream of information (e.g., Olivers & Meeter, 2008)—*and* spatial attention. Dual stream attentional blink—i.e., the inability to report the second of two neutral targets (e.g., a letter and a number) presented within 500 ms of one another (Shapiro, Arnell, & Raymond, 1997)—experiments (e.g., Asanowicz, Kruse, Smigasiewicz, & Verleger, 2017) show there is no asymmetry for temporal attention (see Verleger & Smigasiewicz, 2015, for review). By contrast, spatial attention *is* a strong and reliable RH asymmetry in most people, leading to a slight leftward attentional bias. This leftward bias occurs for simple tasks—e.g., manual line bisection, where people reliably bisect the line slightly to the left of centre (see Jewell & McCourt, 2000, for review)—and more complex tasks—e.g., visual search, where people are faster and (sometimes) more accurate at identifying targets that appear on the left than the right side of a display (Mulckhuyse, Englemann, Schutter, & Roelofs, 2017; Nicholls, Hobson, Petty, Churches, & Thomas, 2017).

But increased attention toward the left side of space is not always advantageous. For example, Du and Abrams (2010) demonstrated that left side distractors *impair* performance on an ongoing task more than right side distractors. They presented 20 different coloured letters (for 40 ms each) in a central stream. Participants had to detect and report a single *red* letter (the target) at the end of each trial. Embedded within the stream was a distractor; a letter (either in the same or a different colour to the target) surrounded by four # signs (one each above, below, to the left, and to the right of the letter). The colour of each sign was also varied; either the same as the other letters (less distracting), or red like the target (more distracting). Accuracy in detecting the centrally presented target was worse when the red #

appeared in the left than the right visual field. In line with EIB and attentional blink, this effect was strongest when the distractor appeared two items before the target (i.e., at lag 2). Thus, paying more attention to the left increases susceptibility to attentional capture on the left, leading to impaired performance in detecting a centrally presented target. There are two unanswered questions from Du and Abrams (2010). First, what happens when the target appears in the *same* location as the target—does increased attentional capture only impair the ability to detect targets appearing in different locations to the distractor? Second, is the effect exacerbated by emotional targets, considering the RH is dominant for initial emotional processing (i.e., the RH is faster in processing emotion)?

The contribution of the RH and LH to emotional processing has been heavily debated, but there is growing consensus that the RH is dominant for automatically identifying and initially processing emotion, particularly negative emotions (e.g., Gainotti, 2012, 2018; Shobe, 2014). The short presentation time used in an EIB paradigm (100 ms per image) should only allow for "initial processing" of the emotional stimuli, especially because the neutral target—which the participant is trying to detect—appears *after* the emotional distractor. Participants must disengage from the emotional stimulus to detect the rotation of the neutral target; therefore, EIB provides insight to how well the RH and LH disengage from emotional stimuli. We propose that RH processing might enhance EIB because the RH will automatically attend to the emotional distractor, making it difficult to disengage from the emotional distractor and detect the neutral target. By contrast, the LH will not automatically attend to the emotional distractor, leaving it free to attend to the neutral target.

We ran two experiments to determine RH and LH contributions to EIB. Experiment 1a investigated differences in the *size* of EIB depending on hemispheric processing. Given our interest in the size of EIB, it was important to choose lags where EIB reliably occurs.

Therefore, we presented the target distractor two (lag 2)—the most robust EIB effect—or four (lag 4)—a robust, but weaker, EIB effect (Kennedy & Most, 2015)—items before the target. Existing dual stream findings suggest EIB only occurs when the distractor and target appear in the same location (e.g., Most & Wang, 2011). Therefore, we placed the distractor and target in the same stream, allowing us to compare the size of emotion induced blindness depending on whether the stream appears in the left vs. the right visual field (i.e., with RH vs. LH processing). In Experiment 1b, we varied whether the distractor and target appeared in the same or opposite stream. This methodological change allowed us to determine the independent *and* collaborative influence of RH and LH processing particularly for disengaging from emotion. We only used lag 2 in Experiment 1b (the lag at which EIB is strongest) to manipulate spatial attention whilst keeping temporal attention constant. In general, we predicted that RH processing would *enhance* EIB for left visual field items because despite people paying increased attention to the left visual field, which might increase target detection, the RH is specialised for the initial processing of emotion (i.e., the RH is faster in processing emotion). Thus, emotional distractors that appear in the left visual field will be automatically processed—or inversely, less easily ignored—than emotional distractors that appear in the right visual field.

3.1 Experiment 1a

We used a 2 (distractor valence: negative, neutral) x 2 (stream: left, right) x 2 (lag: 2, 4) within-subjects design. Our emotional distractors were exclusively negative, and not positive, to remain consistent with most EIB studies. To our knowledge only three have included positive distractors (Most et al., 2007; Olatunji, Armstrong, McHugo, & Zald, 2013; Singh & Sunny, 2017) and, importantly, find similar EIB for positive and negative distractors. Therefore, including positive distractors would have unnecessarily complicated our design. In this experiment, the distractor and target only ever appeared in the same stream. We predicted an overall EIB effect, expecting participants to show greater impairment in detecting the neutral target image when the target was preceded by an emotional compared to a neutral distractor. We expected that this effect would be stronger at lag 2 than lag 4. However, our primary hypothesis was that distractor valence (neutral, negative), lag (2, 4), and stream (left, right) would interact, such that there would be more EIB for images presented in the left-side stream (i.e., images processed by the RH) compared to images presented in the right-side stream (i.e., images processed by the LH). We predicted that this visual-field difference would be greater when the emotional distractor occurred two (lag 2) than four (lag 4) items prior to the target.

EIB may be a promising indicator of current negative affect (Onie & Most, 2017) and PTSD symptoms (Olatunji et al., 2013). Therefore, we also included measures of current depression, anxiety, stress, and PTSD symptoms to determine whether they are associated with exacerbated EIB. We predicted negative correlations between accuracy on negative distractor trials and all symptom scores. This experiment was pre-registered on the Open Science Framework (http://osf.io/xb4fg/).

3.1.1 **Method**

Participants. We recruited 65 university students who were strongly right-handed, to ensure spatial attention centres were in the RH (Hugdahl, 2000); they received course credit or $10.00AUD for their time. This experiment was approved by the Flinders University Social and Behavioural Research Ethics Committee. We based our anticipated effect size on the size of EIB in Most and Wang (2011)’s dual stream experiment and prior research conducted on hemispheric differences (Moeck, Thomas, & Takarangi, 2018). Most and Wang (2011) found that when the distractor and target appeared in the same stream—like in this experiment—participants' accuracy in identifying whether the target was rotated to the left or right was worse when it was preceded by a negative than neutral distractor, (*d*s = 0.7 to 1.3 across two experiments). Although the EIB effect is large and reliable, we are interested in the difference in the size of this effect depending on hemispheric processing. Prior research in our lab (Moeck et al., 2018) suggests hemispheric differences for recognition memory of negative images are small to medium in size (e.g., $d = 0.35$). To estimate required sample size, we conducted a power analysis (G*Power) assuming this lower effect size ($d = 0.35$) for hemispheric differences on target identification accuracy with a negative distractor. We based our sample size on the *t*-test for hemispheric differences following negative distractors, rather than the three-way interaction between valence, visual field, and lag, because G*Power cannot calculate power analyses when there is more than one within-subjects factor. We needed a sample size of at least 61 to maintain 85% power at the .05 significance level. This sample size fits with what Most and colleagues have recently used in their lab (e.g., Kennedy et al., 2018).

We collected 65 participants but excluded three; one who was not strongly right-handed (determined by scoring less than +8 on the Flinders Handnedness Survey [FLANDERS]), one whose overall accuracy[5] (collapsed across all trials) was 2SDs below the rest of the sample, and one who had below chance accuracy on baseline trials, which have no distractors. Our final sample of 62 participants ranged from 18 to 33 years old ($M = 21.3$, 95% CI [20.4, 22.3]) and was predominantly female (77% female, 23% male). All

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[5] In a pilot test of the paradigm with 15 participants, mean overall accuracy was 63%, suggesting the task was an appropriate level of difficulty.

participants were strongly right-handed (*M* = 9.98, 95% CI [9.94, 10.00] on the FLANDERS) and had normal or corrected-to-normal vision. Participants provided written informed consent before beginning the experiment.

Materials.

Depression Anxiety and Stress Scale (DASS-21). We used this scale to establish participants' baseline depression, anxiety, and stress (Lovibond & Lovibond, 1995). The scale consists of three 7-item subscales of depression, anxiety, and stress (e.g., I found it difficult to relax). Participants rated each statement on a 4-point scale (from 0 = did not apply to me at all to 3 = applied to me very much, or most of the time) according to how much it applied to them over the past week. Among our sample we observed high internal consistency (Experiment 1a: $\alpha = .89$ overall, .76 for depression, .72 for anxiety, .84 for stress; Experiment 1b: $\alpha = .91$ overall, .86 for depression, .76 for anxiety, and .77 for stress).

PTSD checklist for Diagnostic and Statistical Manual of Mental Disorders-Fifth Edition (PCL-5). We used the PCL-5 (Weathers et al., 2013) to examine the association between current PTSD symptoms and EIB (Olatunji et al., 2013). The PCL-5 is a 20-item self-report measure of PTSD symptoms, in line with symptomology listed in the DSM-5 (American Psychiatric Association, 2013). We asked participants to think of their most stressful/traumatic event and gave them the option to disclose it. With this event in mind, they indicated how much each problem/symptom related to that event (e.g., *repeated, disturbing, and unwanted memories of the stressful experience)* has bothered them in the past month from 0 (*not at all*) to 4 (*extremely*). The PCL-5 provides an overall PTSD score (from 0 to 80), as well as four symptom cluster scores (re-experiencing, avoidance, negative alterations in cognition and mood, hyperarousal), which will not be analysed here. The PCL-5 holds strong internal consistency ($\alpha = .94$; for our samples .94 in Experiment 1a and .93 in

Experiment 1b) and test-retest reliability (*r* = .82; Blevins, Weathers, Davis, Witte, & Domino, 2015).

Apparatus and Stimuli. We programmed this experiment using MATLAB and Psychophysics Toolbox extensions (Brainard, 1997). We used a 20 x 13 inch monitor, with a refresh rate of 59.86 Hz and screen resolution of 1680 x 1050 pixels. We adapted Zhao and Most's (2018) programming using a modified divided visual field paradigm: a central fixation cross appeared alone for 100 ms and then accompanied by two RSVP image streams, one in each visual field (left and right). The images were 320 x 240 pixels. To ensure lateral presentation, we placed each RSVP stream 125 pixels (2.5 º) from the central fixation cross and instructed participants to concentrate on the fixation cross during image presentation (Bourne, 2006). A chin rest ensured the participant's head maintained a fixed position throughout the experiment, 500 mm from the screen, to avoid changes in visual angle.

There were 56 negative and 56 neutral distractor images sourced from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008) and other public sources. These images matched Kennedy and Most (2012), who previously gathered valence (from 1 = negative to 9 = positive) and arousal (from 1 = low to 9 = high) ratings. The negative distractors included images of medical trauma and violence (valence ratings: *M* = 1.73, *SD* = 0.54; arousal ratings: *M* = 6.04, *SD* = 0.69) and the neutral images were images of animals and people that did not have obvious emotional content (valence: *M* = 4.99, *SD* = 0.45; arousal: *M* = 3.18, *SD* = 0.55). Our target images were 122 landscapes rotated 90° clockwise (to the right) and/or counterclockwise (to the left). We had an additional 253 filler items, comprising upright landscape and architectural images.

Procedure. Following consent, participants completed the DASS-21 and the FLANDERS. They then completed the experiment individually at a computer, beginning with eight practice trials to ensure they understood the task. The speed of the practice trials gradually increased from 200 ms to 100 ms per image. The researcher confirmed participants understood the task instructions at the end of the practice trials and provided clarification when required. Participants then completed four experimental blocks, which each took around five minutes. We gave participants an opportunity to take a break between blocks to reengage their attention. On each trial, we presented an RSVP stream—comprising 10 items serially presented for 100 ms each—in the right and left visual fields. One of the streams contained an embedded rotated image (the target) and participants had to indicate the rotation of the target via key press at the end of each trial. We recorded accuracy in identifying the target's rotation, our dependent variable. To maintain task motivation, a 'bell' sounded on correct answers. The rotated image occurred either two (lag 2) or four (lag 4) items after a distractor. Therefore, of the 10 image pairs presented on each trial, one contained a distractor (negative, neutral, none) image, one contained a target-rotated image, and eight were fillers. There were 352 trials in total (four blocks of 88 trials). Each block included 32 trials with negative distractors, 32 trials with neutral distractors, and 24 trials without distractors—termed baseline trials—to compare the influence of hemispheric processing on trials with vs. without distractors. Figure 3.1 shows an example trial. After the experiment, participants completed the PCL-5. Debriefing procedures concluded the 35-minute session.

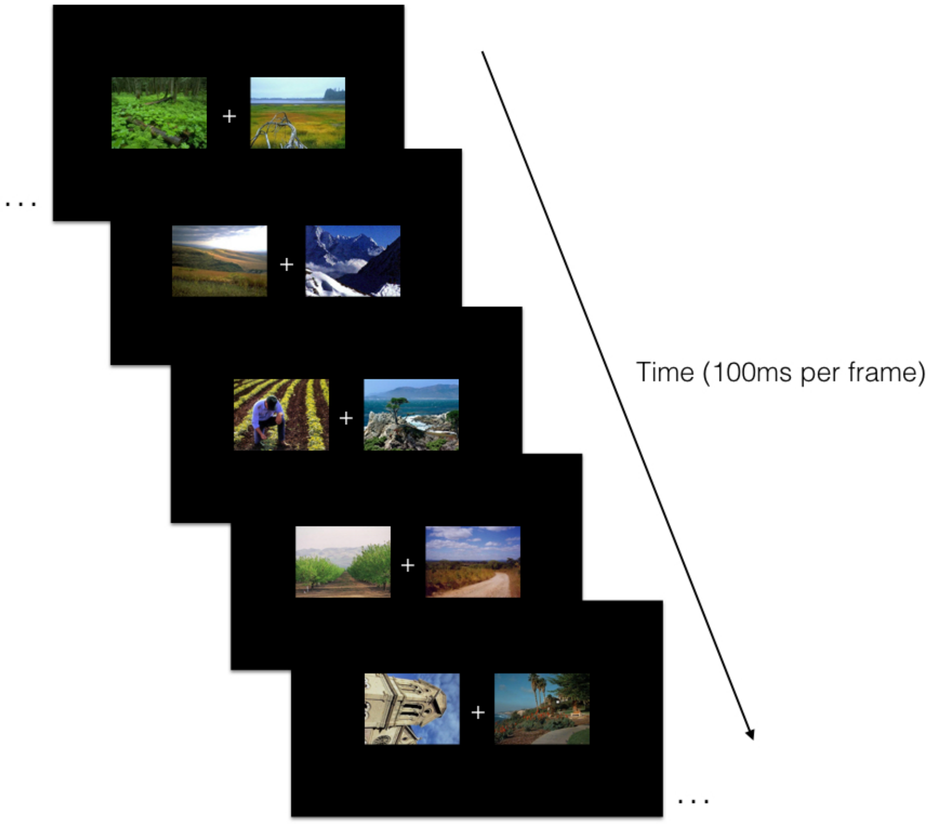

Figure 3.1. Schematic of five frames (out of 10) from one RSVP trial. On this trial, the distractor and target appeared in the left visual field. The distractor was neutral, appeared at lag 2, and the target was rotated to the right.

3.1.2 **Results**

Hypothesis testing. We ran a 2 (visual field: left, right) x 2 (distractor valence: negative, neutral) x 2 (lag: 2, 4) repeated measures ANOVA (see Figure 3.2). We found EIB: participants were less accurate in detecting the target rotation when it was preceded by a negative (M = 59.99, 95% CI[6] [57.55, 62.43]) than neutral (M = 63.87, 95% CI [61.43, 66.31]) distractor; a main effect of valence, $F(1, 61) = 26.06$, $p < .001$, $\eta_p^2 = .30$. As expected,

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[6] We report within-subjects 95% CIs for all descriptive statistics (Masson & Loftus, 2003).

participants were more accurate at detecting the target rotation when the distractors appeared at lag 4 ($M = 63.81$, 95% CI [61.37, 66.25]) than lag 2 ($M = 60.06$, 95% CI [57.62, 62.50]); a main effect of lag, $F(1, 61) = 18.59$, $p <.001$, $\eta_p^2 = .23$. In line with attending more to the left than the right side of space, participants' accuracy in detecting the rotation of the target image was significantly better when the distractor and target appeared in the left ($M = 64.62$, 95% CI [62.18, 67.06]) compared to the right ($M = 59.24$, 95% CI [56.80, 61.68]) visual field. This main effect of visual field ($F(1, 61) = 22.82$, $p < .001$, $\eta_p^2 = .27$) also occurred on trials without distractors (baseline trials). A paired samples t-test comparing visual field differences on baseline trials showed higher accuracy when the target appeared on the left ($M = 69.86$, 95% CI [67.06, 72.66]) than the right side ($M = 65.32$, 95% CI [62.95, 67.69]), $t(61) = 2.83$, $p = .006$, $d = 0.36$.

Contrary to our primary hypothesis that EIB would be larger for images presented in the left than the right visual field and at lag 2 than lag 4, we found no three-way interaction between valence, lag, and field ($F(1, 61) = .23$, $p = .64$, $\eta_p^2 = .004$), or any two way interactions between field and valence ($F(1, 61) = .08$, $p = .78$, $\eta_p^2 = .001$) or field and lag ($F(1, 61) = .001$, $p = .98$, $\eta_p^2 = .000$). Participants were consistently better at detecting the target rotation from the left than the right visual field, regardless of valence or lag. We also found no interaction between lag and valence ($F(1, 61) = .02$, $p = .89$, $\eta_p^2 = .000$), likely due to choosing two lags where EIB is known to occur. Taken together, these findings demonstrate that participants showed similar EIB when the distractor and target appeared on the left and the right side.

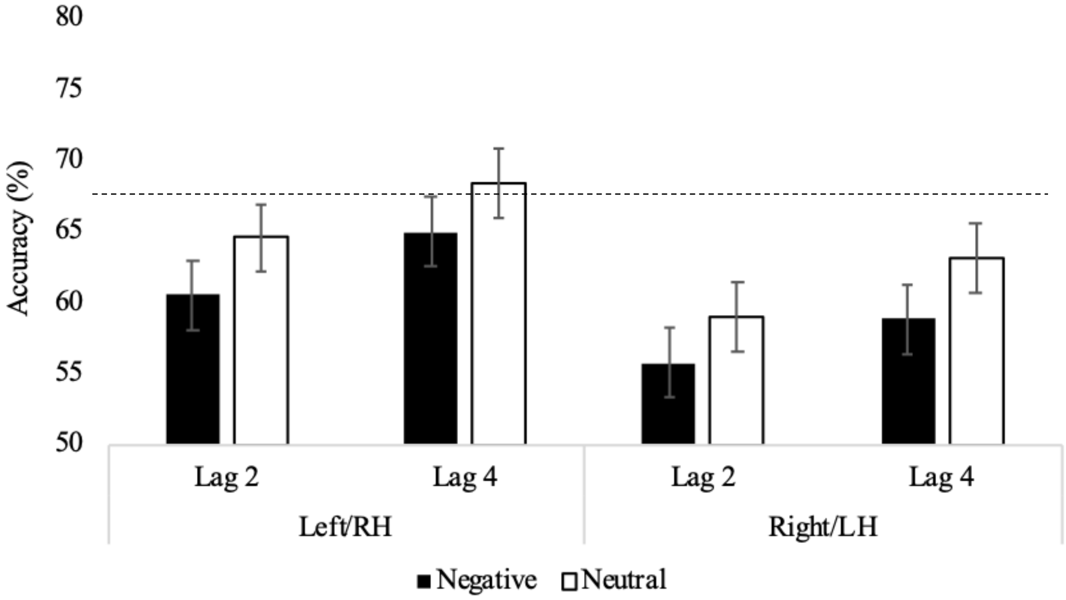

Figure 3.2. Experiment 1a: mean accuracy for correctly detecting the target rotation depending on distractor valence, lag, and the target's visual field. Dotted line represents baseline accuracy (i.e., on trials without distractors). Error bars represent within-subject 95% CIs (Masson & Loftus, 2003).

Influence of symptom scores. Mean scores on baseline measures of depression, anxiety, and stress (DASS-21) were "normal" according to the ranges described by Lovibond and Lovibond (1995) (depression: M = 5.73, 95% CI [4.64, 6.81]; normal: 0 - 7, anxiety: M = 4.47, 95% CI [3.66, 5.28], normal: 0 - 9; stress: M = 7.11, 95% CI [6.02, 8.20], normal: 0 - 14). Mean scores on the PCL-5 were also normal (M = 22.61, 95% CI [18.55, 26.67]). To determine whether symptom scores correlated with EIB, we correlated each symptom measure with accuracy depending on stream, lag, and valence. We found a negative correlation between accuracy following negative distractors and symptom scores, but only when these distractors appeared at lag 2 and on the right-side (PCL-5: r = -.27, p = .03, depression: r = -.28, p = .03, anxiety: r = -.41, p = .001, stress: r = -.45, p <.001). These correlations suggest a moderate negative association between all symptom scores and EIB, but only with left hemisphere processing and at the shortest lag. There were no other correlations between symptom scores and accuracy (*p* values > .14).

3.1.3 **Discussion**

Experiment 1a suggests that a consistent EIB effect occurs in the left and the right visual fields. Contrary to expectations, the size of this effect was similar in both visual fields—participants were consistently 4 to 5% less accurate in detecting the target rotation following negative than neutral distractors. In line with the RH's dominance for spatial attention, overall accuracy was higher for left than right visual field targets. This novel finding suggests RH processing improves left side target detection, which fits with RH processing improving detection of left side targets in visual search tasks (Mulckhuyse et al., 2017; Nicholls et al., 2017). This finding also suggests that increased attentional capture on the left (Du & Abrams, 2010) does not impair target detection when the target appears in the same location as the distractor.

Is this left side advantage in target detection due to participants' reading direction, rather than RH dominance for spatial attention? Smigasiewicz et al. (2010) investigated the role of reading direction in the context of attentional blink, an effect that shows a reliable left side advantage; people are less impaired in detecting the second target (due to having to retain the first target) on the left than the right. Smigasiewicz et al. (2010) compared participants from Germany (left to right reading direction), Israel (right to left reading direction), and Taiwanese (vertical reading direction). Using letters from participants' respective native languages reduced (but did not eliminate) the left side attentional blink advantage. However, when the letters were Latin—i.e., letters that all participants were familiar with—the left side advantage remained and there were no cultural differences.

Because EIB experiments use images, which are even more universal than Latin letters, the left-right reading direction of our Australian participants does not seem like a plausible alternative explanation for the left side advantage in target detection.

In this experiment, the distractor and the target only appeared in the same location as one another. We made this methodological decision because existing work suggests EIB only occurs when the emotional distractor appears *in the same place* as the neutral target (Kennedy et al., 2018; Most & Wang, 2011; Wang & Most, 2017). But when the distractor and target only ever appear in the same location, the two hemispheres do not have to collaborate. Therefore, our conclusions are limited to when the same hemisphere processes both the emotional and neutral stimuli. Another limitation is that participants may have learned that the distractor cued where the target would appear (e.g., Mackintosh, 1975), thus relying less on spatial orienting compared to if the target and distractor could potentially appear in the opposite location (Corbetta, Patel, & Shulman, 2008).

To address these limitations, we ran a second experiment (Experiment 1b) where the distractor and target appeared in the *opposite* as well as the same stream. This experiment allows us to determine (1) if increased attentional capture on the left (Du & Abrams, 2010) impairs target detection on the right, (2) the collaborative, as well as the independent, contributions of RH and LH processing to disengaging from emotional stimuli, and (3) whether hemispheric processing changes the spatial localisation of EIB. Work by Hartikainen, Ogawa, and Knight (2000) suggests that hemispheric processing could lead to non-spatially localised EIB. They had participants detect the direction of a triangle target (up or down). Similar to an EIB paradigm, an emotional or neutral distractor image appeared 150 ms before the target in the same *or* the opposite visual field. Emotional images impaired *left* side target detection when these images appeared in the same *and* the opposite location as the target. That is, the emotional impairment was not spatially localised. This effect was stronger for unpleasant than pleasant images and did not occur for neutral images. There was no influence of picture valence on detection of right visual field targets; an interaction between valence and visual field. The authors concluded that emotional images automatically capture RH processing resources, which interferes with other RH functions. The small sample size of this experiment (*N* = 18) limits the strength of its findings. However, the possibility that hemispheric processing could lead to non-spatially localised EIB is also supported by dual stream attentional blink experiments with larger sample sizes.

Dual stream attentional blink experiments have predominantly used horizontal streams, as we did here. In attentional blink, participants search for two targets (e.g., target 1 [T1]: a different coloured letter, target 2 [T2]: a number) presented among streams located in the right and left visual field (e.g., Asanowicz et al., 2017). Accuracy in identifying T2 is markedly better when it is presented in the left than the right visual field[7] (Asanowicz, Śmigasiewicz, & Verleger, 2013; Holländer, Corballis, & Hamm, 2005; Scalf, Banich, Kramer, Narechania, & Simon, 2007; Kranczioch, Lindig, & Hausmann, 2016; Verleger et al., 2009; Verleger, Śmigasiewicz, & Möller, 2011; Verleger et al., 2013; Śmigasiewicz et al., 2010). Importantly, the left side T2 advantage is larger when T1 and T2 appear in the opposite visual field compared to when T1 and T2 appear in the same visual field. The advantage of identifying T2 when it appears in the left visual field, particularly on trials where T1 appears in the right visual field, suggests that it is easier to shift spatial attention from the right to the left than the left to the right visual field. Will this left side advantage, when target location is uncertain, occur for EIB?

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[7] This left side advantage (RH benefit) could be interpreted as a right side disadvantage (LH deficit). We have chosen to use the advantage/benefit terminology.

When there is uncertainty regarding where a target will appear, the RH and LH simultaneously monitor their respective (contralateral) visual field (Corbetta et al., 2008). This simultaneous monitoring leads the two hemispheres to compete for attention resources; a competition favouring the RH because spatial attention is lateralised to this hemisphere (e.g., de Haan, Bither, Brauer, & Kamath, 2015). The RH has direct access to left visual field stimuli, while the LH does not have direct access to right visual field stimuli because it relies on interhemispheric transfer of information (Moscovitch, 1986). This transfer process takes time and may degrade the quality of information, especially when the RH is simultaneously monitoring the left visual field. Hence, there is a strong and reliable left side advantage with simultaneous monitoring of dual streams, particularly when target location is uncertain (e.g., Corbetta et al., 2008). Attentional blink and EIB paradigms are similar in that they require monitoring of a RSVP stream and T1 is like the distractor while T2 is like the target. However, there are notable differences between attentional blink and EIB paradigms—e.g., more complex stimuli in EIB—highlighting the need to systematically address whether the left side advantage when target location is uncertain occurs with a horizontal EIB paradigm.

3.2 Experiment 1b

We replaced our lag manipulation from Experiment 1a with a distractor location manipulation. We chose to use lag 2 only, because in Experiment 1a EIB was stronger at lag 2 than lag 4. The distractor appeared in either the same stream as the target (e.g., both in the left visual field) or the opposite stream (e.g., distractor in the left and target in the right visual field). Thus, we used a 2 (visual field: left, right) x 2 (distractor valence: negative, neutral) x 2 (distractor location: same, opposite stream) within-subjects design.

Based on our Experiment 1a results and attentional blink research, we predicted that participants would be more accurate on left than right visual field targets; a main effect of visual field. We expected an interaction between visual field and distractor location, but there are competing predictions for the direction of this interaction. RH superiority when the two hemispheres compete for attentional resources (Asanowicz et al., 2017) suggests a larger left side advantage on opposite compared to same stream trials. However, increased attentional capture with left than right side distractors (Du & Abrams, 2010) suggests a smaller left side advantage on opposite compared to same stream trials. But would *emotional* (compared to neutral) distractors influence RH superiority in identifying left visual field targets on opposite stream trials? In other words, would we see EIB when the distractor and target appear in opposing streams?

Existing dual stream EIB research predicts that we would only see emotion induced blindness when the distractor and target appear in the same stream, because EIB is spatially localised. We argue that by moving to horizontal streams, there may be circumstances under which EIB is not spatially localised. The RH is superior in target detection and the LH lacks specialisation for initial emotional processing (Shobe, 2014). Therefore, we expected no difference in target detection by valence (i.e., no EIB) on trials when the distractor appears in the right (LH processing) and the target appears in the left visual field (RH processing). By contrast however, we expected to see EIB on trials when the distractor appears in the left and the target appears in the right visual field. The LH relies on interhemispheric transfer of information from the RH. On trials where an emotional distractor appears in the left visual field, the RH will automatically process the emotional distractor, leaving few resources to transfer target related information from the LH. On trials where a neutral distractor appears in the left visual field, the distractor will not be preferentially processed, leaving the RH free to transfer target related information from the LH.

3.2.1 **Method**

Participants. We recruited 66 university students but excluded three who were not sufficiently right handed and two whose accuracy was below chance. The remaining 61 participants were aged between 18 and 42 years (*M* = 21.0, 95% CI [20.1, 21.8), had normal or corrected-to-normal vision, were strongly right-handed (*M* = 9.68, 95% CI [9.85, 10.0] on the FLANDERS), and were predominantly female (85% female, 15% male, 0% non-binary). This experiment was pre-registered on the Open Science Framework (https://osf.io/4a6fg/).

Procedure. Our materials matched Experiment 1a, except for changes to distractor location and lag. In this experiment, the target and distractor appeared in the same, as well as the opposite stream, from one another. To make this change without disrupting the counterbalance, we replaced the lag with the distractor location manipulation. Thus, the rotated image only ever occurred two items (lag 2) after a distractor—where EIB is strongest (Kennedy & Most, 2015). The distractor appeared in the same stream as the target on half the trials and in the opposite stream as the target on the other half. The procedure matched Experiment 1a; participants completed the DASS-21 and FLANDERS, the experiment, and then the PCL-5.

3.2.2 **Results**

Hypothesis testing. We ran a 2 (visual field: left, right) x 2 (distractor valence: negative, neutral) x 2 (distractor location: same, opposite stream) repeated measures ANOVA (see Figure 3.3). As in Experiment 1a, participants showed EIB. They were less accurate in detecting the target rotation following negative (*M* = 59.34, 95% CI [56.95, 61.73]) than neutral (*M* = 63.92, 95% CI [61.53, 66.31]) distractors; a main effect of valence, $F(1, 60) = 26.5$, $p < .001$, $\eta_p^2 = .306$. Target detection accuracy was similar when the distractor appeared in the same ($M = 61.16$, 95% CI [58.77, 63.55]) and the opposite ($M = 62.11$, 95% CI [59.72, 64.50]) stream as the target; there was no main effect of distractor location, $F(1, 60) = 1.33$, $p = .25$, $\eta_p^2 = .022$. Inconsistent with Experiment 1a and our hypothesis, accuracy was similar when the target appeared in the left ($M = 62.40$, 95% CI [60.01, 64.79]) vs. the right ($M = 60.86$, 95% CI [58.47, 63.25]) visual field; there was no main effect of visual field, $F(1, 60) = 1.50$, $p = .23$, $\eta_p^2 = .024$. This visual-field similarity on distractor trials occurred despite higher baseline accuracy—i.e., trials without distractors—for left ($M = 69.70$, 95% CI [67.13, 72.28]) than right ($M = 64.19$, 95% CI [62.04, 66.33]) visual field items, $t(60) = 3.42$, $p < .001$, $d = 0.40$. The leftward advantage on baseline trials replicates Experiment 1a.

Contrary to EIB being spatially localised (e.g., Kennedy et al., 2017), accuracy was worse following negative than neutral distractors on both same (negative = 58.89, 95% CI [56.50, 61.28], neutral = 63.43, 95% CI [61.04, 65.82]; t(60) = 4.11, $p < .001$, $d = 0.54$) *and* opposite (negative = 59.79, 95% CI [57.4, 62.18], neutral = 64.42, 95% CI [62.03, 66.81]; $t(60) = 3.91$, $p < .001$, $d = 0.51$) stream trials. This lack of interaction between distractor location and valence, $F(1, 60) = .005$, $p = .94$, $\eta^2 = .000$, suggests EIB is not spatially localised with horizontal streams. There was a marginal interaction between visual field and valence, $F(1, 60) = 4.00$, $p = .05$, $\eta_p^2 = .063$. Paired samples t-tests revealed that although EIB occurred when the target appeared in the left ($t(60) = 4.62$, $p < .001$, $d = 0.55$) and the right ($t(60) = 2.85$, $p = .006$, $d = 0.35$) visual fields, there was a larger impairment following negative than neutral distractors when the target appeared in the left (negative: $M = 59.30$, $SD = 8.21$; neutral: $M = 65.50$, $SD = 9.59$) than the right (negative: $M = 59.38$, $SD = 8.26$; neutral: $M = 62.35$, $SD = 9.03$) visual field. However, this visual field difference in the size of EIB was driven by worse right than left side target detection following neutral distractors ($t(60) = 1.96$, $p = .054$, $d = 0.24$) but not following negative distractors ($t(60) = -.06$, $p = .96$,

$d = 0.01$). Contrary to predictions, visual field did not interact with distractor location, $F(1, 60) = 2.66$, $p = .11$, $\eta_p^2 = .042$, and we found no three-way interaction between visual field, valence, and distractor location, $F(1, 60) = .103$, $p = .75$, $\eta_p^2 = .002$.

Influence of symptom scores. Mean scores on baseline measures of depression, anxiety, and stress were “normal” (depression: $M = 4.08$, 95% CI [3.11, 5.05]; anxiety: $M = 4.65$, 95% CI [3.66, 5.63]; stress: $M = 7.47$, 95% CI [6.48, 8.45]). Mean scores on the PCL-5 were also normal ($M = 21.50$, 95% CI [17.59, 25.41]). We found no significant correlations between accuracy—depending on valence, visual field, or distractor location—and any symptom measure (p values > .05). The negative correlations between accuracy for lag 2 negative right-side items (i.e., negative right-side same stream items) and all symptom scores observed in Experiment 1a did not replicate.

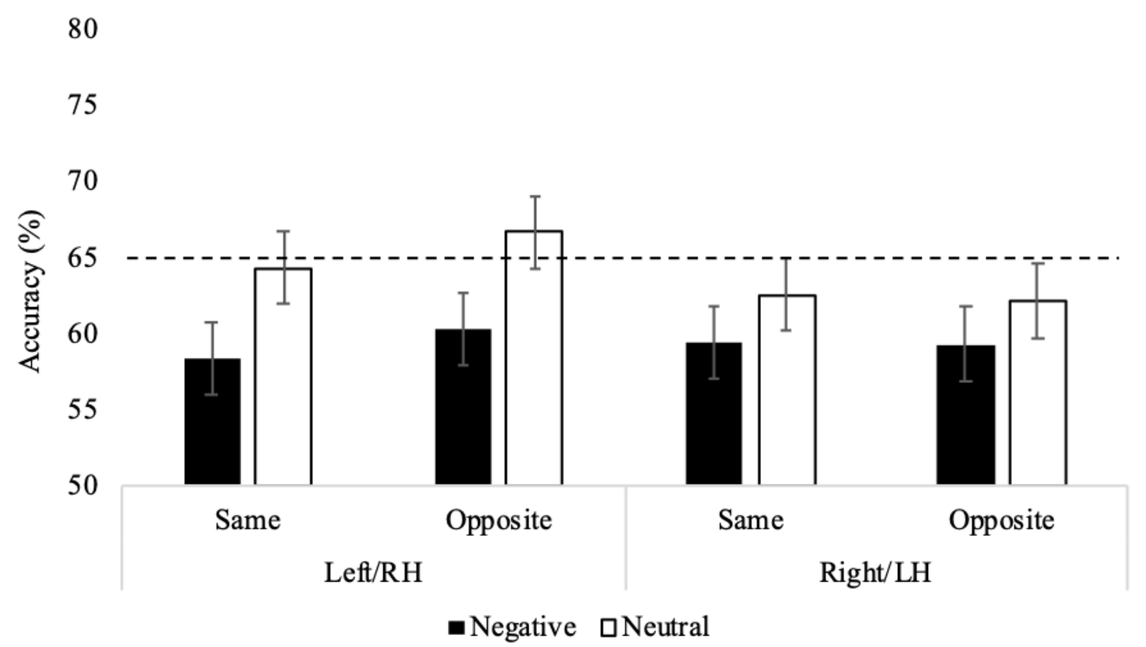

Figure 3.3. Experiment 1b: mean accuracy in correctly detecting the target rotation depending on distractor valence, distractor location, and the target's visual field. Dotted line represents overall baseline accuracy (i.e., on trials without distractors). Error bars represent within-subject 95% CIs (Masson & Loftus, 2003).

3.2.3 **Discussion**

Experiment 1b examined the independent and collaborative contributions of RH and LH processing in EIB. We also aimed to determine whether EIB is spatially localised when the RH and LH process an image stream each. In line with our expectations EIB was not spatially localised which differs from vertical dual stream EIB experiments (as summarised by Wang et al., 2012). Contrary to Experiment 1a, participants showed similar accuracy following negative distractors, regardless of distractor location or visual field. The lack of visual-field difference following negative distractors was surprising and does not fit with the RH being dominant for the initial processing of emotional stimuli (Gainotti, 2012). However, it does fit with emotional processing asymmetries having no influence on behavioural measures of response inhibition (Ocklenburg et al., 2017). Ocklenburg et al. used a lateralised No-Go/Go task, where participants had to respond to scrambled images and withhold their responses to unscrambled images. The unscrambled images were either neutral or emotional and served as task *irrelevant* distractors. This No/Go task is similar to EIB tasks in which the emotional and neutral distractor images are task irrelevant. Ocklenburg et al. found that participants were more accurate in withholding responses to emotional than neutral images, but there was no influence of visual field nor an interaction between visual field and emotional valence. The authors concluded that asymmetries for emotional processing do not affect behavioural response inhibition.

3.3 **General Discussion**

Until now, researchers have studied EIB exclusively using a single central stream or two vertically placed streams. Using horizontal streams, we found a consistent EIB effect across visual field, lag (Experiment 1a), and distractor location (Experiment 1b). This consistency clearly demonstrates that EIB is not restricted to central or vertically placed streams. In general, accuracy in detecting the rotation of the neutral target image was 3 to 6% worse following negative than neutral distractors. This valence difference is smaller than what other EIB experiments report. At lag 2 in single stream experiments, the accuracy difference ranges from 7 to 14% (Kennedy & Most, 2012, 2015; Most et al., 2005; Most & Junge, 2008). When Singh and Sunny (2017) distinguished distractors based on arousal only, they found an 18% difference with worse accuracy following high than low arousal distractors. On same stream trials of dual stream experiments, the accuracy difference at lag 2 ranges from 10 to 15% (Kennedy et al., 2018; Most & Wang, 2011; Wang & Most, 2017).

We propose that our smaller difference occurred because presenting an image stream in each visual field isolated one stream per hemisphere (Bourne, 2006). By contrast, both hemispheres can contribute to processing the images when they appear centrally or vertically.

In line with spatial attention being a RH function (e.g., de Schotten et al., 2011), participants showed approximately 5% higher accuracy in detecting the rotation of the neutral targets when they appeared in the left than the right visual field. This left-side advantage was particularly robust in Experiment 1a, when the distractor and target only ever appeared in the same location as one another, and on baseline trials (which have no distractors). It fits with Mulckhuyse et al. (2017) and Nicholls et al. (2017)—where people were better at searching for targets that appeared on the left than the right side of a display—and Benedetto, Pedrotti, Bremond, and Baccino (2013)—who found right-side drivers[8] were more likely to look at road signs on their left than their right. In Experiment 1a, this left side advantage occurred regardless of whether the distractor was present or absent. In Experiment 1b, the left side advantage only occurred on trials without distractors; there was no left side advantage on same stream trials. This finding is surprising because these trials are directly comparable to Experiment 1a, lag 2, trials where we did observe a left side advantage. We can rule out participants paying less attention toward the left side of space in Experiment 1b than Experiment 1a as an explanation, because the size of the difference on trials without distractors was consistent across both experiments. Therefore, a viable explanation for why we observed an inconsistent left side advantage in Experiment 1b may stem from the relationship between the distractor and target image becoming unpredictable. Given our findings counter attentional blink research suggesting the left side advantage should be

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[8] We acknowledge that these results may change with left-side drivers, which is yet to be researched.

stronger when the location of the target is unpredictable (e.g., Corbetta et al., 2008), we propose that the presence of emotional stimuli and the target's unpredictability interacted to disrupt the RH advantage in Experiment 1b. Future research should replicate our unexpected finding and directly test this potential explanation.

Across both experiments, we found no interaction between negative and neutral valence and visual field. This finding was surprising because, despite their differences, emotional processing theories converge on RH dominance for the initial processing of emotion (e.g., Shobe, 2104). There are several explanations for why there were no visual field differences depending on distractor valence. First, perhaps the dominance of the RH for initial emotional processing competed with its dominance for spatial attention, leading to no behaviourally observable difference in EIB. In Experiment 1b, there were visual field differences in target detection following neutral, but not negative distractors, suggesting the presence of emotional distractors overode any visual field differences. Second, perhaps the emotional scenes were too complex to show the lateralised effects we would expect based on work with basic emotions. Alba-Ferrara, Hausmann, Mitchell, and Weis' (2011) research on emotional prosody comprehension (i.e., interpreting how others feel based on their tone of voice) supports this possibility. They compared neural activation when participants comprehended simple (happy, sad, angry) vs. complex (proud, guilty, bored) emotional tone of voice and found *bilateral* activation for complex emotions and lateralised activation for simple emotions. Future research could investigate this possibility by comparing EIB following simple vs. complex emotional scenes.

Another possibility is that we did not find any visual field differences in EIB because the distractors were task irrelevant. The *Asymmetric Inhibition Model* (Grimshaw & Carmel, 2014) posits that for task-irrelevant emotional distractors, the *left* dorsolateral pre-frontal cortex (dlPFC) inhibits negative distractors, while the *right* dlPFC inhibits positive distractors (Grimshaw & Carmel, 2014). However, an experiment by Mulckhuyse et al. (2017) suggests that for behaviourally relevant distractors, the *right* posterior parietal cortex is involved in inhibiting threatening (vs. non-threatening) distractors. Participants completed a visual search task, looking for a grey diamond presented amongst grey circles. On some trials, a red or green distractor circle appeared. For each participant, one set of distractors (e.g., the red circles) was conditioned to be threatening (by pairing it with a loud noise in a prior phase) and one set of distractors (e.g., the green circles) was conditioned to be non-threatening (by not being paired with any noise). Thus, the distractors were behaviourally relevant because they were conditioned as ‘fear inducing’ vs. ‘safe’ stimuli. Before completing the visual search task, participants had their right or left posterior parietal cortex inhibited via transmagnetic stimulation (TMS). With inhibition of the right PPC, participants took longer to detect the target on trials when the threatening distractor (vs. non-threatening distractor) was present. There were no differences in reaction time for threatening vs. non-threatening trials with inhibition of the left PPC.

Taken together, Grimshaw and Carmel (2014) and Mulckhuyse et al. (2017) suggest that areas localised to the RH process behaviourally *relevant* negative distractors, but areas localised to the LH process behaviourally *irrelevant* negative distractors. As Ocklenburg et al. (2017) echoes, this potential interaction between task relevance and hemispheric processes may be crucial in predicting if and how hemispheric asymmetries influence behaviour. In line with this view, people show behavioural differences because of emotional processing asymmetries on tasks that require explicit judgments of the emotional stimuli. These judgments include recognition memory for emotional vs. neutral scenes (Moeck et al., 2018), number of eye-fixations when judging the attractiveness of happy vs. sad faces (Thomas, Wignall, Loetscher, & Nicholls, 2014), and discriminating whether a stimulus presented in the periphery is emotional or not (Calvo, Rodriguez-Chinea, & Fernandez-Martin, 2015). To disentangle if and how the RH and LH contribute to disengaging from emotional stimuli, future research could use a horizontal stream EIB paradigm and vary whether the distractors are task relevant vs. irrelevant. Testing participant's memory for the distractor images at the end of each block would make the distractors task-relevant (Kennedy et al., 2017).

We found evidence that with horizontal stream placement, EIB is not spatially localised. This finding counters the existing view that EIB only occurs when the emotional and neutral stimuli appear in the same location as one another (as summarised by Wang et al., 2012). However, given this work was the first to use horizontal streams, we interpret our Experiment 1b findings with caution. Future research should directly compare EIB with horizontal vs. vertical streams, to test the robustness of our findings and to elucidate exactly when EIB is and is not spatially localised. Replicating the finding that EIB occurs when the distractor and target appear in the same as well as the opposite stream is critical, because of the practical implications of this effect. We know that people (in this case, right-side drivers) are more likely to look at left than right side road signs for driving related information (Benedetto et al., 2013). What if these road signs depicted graphic information, e.g., a billboard promoting road safety? These graphic billboards intend to increase concentration on the road. But our findings suggest they might impair subsequent attention for neutral stimuli (e.g., brake lights from the car in front) appearing directly after on the opposite *and* the same side of the road. Future research could use a driving simulator with graphic vs. neutral billboards and targets that vary in their location to determine the ecological validity of this finding. At present, research on the influence of billboards on driver visual behaviour has exclusively focused on billboards without graphic content (e.g., Edquist, Horberry, Hosking,

& Johnston, 2011; see Decker et al., 2015 for review).

Across these experiments, symptom scores (depression, anxiety, stress, and PTSD symptoms) inconsistently correlated with EIB. In Experiment 1a, there were significant negative correlations between *all* symptom measures and participants' ability to identify a neutral target image but only when a negative distractor appeared on the right and two items prior. Interestingly, these correlations only occurred for *right* side items, suggesting a relationship between LH processing and difficulty disengaging from negative distractors. This potential relationship should be explored in the future, considering we know that reduced activity in the left frontal cortex is associated with depression and anxiety (e.g., Cisler & Koster, 2010). These correlations need to be replicated with a larger sample size (e.g., of 150-250 participants; Schönbrodt & Perugini, 2013) to ensure they are stable. Although we did not find these correlations in Experiment 1b, we recommend replication, rather than concluding the correlations are spurious, because the Experiment 1a correlations were consistent across symptoms of PTSD, depression, anxiety, *and* stress and EIB may be a promising predictor of negative affect (e.g., Onie & Most, 2017). Another possibility is that correlations between EIB and PTSD symptoms may only exist when the distractors are trauma-related. This possibility is supported by Olatunji et al. (2013), who found that people with current PTSD symptoms (compared to recovered PTSD and control participants) showed greater EIB following trauma related distractors (compared to negative but not trauma related and neutral distractors).

These experiments have limitations. First, we did not control for differences in the low-level properties of our distractors, including colour and luminance. Future research should compare horizontal EIB following negative distractors with neutral and scrambled (as in Kennedy & Most, 2015) distractors. Second, the categories of negative and neutral distractors differed on valence as well as arousal dimensions. A future study could include positive as well as negative distractors, matched on arousal, to investigate arousal-based hemispheric differences. This study would have important theoretical implications, given the circumplex model of emotional processing (e.g., Heller, 1993) predicts hemispheric differences are due to arousal and not valence, and because Singh and Sunny (2017) found a strong EIB effect when comparing high vs. low arousal distractors. Third, we only used lag 2 (Experiment 1a and 1b) and lag 4 (Experiment 1a). Therefore, these experiments do not allow us to disentangle the role of temporal from spatial attention in EIB. Interestingly, no dual stream EIB experiments have included anything past lag 2 (Kennedy et al., 2018; Most & Wang, 2011; Wang & Most, 2017) suggesting future research including later lags (i.e., lag 7 and 8) is warranted. This research would allow us to confirm that EIB does not exist when the distractor and target are sufficiently separated in dual streams, like in a single central stream (e.g., Kennedy & Most, 2015); an assertion supported by the weaker EIB effect we found at lag 4 (than lag 2) in Experiment 1a. Fourth, we did not eye-track our participants; relying on them following instructions to keep their eyes centrally fixated. Because we used 100 ms presentation time per image pair, we are confident that participants could not move their eyes toward one particular image stream, because eye movements take 150 ms (Bourne, 2006). However, future research could include gaze-contingent eye-tracking (as in Kennedy et al., 2018) to ensure our visual field differences were not due to participants looking at the left side stream more often than the right.

Emotional stimuli alert us to potential environmental threats, increasing our vigilance and capacity for survival. But our automatic response to emotion can come at a cost; it can interrupt ongoing activities (e.g., Hartikainen et al., 2000) and prevent us from noticing potentially important neutral stimuli that appear directly after. Here, we found that EIB occurs across both visual fields and was not spatially localised. Due to the important practical implications of this work (e.g., for driver attention), future research should further investigate the exact contribution of the RH and LH in emotion induced blindness.

4 Lateralised Processing of Emotional Images: A Left Hemisphere Memory Deficit[9]

4.1 Abstract

The right hemisphere plays a critical role in visuospatial attention and emotional perception, particularly for negative emotions. Therefore, preferential processing of emotional stimuli by the right, compared to the left, hemisphere could enhance our memory for emotional stimuli. We examined whether recognition memory for negative vs. neutral images (Experiment 2a) and negative vs. positive images (Experiment 2b) differed depending on initial right or left hemisphere processing—manipulated by presenting images in the left (i.e., right hemisphere) or the right (i.e., left hemisphere) visual field. We tested recognition memory for valence-matched image pairs encoded for 500 ms. We manipulated image valence and visual field of presentation within-participants. In Experiment 2a, valence and visual field interacted to influence recognition memory: people recognised negative images encoded from the left visual field (right hemisphere) more accurately than negative images encoded from the right visual field (left hemisphere). There were no visual field differences for neutral images. In Experiment 2b, recognition memory for positive and negative images was equally enhanced when these images appeared in the left compared to the right visual field. Our findings suggest preferential right hemisphere processing of visuospatial and emotional information enhances recognition memory for emotional images. We interpret these findings as a left hemisphere memory deficit for emotional images, because right

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[9] Moeck, E. K., Thomas, N. T., & Takarangi, M. K. T. (2018, December 20). Lateralised processing of emotional images: a left hemisphere memory deficit. *Emotion*. Advance online publication. doi: 10.1037/emo0000554

hemisphere processing led to similar recognition memory of emotional as neutral images, while left hemisphere processing led to worse recognition memory of emotional than neutral images. These findings aid our understanding of how lateralised functions contribute to emotional processing.

4.2 Introduction

What people later remember about emotionally charged events (e.g., a loved one's death) depends on the information they encoded during the event, which might be determined by where their attention was directed (e.g., Levin, Simons, Angelone, & Chabris, 2002). Right hemisphere (RH) processing may be one factor that affects visual memory for emotional events. We know that the RH plays a critical role in visuospatial (e.g., Hervé, Zago, Petit, Mazoyer, & Tzourio-Mazoyer, 2013) and—although more contentious—emotional (e.g., Demaree, Everhart, Youngstrom & Harrison, 2005) processing; but do these specialized roles of the RH influence how emotional images are remembered?

Pseudoneglect—a slight attentional bias toward the left side of space (Bowers & Heilman, 1980)—explicitly demonstrates the RH asymmetry for visuospatial attention. Pseudoneglect influences memory in the same direction as visual attention; people remember visual information presented in the left visual field—and initially processed by the RH—more accurately than equivalent information initially processed by the left hemisphere (LH) (Dickinson & Intraub, 2009; Della Sala, Darling, & Logie, 2010; McGeorge, Beschin, Colnaghi, Rusconi, & Della Sala, 2007; Petrini, Hennings, & Arendt-Nielsen, 2009). However, existing studies have used neutral stimuli, failing to acknowledge how emotional valence might alter this RH memory bias.

The RH and the LH make unique contributions to emotional processing (Grimshaw &

Carmel, 2014). Theorists have previously searched for a basic dichotomy, viewing each hemisphere as a unitary processor that independently contributes to emotional processing. Three influential emotional processing models took this approach: the right-hemisphere hypothesis (e.g., Borod, Bloom, Brickman, Nakhutina, & Curko, 2002), the valence-specific hypothesis (e.g., Ahern & Schwartz, 1985), and the circumplex model (e.g., Heller, 1993). According to the RH hypothesis, the RH is predominant for perceiving *all* emotions, regardless of valence. In support of this hypothesis, Calvo, Rodriguez-Chinea, and Fernandez-Martin (2015) found people were more accurate at identifying the valence of scenes briefly presented (150 ms) in the periphery, when processed by the RH rather than the LH, particularly when these scenes were emotional. By contrast, the valence-specific hypothesis posits that the RH is specialized for processing negative emotion, and the LH is specialized for processing positive emotion (e.g., Ahern & Schwartz, 1985). Face perception research provides the primary support for this hypothesis; people identify positive expressions more accurately when processed by the LH, and negative expressions more accurately when processed by the RH (Jansari, Rodway, & Goncalves, 2011). Finally, according to the circumplex model of emotion (e.g., Heller, 1993), differences in hemispheric activation in anterior cortices relate to emotional valence and differences in hemispheric activation in posterior cortices relate to *arousal*. For example, viewing pleasant stimuli leads to greater left than right anterior cortex activity, while viewing high-arousal stimuli leads to greater right than left posterior cortex activity (Heller, Koven, & Miller, 2003).

Recent models of hemispheric contributions to emotional processing—including the hemispheric independence and collaboration model (Shobe, 2014) and the asymmetric inhibition model (Grimshaw & Carmel, 2014)—demonstrate a shift from a basic dichotomy, to localizing component processes. Rather than viewing each hemisphere as an independent unitary processer, these models explain how different cortical areas—lateralised to the RH or LH—may be responsible for component processes, e.g., emotional perception, understanding, and expression (Grimshaw & Carmel, 2014). They emphasize that it is the *interaction* within, and between, the hemispheres that leads to our experience of emotion (Shobe, 2014).

Neuroimaging (EEG, PET and fMRI) research primarily informs emotional processing models by measuring neural activation during passive viewing or when making simple judgments (e.g., discriminating whether stimuli are emotional or not) of relatively simple stimuli (e.g., words, faces, objects). Although these methods shed light on cortical activation, we need behavioural methods to draw causal conclusions (Grimshaw & Carmel, 2014; Shobe, 2014) and to understand how hemispheric responsibilities influence behaviour. We seek to fill this gap. Empirical work has begun to focus on how hemispheric differences in emotional processing influence behaviour (Abbott, Cumming, Fidler, & Lindell, 2013; Borod et al., 2002). For example, eye-tracking data shows more fixations on the left than the right side of the face when judging the attractiveness of sad faces (Thomas, Wignall, Loetscher, & Nicholls, 2014). This bias to fixate on the left side of sad faces suggests RH activation occurs in response to negative facial expressions. But does this RH emotional processing bias influence *memory* the same way it influences discrimination accuracy (Calvo et al., 2015) and attractiveness ratings (Thomas et al., 2014)?

Kensinger and Choi (2009) addressed this question by testing participants' memory for photos of negative, positive, and neutral objects processed by the LH or the RH. Due to potential hemispheric differences in processing visual details[10] (e.g., Kauffmann, Ramanoel,

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[10] Over the last 30 years, researchers have proposed basic dichotomies for the lateralization of visual processing distinguishing by global vs. local processing (e.g., Volberg et al., 2009), coarse (low) vs. fine-grain (high) spatial frequencies (e.g., Kauffmann et al., 2014), and specific vs. category-based details (e.g., Burgund & Marsolek, 2000; see Hugdahl, 2000 for review). It is worth noting that while these distinctions exist, reviewing them is beyond the scope of this paper.

& Peyrin, 2014) they measured *general* (i.e., identifying test objects as the same/ similar to encoded objects) as well as *specific* recognition memory (i.e., identifying test objects as the same as encoded objects). General recognition memory was higher for emotional than neutral objects but did not differ by hemispheric processing. However, RH processing enhanced specific recognition memory of negative objects. These results reflect the complex interplay between emotional valence, hemispheric processing, and memory specificity. At present, the generalizability of this research is unknown. Therefore, we aimed to determine whether lateralised processes influence memory for more complex real-world stimuli—as opposed to isolated objects and faces—using negative and neutral (Experiment 2a) or negative and positive (Experiment 2b) naturalistic scenes.

As a secondary aim, we investigated whether a RH asymmetry for recognition memory of negative images might be associated with psychological well-being. We know that emotional scenes elicit more intense self-reported emotions than objects or faces (Thom et al., 2014). Prior research suggests depression and anxiety can alter the magnitude of lateralised emotional processing (e.g., Gotlib & Joorman, 2010; Heller, Etienne, & Miller, 1995). Thus, we measured depression, anxiety, and stress symptoms (Experiments 2a and 2b) and current Post Traumatic Stress Disorder (PTSD) symptoms (Experiment 2b) to examine any influence of these symptoms on recognition memory accuracy.

4.3 Experiment 2a

To determine whether RH processing enhances memory for negative images, we measured recognition memory for negative and neutral image pairs, presented for 500 ms, and to which attention was not actively devoted. Because emotion enhances memory accuracy (e.g., Kensinger, 2007), we predicted recognition memory to be better for negative than neutral images. Consistent with pseudoneglect memory research, we expected higher recognition memory for images encoded from the left visual field—processed by the RH—than for images encoded from the right visual field—processed by the LH. We predicted, however, that pseudoneglect would be stronger for negative than neutral images. Thus, our primary hypothesis was that valence (negative, neutral) and visual field (left, right) would interact to influence recognition memory accuracy. This prediction stems from emotional processing theories that, despite their differences, converge on RH predominance for processing negative emotions (Ahern & Schwartz, 1985; Borod et al., 2002; Grimshaw & Carmel, 2014; Shobe, 2014), which are inherently high in arousal (Heller, Nitschke, & Miller, 1998).

4.3.1 **Method**

Participants. We recruited university students who were strongly right-handed, to ensure visuospatial attention centres were in the RH (Hugdahl, 2000); they received course credit or $10.00AUD for their time. This experiment was approved by the Flinders University Social and Behavioural Research Ethics Committee. To estimate required sample size, we conducted a power analysis (G*Power) assuming a small-medium effect size ($d = 0.3$) for visual field differences on negative images. We chose this effect size due to the small-medium sized differences observed previously using similarly short image presentation times (e.g., Dickinson & Intraub, 2009). We needed a sample of at least 90 to maintain 80% power at the .05 significance level (two-tailed). To maintain counterbalancing—and achieve greater than 80% power—we increased this sample size to 108.

We excluded and replaced two participants due to technical difficulties, five who had a handedness score of less than +8 on the Flinders Handedness Survey (FLANDERS;

Nicholls, Thomas, Loetscher, & Grimshaw, 2013), three whose overall memory accuracy scores were below chance (statistically defined as 52.6% using a Fisher's Exact test), and four whose overall response times were 2SD slower than the sample mean[11] (3597.32 ms). Our analyses focus on the target sample of 108 participants (69% female, 31% male). Participants ranged from 18 to 65 years old (*M* = 22.86, 95% CI [21.24, 24.48]), had normal or corrected-to-normal vision, and were strongly right-handed (*M* = 9.76, 95% CI [9.66, 9.87]) on the FLANDERS). All participants provided written informed consent before beginning the experiment. The data are publicly available on the Open Science Framework (see http://osf.io/enkbj/).

Materials.

Depression Anxiety and Stress Scale. We used the Depression Anxiety and Stress Scale (DASS-21; Lovibond & Lovibond, 1995) to establish participants' baseline depression, anxiety, and stress. This scale consists of three 7-item subscales of depression, anxiety, and stress (e.g., *I found it difficult to relax*). Participants rated each statement on a 4-point scale (from 0 = *did not apply to me at all* to 3 = *applied to me very much, or most of the time)* according to how much it applied to them over the past week. Among our sample we observed high internal consistency (Experiment 2a: .92 overall, .88 for depression, .77 for anxiety and .87 for stress subscales; Experiment 2b: .92 overall, .88 for depression, .81 for anxiety and .81 for stress subscales).

Positive Affect Negative Affect Schedule. We used the 20-item Positive and Negative Affect Schedule (PANAS) state measure to determine whether participants' mood changed

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[11] We acknowledge that these response times are longer than what is usually observed with divided visual field paradigms. The difficulty of our memory task compared to the simpler tasks usually used in divided visual field paradigms (e.g., chimeric faces tasks: which of these faces looks happier?) and emphasising speed and accuracy equally in the experiment instructions likely drove this effect.

after image exposure (Watson, Clark, & Tellegen, 1988). Participants rated the extent to which 10 positive (e.g., *excited*) and 10 negative words (e.g., *scared*) reflected their current mood before and after image exposure, from 1 (*very slightly or not at all*) to 5 (*extremely*). Each subscale has a total score from 10 to 50, with higher scores representing more Positive Affect (PA) or Negative Affect (NA). The PANAS has excellent test-retest reliability and internal consistency for PA—ranging from .86 to .90 (.88 for Experiment 2a sample, .89 for Experiment 2b sample)—and NA—ranging from .84 to .87 (.90 for Experiment 2a sample, .87 for Experiment 2b sample). The PANAS yields excellent convergent and discriminant validity with other mood measures (Watson et al., 1988).

Images. We selected negative (themes of violence, death, injury, mutilation, disgust) and neutral images from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008)—listed in Appendix A. The IAPS includes coloured photographs normed—primarily by psychology students—on valence (1 = most negative to 9 = most positive), arousal (1 = least arousing to 9 = most arousing), and control/dominance. These photographs reliably induce desired emotional responses (e.g., Lang, Greenwald, Bradley, & Hamm, 1993; Oulton, Takarangi, & Strange, 2016). The normative ratings (Lang et al., 2008) of our selected negative images were 1.45 - 2.45 for valence ($M = 2.34$, $SD = .41$) and 4.06 - 7.35 for arousal ($M = 5.95$, $SD = .72$). The normative ratings of our selected neutral images were 4.52 - 5.49 for valence ($M = 5.01$, $SD = .26$) and 2.00 - 6.03 for arousal ($M = 3.61$, $SD = .81$). We matched the two images in each negative-negative or neutral-neutral pair to within 0.04 on both valence and arousal. We also created mirror-reversals of each image to rule out idiosyncrasies in the scene—specifically differences on the left and right sides (Dickinson & Intraub, 2009)—from influencing recognition memory. We counterbalanced the images, and their mirror-reversals, to create 36 versions of the experiment.

There were 96 pairs of negative and 96 pairs of neutral images, which we divided into 3 sets of 32 pairs. Participants saw two sets of images during encoding (‘seen’ images). Within each encoding pair, we classified either the left or the right visual field image as the target, tested on recognition trials. We did not present the third image set (‘unseen’ images) on encoding trials. For recognition trials, we paired each ‘seen’ image with an ‘unseen’ image. Test images were placed vertically, 4.12° from each other (aligned 1.95° from the top/bottom and 17.06° from the side of the screen) to make the location of the image at testing orthogonal to the location at encoding. We counterbalanced test images so that ‘seen’ and ‘unseen’ images appeared equally often at the top and the bottom of the screen.

Procedure. Following consent, participants completed the Depression Anxiety and Stress Scale (DASS-21; Lovibond & Lovibond, 1995), PANAS, and FLANDERS. They then completed the combined encoding and recognition phase—administered by E-Prime 2.0—individually at a computer. A chin rest ensured the participant’s head maintained a fixed position throughout the experiment, 500 mm from the screen, to avoid changes in visual angle (Bourne, 2006). We used a modified divided visual field paradigm: a central fixation cross (font: courier new, 18 pt, bold) appeared alone for 500 ms, then accompanied by a negative or neutral image pair for 500 ms. Each image (width: 14.93°, height: 11.19°) appeared 2.3° from the fixation cross and the opposing edge of the image aligned 1.7° from the end of the screen. The positioning of the images relative to fixation maximized unilateral processing, because it ensured the majority of each image was located in the intended visual field—rather than the region of overlap between the visual fields (Bourne, 2006). We instructed participants to concentrate on the fixation cross throughout the experiment and avoid actively attending to the images.

We acknowledge that 500 ms is a longer encoding time than many traditional divided visual field paradigms and is sufficient to allow each hemisphere to contribute to processing the images. However, our interest in memory performance precluded the use of extremely brief presentation times (e.g., the 120 - 180 ms presentation time range Bourne (2006) recommends)[12]. Importantly, hemispheric asymmetries are not restricted to divided visual field paradigms; they can be reliably elicited with free viewing paradigms (see Voyer, Voyer, & Tramonte, 2012). Further, Dickinson and Intraub (2009) observed a left visual field memory bias for neutral visual scenes presented for 500 ms with central fixation. These findings provide evidence that 500 ms is an appropriate presentation time for examining a left visual field memory bias, especially when participants maintain central fixation. To ensure central fixation, an additional 20 participants completed the experiment while being eye-tracked[13].

As Figure 4.1A shows, fixations were concentrated on the central fixation cross. These data confirm that our participants did not visually examine the images; thus, we are confident that our participants maintained central fixation, and did not divert their attention toward the image pairs. Furthermore, overall memory accuracy was comparable in our eye tracking and our primary sample (*M* = .71 vs. .72 respectively), *d* = 0.14. Importantly we found the same pattern of results for our key analysis—recognition memory accuracy for negative vs. neutral images encoded from the right vs. left visual field—in our eye-tracked

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[12] We conducted a pilot experiment (*N* = 36) to determine whether 250ms was a viable presentation time. Memory performance was below chance (determined for this experiment as 52.6% using a binomial test to account for variability in 'chance') among 36% of our pilot sample. Therefore, these results confirmed our assumption that, due to our interest in memory performance, we could not use presentation times of 250 ms (and below).

[13] We decided post-hoc to eye track an additional group of participants in the same procedure. We collected an additional 20% of our full sample size, due to resource limitations. These participants (*N* = 20) are not included in our primary analyses.

and primary samples (summarized in the results section).

Figure 4.1. Heat maps demonstrating overall pattern of eye-movements on **(A)** negative and neutral (Experiment 2a: separate sample) and **(B)** negative and positive (Experiment 2b: subset of main sample) image pairs. Colors represent fixation frequency, progressing from red (dark grey: most) to yellow to green (light grey: least). These colors show fixations were primarily focused on the central cross, with slight deviations across the horizontal and vertical axes.

We used a two alternative forced-choice testing paradigm[14] to increase accuracy in recognizing 'seen' images. Given visual short-term memory capacity is four items or less, test items occurred at random intervals, between five and eight items after the target item was initially shown (Cowan, 2000). This placement ensured the image had passed through visual short-term memory and into visual long-term memory, which has the capacity to store a large number of detailed scene representations (see Brady, Konkle, & Alvarez, 2011 for review). On test items, participants identified which image they had previously seen by pressing a key labelled 'TOP' or a key labelled 'BOTTOM'. In line with several recognition memory paradigms, we measured participants' retrospective confidence (Busey, Tunnicliff, Loftus, & Loftus, 2000; Roediger, Wixted, & Desoto, 2012) in each answer using 10% increments labelled on the keyboard. We provided anchors of 0% (*completely guessing*) to 100% (*entirely confident*). Halfway through the experiment, participants took a short break to re-engage their attention, before continuing. We recorded response times for recognition judgments and stressed speed—by asking participants to respond as quickly as possible—and accuracy—by asking participants to be as accurate as possible in making their selection—equally in the experiment instructions. After the combined encoding and recognition phase, participants completed the PANAS a second time. Debriefing procedures concluded the 30-minute session.

4.3.2 **Results**

We first examined whether exposure to negative images worsened participants' mood.

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[14] Forced choice tests might encourage people to "listen" to their gut feeling more than if they were given an opportunity to ignore this feeling, as in an old/new or yes/no paradigm (e.g., Voss, Baym, & Paller, 2008). Therefore, in forced-choice testing paradigms, the amount of evidence needed to make a decision may remain constant throughout the task (Green & Swets, 1974).

Indeed, time (pre, post) and affect (positive, negative) interacted to predict PANAS scores, $F(1, 107) = 100.37, p < .001, \eta_p^2 = .48$. After photo exposure participants reported a significant decrease in positive ($M = 20.56$, 95% CI [18.65, 22.47]) accompanied by a significant increase in negative ($M = 16.93$, 95% CI [15.02, 18.84]) affect compared to their baseline mood (PA: $M = 26.67$, 95% CI [24.76, 28.58], $t(107) = 10.71, p < .001, d = 1.04$; NA: $M = 14.04$, 95% CI [12.13, 15.95], $t(107) = -4.60, p < .001, d = -0.46$).

Next, we turned to our primary research question: whether visual field (left, right) and valence (negative, neutral) interact to influence recognition memory. We excluded response times for memory judgments that were > 3*SD* from each individual's mean from analyses (1.4% of all judgments). Because we used a forced-choice testing paradigm, correctly recognizing a 'seen' image (i.e., a hit) is the same as rejecting an 'unseen' image (i.e., a correct rejection). Similarly, incorrectly rejecting the 'seen' image (i.e., a miss) is the same as incorrectly recognizing the 'unseen' image (i.e., a false alarm). Recognition memory accuracy—our key dependent variable—refers to hit rates, i.e., the proportion of test items where participants correctly recognised the target image.

We ran a 2 (valence: negative, neutral) x 2 (visual field: left, right) repeated-measures ANOVA (see Figure 4.2A). We found a main effect of visual field, $F(1,107) = 9.52, p = .003, \eta_p^2 = .08$; participants recognised a higher proportion of images presented in the left ($M = .73$, 95% CI[15] [.72, .75]) than the right visual field ($M = .71$, 95% CI [.69, .73]). For valence, we found—contrary to our hypothesis—that participants recognised a higher proportion of neutral images ($M = .74$, 95% CI [.72, .76]) than negative images ($M = .70$, 95% CI [.68, .72]), $F(1,107) = 11.20, p < .001, \eta_p^2 = .10$. Consistent with our primary hypothesis, valence

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[15] We report within-subject 95% CIs for all analyses (Masson & Loftus, 2003).

and visual field interacted to influence recognition memory, $F(1,107) = 4.59$, $p = .035$, $\eta_p^2 = .04$. Paired samples *t*-tests (Bonferroni-corrected *p*-value = .025) showed that participants correctly identified a higher proportion of negative images that were encoded from the left ($M = .72$, 95% CI [.70, .74]) than negative images encoded from the right ($M = .68$, 95% CI [.66, .70]) visual field, $t(107) = 3.83$, $p < .001$, $d = 0.37$. However, visual field did not affect recognition memory for neutral images; memory accuracy was similar for neutral images encoded from the left ($M = .75$, 95% CI [.73, .77]) and the right ($M = .74$, 95% CI [.72, .76]) visual field, $t(107) = .99$, $p = .325$, $d = 0.10$. We also isolated recognition memory for negative and neutral images within each visual field. For images presented in the left visual field only, we found no significant difference in recognition memory accuracy for negative compared to neutral images, $t(107) = -1.93$, $p = .06$, $d = -0.20$. By contrast, recognition memory accuracy was significantly lower for negative than neutral images presented in the right visual field, $t(107) = -4.02$, $p < .001$, $d = -0.40$.

Similar to our primary sample, eye-tracked participants ($n = 20$, $M_{\text{age}} = 21.15$ years, 85% female, 15% male) more accurately identified neutral ($M = .73$, 95% CI [.70, .76]) compared to negative ($M = .68$, 95% CI [.65, .71]) images ($F(1, 19) = 11.54$, $p = .003$, $\eta_p^2 = .38$) and images presented in the left ($M = .73$, 95% CI [.70, .76]) compared to the right ($M = .69$, 95% CI [.66, .72]) visual field ($F(1, 19) = 9.93$, $p = .005$, $\eta_p^2 = .34$). Valence and visual field interacted to predict recognition memory accuracy ($F(1, 19) = 6.78$, $p = .020$, $\eta_p^2 = .26$); participants correctly identified a higher proportion of negative images that were encoded from the left ($M = .72$, 95% CI [.69, .75]) than negative images encoded from the right ($M = .64$, 95% CI [.61, .67]) visual field ($t(19) = 3.15$, $p = .005$, $d = 1.05$), while visual field did not affect recognition memory for neutral images (left visual field: $M = .74$, 95% CI [.71, .77], right visual field: $M = .73$, 95% CI [.70, .76]), $t(19) = -3.40$, $p = .003$, $d = 0.10$.

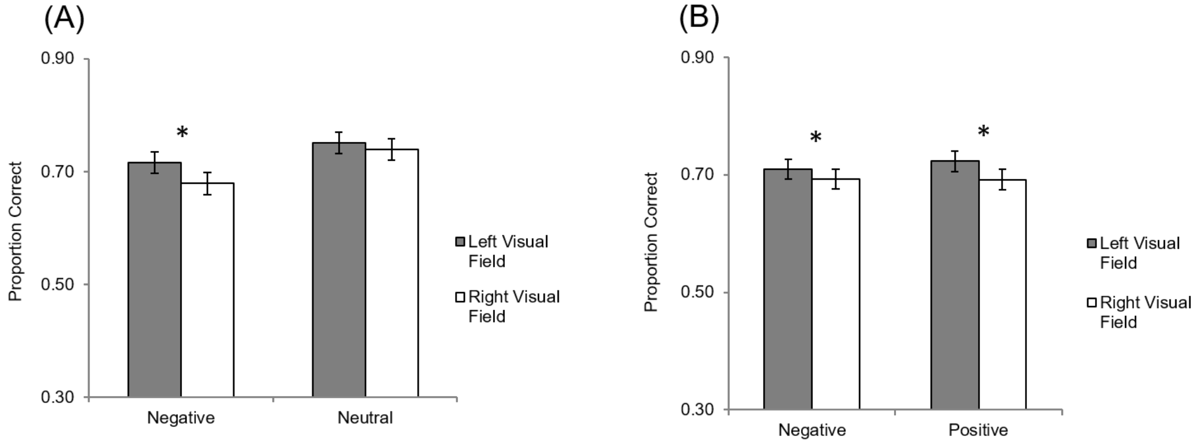

Figure 4.2. Mean proportion of images correctly recognised depending on valence and visual field. Y-axis only includes hit rates achieved by participants. Error bars represent within-subject 95% CIs (Masson & Loftus, 2003). * indicates significant differences ($p < .05$). **(A)** Experiment 2a: negative vs. neutral images. **(B)** Experiment 2b: negative vs. positive images.

These data support four key conclusions: first, that memory for briefly presented negative scenes is worse when these scenes appear in the right visual field (LH processing) compared to the left visual field (RH processing). Second, contrary to prior research, this right visual field disadvantage does not influence memory for neutral scenes. Third, recognition memory for negative images is worse than neutral images, only when these images appear in the right visual field. Fourth, counter to the emotional enhancement of memory effect (e.g., Kensinger, 2007), participants correctly recognised neutral more often than negative scenes, particularly when these scenes appeared in the right visual field. To assess these conclusions further, we examined participants' confidence in their recognition memory.

To confirm that confidence aligned with recognition memory accuracy, we calculated resolution for each participant, using Goodman and Kruskal's gamma correlation (Dunlosky

& Metcalfe, 2009). This correlation is based on the number of correct vs. incorrect responses the participant provided at each of the 11 possible confidence ratings (0 - 100%). Across our sample, mean within-participant gamma correlation was positive but moderate ($M = .47$, 95% CI [.44, .51]). We used two 2 (valence: negative, neutral) x 2 (visual field: left, right) repeated-measures ANOVAs—one for correct and one for incorrect answers—to analyze confidence ratings[16].

We first turn to confidence ratings (%) for correct answers (see Figure 4.3A). We found a small, but significant, main effect of visual field; participants reported higher confidence for images encoded from the left ($M = 58.6$, 95% CI [57.2, 60.0]) than the right ($M = 57.1$, 95% CI [55.7; 58.5]) visual field, $F(1, 104) = 4.60, p = .03, \eta_p^2 = .04$. Unlike recognition memory accuracy, we found no main effect of valence, $F(1, 104) = 1.04, p = .31, \eta_p^2 = .05$. Valence and visual field interacted to predict participants confidence ratings on correct answers, $F(1, 104) = 6.27, p = .01, \eta_p^2 = .06$. Paired samples t-tests revealed that—unlike recognition memory accuracy—this interaction was driven by higher confidence on neutral images encoded from the left ($M = 59.8$, 95% CI [58.4, 61.2]) than the right ($M = 56.6$, 95% CI [55.2, 58.0]) visual field, $t(104) = 2.95, p = .004, d = 0.29$. By contrast, confidence ratings were similar for negative images encoded from the left ($M = 57.4$, 95% CI [56.0, 58.8]) and right ($M = 57.6$, 95% CI [56.2, 59.0]) visual fields, $t(104) = -.24, p = .81, d = -0.02$. For images presented in the left visual field only, participants were more confident for correctly recognised neutral than negative images, $t(104) = -2.49, p = .01, d = 0.25$. By contrast, for images presented in the right visual field, confidence ratings were similar for

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[16] We excluded three participants from these confidence analyses: one who used the confidence scale incorrectly and two who had incomplete data because they achieved 100% accuracy on neutral images (i.e., no data were available for neutral, incorrect responses). From the remaining data we excluded 0.40% of confidence responses, where participants responded using incorrect keys.

correctly recognised neutral and negative images, *t*(104) = .93, *p* = .36, *d* = -0.09.

Unlike confidence ratings for correct answers, we found no main effect of visual field for incorrect answers (see Figure 4.3B), *F*(1, 104) = 1.71, *p* = .19, $ŋ_p^2$ = .02. We found a main effect of valence, *F*(1, 104) = 25.22, *p* < .001, $ŋ_p^2$ = .20; participants gave higher confidence ratings on incorrect negative (*M* = 36.9, 95% CI [35.0, 38.8]) than neutral images (*M* = 31.6, 95% CI [29.8, 33.5]). This valence main effect was qualified by an interaction between valence and visual field, *F*(1, 104) = 6.77, *p* = .01, $ŋ_p^2$ = .06. Confidence ratings for neutral incorrect answers were higher for images encoded from the left (*M* = 33.4, 95% CI [31.5, 35.3]) than the right (*M* = 29.9, 95% CI [28.0, 31.8]) visual field, *t*(104) = 2.75, *p* = .007, *d* = 0.27. By contrast, confidence ratings for negative incorrect answers were similar regardless of whether images were encoded from the left (*M* = 36.4, 95% CI [34.5, 38.3]) or the right (*M* = 37.4, 95% CI [35.5, 39.3]) visual field, *t*(104) = -.78, *p* = .44, *d* = -0.08. For images that appeared in the left visual field only, confidence was slightly higher for incorrect negative than neutral answers, *t*(104) = 2.28, *p* = .03, *d* = -0.21. This effect—higher confidence on negative than neutral incorrect answers—was larger for images presented in the right visual field, *t*(104) = 5.59, *p* < .001, *d* = -0.47.

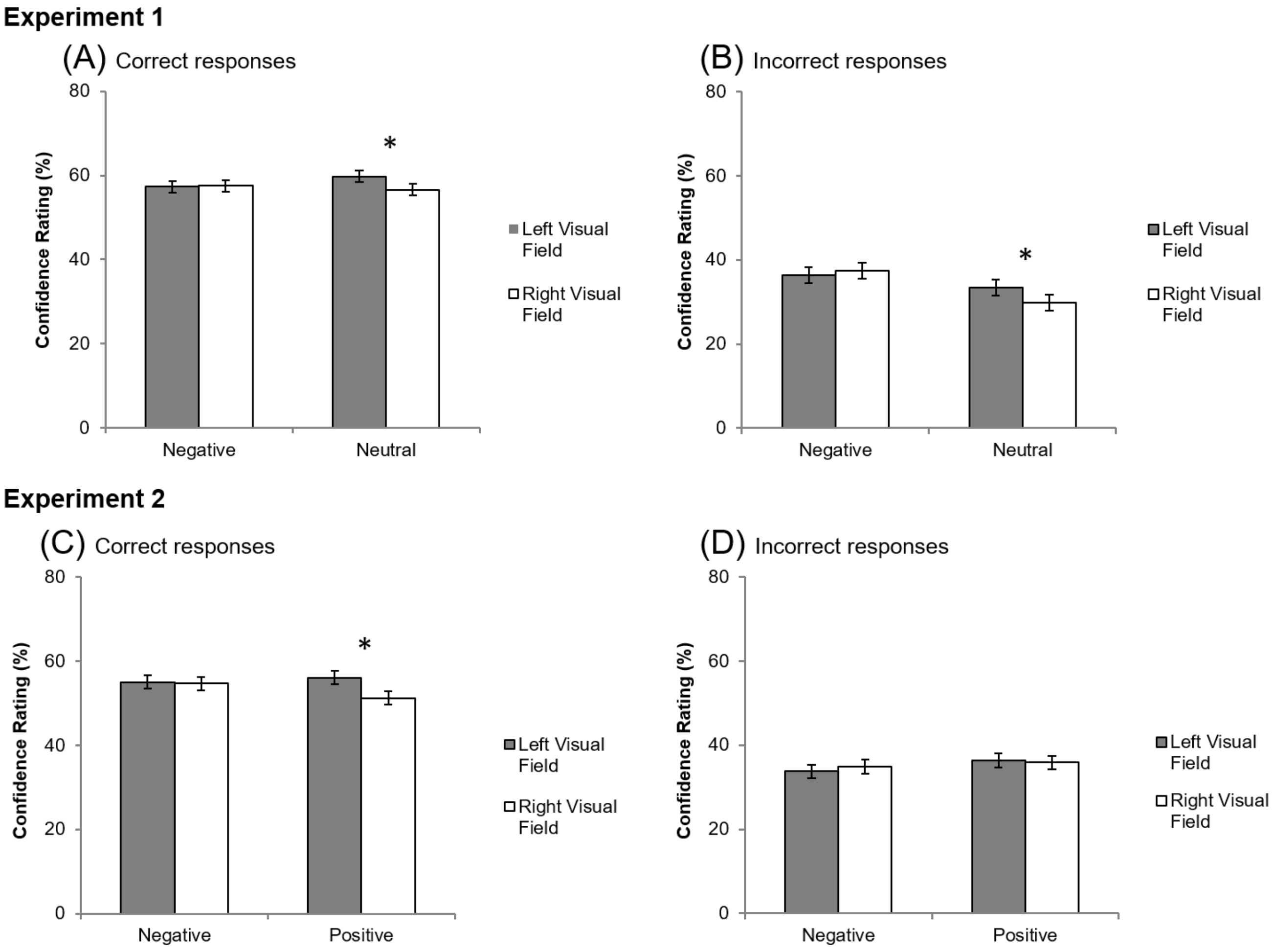

Figure 4.3. Mean confidence ratings in Experiment 2a and 2b depending on valence and visual field. Error bars represent within-subject 95% CIs (Masson & Loftus, 2003). * indicates significant differences (p < .05). (**A**) Experiment 2a: negative vs. neutral images, correct responses. **(B)** Experiment 2a: negative vs. neutral images, incorrect responses. **(C)** Experiment 2b: negative vs. positive images, correct responses. (**D**) Experiment 2b: negative vs. positive images, incorrect responses.

To assess whether valence and visual field also influenced response speed of memory judgments, we next looked at response time (ms) data (see Figure 4.4A). Participants were significantly slower on test items that were encoded from the left (M = 3511, 95% CI [3431, 3591]) than the right (*M* = 3343, 95% CI [3263, 3423]) visual field, *F*(1,107) = 23.64, $p < .001$, $\eta_p^2 = .18$, despite higher accuracy for left side items. Participants were also slower on negative (*M* = 3682, 95% CI [3602, 3762]) compared to neutral (*M* = 3172, 95% CI [3092, 3252]) test items, a main effect of valence, *F*(1,107) = 86.21, $p < .001$, $\eta_p^2 = .45$. In contrast to our recognition memory data, valence and visual field did not interact to predict response time, *F*(1,107) = .002, $p = .96$, $\eta_p^2 = .000$.

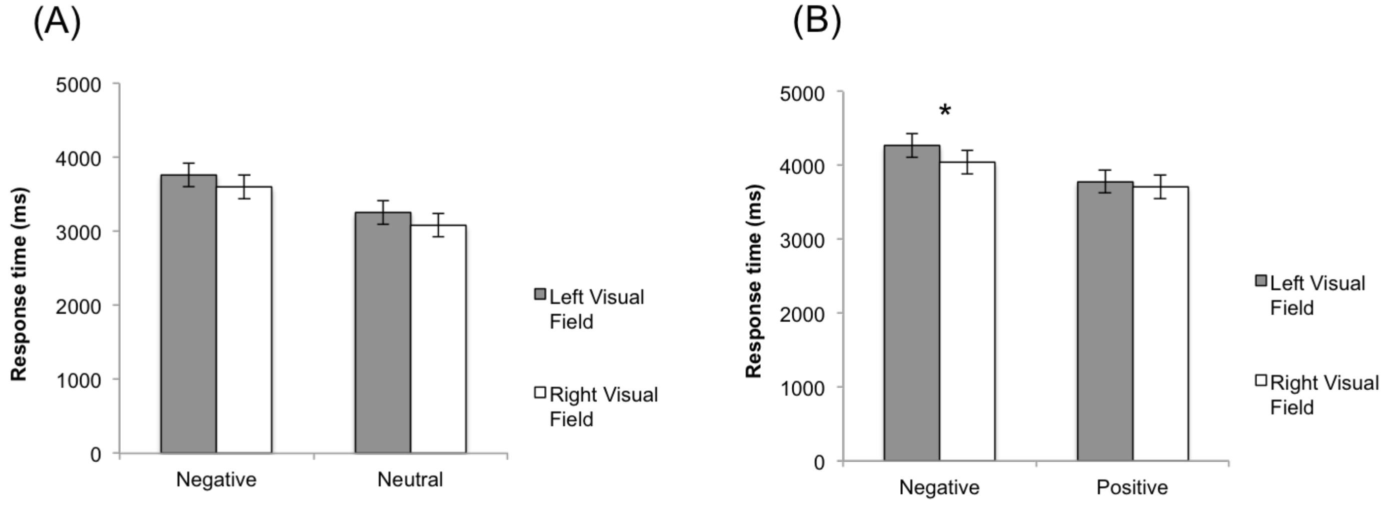

Figure 4.4. Mean response time (ms) for recognition memory judgments. Error bars represent within-subject 95% CIs (Masson & Loftus, 2003). * indicates significant differences (p < .05). **(A)** Experiment 2a: negative vs. neutral images. **(B)** Experiment 2b: negative vs. positive images.

Finally, we assessed any association between memory accuracy and symptom scores. Mean DASS-21 scores were “normal” according to the ranges described by Lovibond and Lovibond (1995) (depression: *M* = 4.25, 95% CI [3.45, 5.05]; normal: 0 - 7, anxiety: *M* = 3.70, 95% CI [3.04, 4.37], normal: 0 - 9; stress: *M* = 6.63, 95% CI [5.77, 7.48], normal: 0 - 14). There were no significant correlations between subscale scores and recognition memory of negative or neutral images (*r* values = .04 to .19, all *p* values > .05). Similar to depression, anxiety, and stress ratings change in positive or negative affect—as measured by the PANAS (Watson et al., 1988)—from before to after viewing the images did not correlate with recognition memory of negative or neutral images (*r* values = -.13 to .19).

4.3.3 **Discussion**

Experiment 2a demonstrates that recognition memory for negative images is worse when these images are encoded from the right than the left visual field. By contrast, memory for neutral images is similar regardless of the visual field they appear within. Because recognition memory for negative images is worse than neutral images only when these images appear in the right visual field, these data can be interpreted as a LH deficit for recognition memory of negative images. Our Experiment 2a findings fit with data from Kensinger and Choi (2009); their participants had worse recognition memory for visual details of negative objects processed by the LH compared to the RH. We extended their findings by measuring recognition memory for visual scenes, which are naturally higher in visual detail than photos of isolated objects (Brady et al., 2011).

Experiment 2a is limited because comparing negative and neutral images introduces an arousal confound. Arousal increases when normal physiological functions are intensified, e.g., by viewing emotionally-charged stimuli (Perkins, Wilson, & Kerr, 2001). As is true in our experiment, neutral stimuli have significantly lower arousal ratings because they do not intensify normal physiological functions. Therefore, we wondered: are visual-field differences in recognition memory driven by arousal or emotional valence? Answering this question has theoretical significance for the circumplex model of emotional processing (e.g., Heller, 1993), which posits that differences in hemispheric activation in posterior cortices relate to differences in arousal.

To address this question, we ran a second experiment comparing negative and positive images. This experiment allows us to separate the influence of valence and arousal, because positive and negative images differ on valence but can be matched on arousal. Further, it addresses a limitation of existing studies investigating hemispheric asymmetries in emotional processing, which rarely include both positive and negative stimuli (Grimshaw & Carmel, 2014). This research is important, because recent papers have failed to support LH specialization in processing positive emotions (Shobe, 2014) predicted by emotional processing theories (e.g., valence-specific hypothesis and the circumplex, hemispheric independence and collaboration, and asymmetric inhibition models).

4.4 Experiment 2b

If both hemispheres can independently process positive stimuli, we should not see any visual field differences for positive images. By contrast, negative images should be correctly recognised less often when encoded from the right than the left visual field. Alternatively, the RH hypothesis (e.g., Borod et al., 2002) predicts that *both* positive and negative images will be correctly recognised less often when encoded from the right than the left visual field—indicated by a main effect of visual field, but no interaction.

4.4.1 **Method**

Participants. We sourced participants from the university pool and the wider community. We excluded and replaced five participants due to technical difficulties and eight whose overall memory accuracy scores were below chance (statistically defined as 51.86% using a Fisher's Exact test). Analyses focused on our target sample of 108 participants (university pool: 102, wider community: 6, 71% female, 29% male), 18 of whom were eye-tracked. Participants ranged from 18 to 48 years old ($M = 22.19$, 95% CI [21.04, 23.33]), had normal or corrected-to-normal vision, and were strongly right-handed (*M* = 9.43, 95% CI [9.14, 9.73] on the FLANDERS). As in Experiment 2a, all participants provided written informed consent before beginning the experiment. We pre-registered Experiment 2b on the Open Science Framework (see https://osf.io/5yc8g/) where the data are publicly available (see http://osf.io/enkbj/).

Materials

Images. We aimed to source positive images matching our existing negative images on arousal; unfortunately, many positive images in the IAPS database were not high enough on arousal. Therefore, we selected new negative and positive images from the Nencki Affective Picture System (NAPS: Marchewka, Zurawski, Jednorog, & Grabowska, 2014) to supplement our Experiment 2a IAPS images—listed in Appendix A. The NAPS database includes recent (i.e., from 2006-2012) colour photographs from five categories (people, faces, animals, objects, landscapes) rated by 204 healthy Polish adults on valence (1 = very negative to 9 = very positive), and arousal (1 = relaxed to 9 = aroused). Pooled across both databases and their normative ratings (IAPS and NAPS), selected negative images were rated 1.45 - 3.96 on valence (*M* = 2.63, *SD* = .02), and 4.06 - 7.35 on arousal (*M* = 5.79, *SD* = .04). Positive images were rated 6.07 - 8.34 on valence (*M* = 6.98, *SD* = .01) and 4.98 - 7.35 on arousal (*M* = 5.77, *SD* = .09).

To obtain similar arousal means between the positive and negative images, we made three concessions to our Experiment 2a image selection criteria. First, we reduced the number of image pairs for each valence from 96 to 81 (i.e., three sets of 27). Second, we were less stringent on the range of valence ratings for our negative images but ensured that all negative images were rated below 4 (i.e., definitely negative and not neutral). Third, we broadened our criterion for matching images within each pair from 0.04 to 0.20 for valence and 0.30 for arousal.

PTSD checklist for DSM-5. We added the PTSD checklist for DSM-5 (PCL-5; Weathers et al., 2013) to examine the association between current PTSD symptoms and visual field differences for recognition memory of negative stimuli. The PCL-5 is a 20-item self-report measure of PTSD symptoms, in line with symptomology listed in the DSM-5 (American Psychiatric Association, 2013). We asked participants to think of their most stressful/traumatic event, and gave them the option to disclose it. With this event in mind, they indicated how much each problem/symptom related to that event (e.g., *repeated, disturbing, and unwanted memories of the stressful experience)* has bothered them in the past month from 0 (*not at all*) to 4 (*extremely*). The PCL-5 provides an overall PTSD score (from 0 to 80), as well as four symptom cluster scores—re-experiencing (from 0 to 20), avoidance (from 0 to 8), negative alterations in cognition and mood (from 0 to 28), and hyperarousal (from 0 to 24). The PCL-5 holds strong internal consistency ($\alpha = .94$; .94 for our sample) and test-retest reliability ($r = .82$; Blevins, Weathers, Davis, Witte, & Domino, 2015).

***Procedure*.** Our procedure was identical to Experiment 2a, but we added the PTSD Checklist for DSM-5 (PCL-5; Weathers et al., 2013) after the second PANAS. Although we had fewer image pairs, adding the PCL-5 kept the overall experiment length consistent (approximately 30 minutes). We also conducted the combined encoding and recognition phase in a darkened room[17]. We eye-tracked[18] a subset of participants ($n = 18$) who confirmed fixations were concentrated on the central fixation cross (see Figure 4.1B).

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[17] Darkened rooms increase the likelihood of contralateral processing because the darkness removes the possibility of biased responding due to one side of the room being lighter than the other (Bourne, 2006).

[18] The eye-tracked participants are included in the main analyses for Experiment 2b because they—unlike in Experiment 2a—comprise a subset of the target sample.

4.4.2 Results

We first examined whether exposure to positive images reduced the influence of negative images on mood. Similar to Experiment 1, time (pre, post) and affect (positive, negative) interacted to predict PANAS scores, $F(1, 107) = 64.47$, $p <.001$, $\eta_p^2 = .38$. After photo exposure, participants reported a significant decrease in PA ($M = 20.73$, 95% CI [19.58, 21.88]) accompanied by a significant increase in NA ($M = 18.16$, 95% CI [17.01, 19.31]) compared to their baseline mood (PA: $M = 25.88$, 95% CI [24.73, 27.03], $t(107) = 8.03$, $p < .001$, $d = 0.77$; NA: $M = 15.76$, 95% CI [14.61, 16.91], $t(107) = -4.11$, $p < .001$, $d = -0.40$. The effect size reduction in PA was medium ($d = 0.77$) whereas in Experiment 1 it was large ($d = 1.04$) suggesting that presenting negative and *positive* images led to a smaller mood reduction than presenting negative and *neutral* images.

Next, we looked at recognition memory (Figure 4.2B) excluding memory judgments where response times fell > 3*SD* from each individual's mean (1.18%). In line with Experiment 1, we found a main effect of visual field, $F(1,107) = 9.81$, $p = .01$, $\eta_p^2 = .06$; participants recognised a lower proportion of images presented in the right ($M = .69$, 95% CI [.67, .71) than the left ($M = .72$, 95% CI [.70, .73]) visual field. Contrary to Experiment 1, we found no influence of valence on recognition memory accuracy; participants recognised a similar proportion of negative ($M = .70$, 95% CI [.68, .72]) and positive images ($M = .71$, 95% CI [.69, .72), $F(1,107) = .56$, $p = .46$, $\eta_p^2 = .005$. Also contrary to Experiment 1, there was no interaction between valence and visual field, $F(1,107) = .75$, $p = .39$, $\eta_p^2 = .007$; memory for positive and negative scenes was similarly decreased when they appeared in the right (negative: $M = .69$, 95% CI [.68, .71]; positive: $M = .69$, 95% CI [.68, .71]) compared to the left (negative: $M = .71$, 95% CI [.69, .73]; positive: $M = .72$, 95% CI [.70, .74]) visual field.

We next examined participants' confidence[19] in their recognition memory. Across our Experiment 2b sample, gamma correlation was moderate ($M = .43$, 95% CI [.43, .46]). For correct responses (see Figure 4.3C), we found a main effect of visual field in line with our recognition memory result; participants were less confident in correct responses for images encoded from the right ($M = 52.9$, 95% CI [51.4, 54.5]) than the left ($M = 55.5$, 95% CI [53.97, 57.06]) visual field, $F(1, 106) = 9.02$, $p = .003$, $\eta_p^2 = .08$. We found no difference in confidence depending on valence, $F(1, 106) = 2.26$, $p = .14$, $\eta_p^2 = .02$; participants were equally confident in their correct responses for negative ($M = 54.8$, 95% CI [53.3, 56.4]) and positive ($M = 53.6$, 95% CI [52.1, 55.2]) images. Unlike recognition memory, valence and visual field interacted to predict confidence ratings $F(1, 106) = 10.57$, $p = .002$, $\eta_p^2 = .09$. Paired samples t-tests revealed that this main effect was driven by a visual field difference for positive but not negative images. For positive images, participants were significantly less confident in their responses for items encoded from the right ($M = 51.2$, 95% CI [49.7, 52.8]) than the left ($M = 56.0$, 95% CI [54.5, 57.6]) visual field, $t(106) = 4.22$, $p < .001$, $d = 0.42$. For negative images, however, confidence was similar for items encoded from the right ($M = 54.7$, 95% CI [53.1, 56.2]) and the left ($M = 55.0$, 95% CI [53.5, 56.6]) visual field, $t(106) = .32$, $p = .75$, $d = 0.03$. To look closer at this interaction we isolated confidence ratings on correct answers within each visual field. Participants made similar confidence ratings for positive and negative images presented in the left visual field, $t(106) = -.92$, $p = .36$, $d = 0.09$, but were more confident for negative than positive images presented in the right visual field, $t(106) = 3.40$, $p = .001$, $d = -0.33$.

For incorrect answers (see Figure 4.3D) confidence was similar regardless of visual

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[19] We excluded one participant who used the confidence scale incorrectly. From the remaining data we excluded 0.78% of confidence responses, where participants responded using incorrect keys.

field ($F(1, 106) = .17$, $p = .69$, $\eta_p^2 = .00$) and valence ($F(1, 106) = 3.52$, $p = .06$, $\eta_p^2 = .03$). Unlike correct answers, we found no interaction between valence and visual field for confidence ratings on incorrect answers, $F(1, 106) = 1.22$, $p = .27$, $\eta_p^2 = .01$.

We next looked at response time (ms) data (see Figure 4.4B). Like Experiment 2a, participants were significantly slower on test items that appeared in the left ($M = 3878$, 95% CI [3799, 3957]) than the right ($M = 4025$, 95% CI [3946, 4104]) visual field ($F(1,107) = 19.37$, $p < .001$, $\eta_p^2 = .15$) despite higher accuracy for left side items. They were also slower on negative ($M = 4156$, 95% CI [4077, 4235]) compared to positive ($M = 3747$, 95% CI [3668, 3826]) test items ($F(1,107) = 60.82$, $p < .001$, $\eta_p^2 = .36$) even though we found no difference in recognition memory accuracy by valence. However, these main effects were qualified by an interaction between valence and visual field, $F(1,107) = 5.52$, $p = .02$, $\eta_p^2 = .05$; participants made faster responses for right, compared to left, visual field negative ($t(107) = 4.78$, $p < .001$, $d = 0.47$; Bonferroni-corrected p-value = .025) but not positive ($t(107) = 1.59$, $p = .11$, $d = 0.15$) items. Response times were consistently slower for negative than positive items when these images appeared in the left ($t(107) = 7.40$, $p < .001$, $d = -0.69$) and the right ($t(107) = 5.89$, $p < .001$, $d = -0.55$) visual field.

Symptom Scores. Consistent with Experiment 2a, mean scores on baseline measures of depression, anxiety, and stress (DASS-21) were “normal” (depression: $M = 5.13$, 95% CI [4.29, 5.95]; normal: 0-7, anxiety: $M = 4.50$, 95% CI [3.73, 5.27], normal: 0-9; stress: $M = 7.24$, 95% CI [6.42, 8.06], normal: 0-14; Lovibond & Lovibond, 1995). Baseline symptomology was not related to memory for the images; there were no significant correlations between subscale scores and recognition memory of negative or positive images (r values = -.003 to -.10). Change in positive or negative affect did not correlate with recognition memory of negative or positive images (r values = -.04 to .06).

One participant did not complete the PCL-5, leaving 107 useable participants. Mean total PTSD symptom scores were low (*M* = 23.50, 95% CI [20.36, 26.63], range: 0 – 65). Scores were also low for the four subscales; re-experiencing (*M* = 12.38, 95% CI [9.70, 15.06]), avoidance (*M* = 3.25, 95% CI [3.78, 3.72]), negative alterations in cognition and mood (*M* = 7.92, 95% CI 6.77, 9.06]), and hyperarousal (*M* = 6.81, 95% CI [5.71, 7.92]). Approximately one third (30.8%) of our participants showed probable PTSD diagnosis (using a cut-off score of 33; Weathers et al., 2013) for symptoms experienced in the last month, in relation to their worst stressful/traumatic event.

We then examined whether participants' current level of PTSD symptomology related to their recognition memory accuracy. We found no correlation between overall PCL-5 scores and recognition memory accuracy for positive or negative images, regardless of which visual field they appeared in: positive: left ($r = .06$, $p = .55$), right ($r = .01$, $p = .91$); negative: left ($r = .14$, $p = .14$), right ($r = -.05$, $p = .63$).

4.4.3 **Discussion**

Experiment 2b replicated our prior finding that recognition memory for negative images is worse when these images are encoded from the right visual field—and initially processed by the LH—than when they are encoded from the left visual field—and initially processed by the RH. This right visual field disadvantage also occurred for positive images, suggesting LH processing decreases recognition memory for *emotional,* not just negative, images.

Recall that we matched our positive and negative image sets on arousal, meaning that they only differed on emotional valence. Our data shed light on hemispheric asymmetries when valence is isolated. However, they also allow us to speculate about the role of arousal.

When positive and negative stimuli were matched on arousal, LH processing, compared to RH processing, worsened recognition memory for positive and negative images. We did not find evidence of any hemispheric specialization. Therefore, perhaps the hemispheric specialization observed in prior research from which the valence hypothesis is based (e.g., Jansari et al., 2011)—where positive and negative stimuli may be compared without controlling for arousal—is driven by differences in arousal, rather than valence (though note, there were a number of other differences in the methods between the present study and Jansari et al., (2011), namely faces vs. complex scenes). This speculative suggestion fits with the circumplex model of emotion (Heller, 1993), which states the posterior RH is predominant in processing high-arousal stimuli, while the posterior LH is predominant in processing low-arousal stimuli; though we note that our experiment cannot discriminate between posterior and anterior cortical processes. Future research should investigate the possibility that hemispheric differences are due to arousal rather than valence by systematically manipulating arousal and valence (as in O'Hare, Atchley, & Young, 2017).

4.5 General Discussion

Our findings suggest lateralised component processes do manifest to influence recognition memory of emotional images. Across both experiments, recognition memory was worse for emotional images (positive and negative) initially processed by the LH, compared to the RH. This decrease in recognition memory accuracy with LH processing occurred for emotional, but not neutral, images. Second, memory accuracy was similar for all neutral images and emotional images initially processed by the RH. This finding fits with the hemispheric independence and collaboration model (Shobe, 2014), which posits the RH can process emotional information of any valence on first perception, highlighting the importance of the RH in initial and automatic emotional processing.

Our data suggests a LH deficit for processing emotional images decreases recognition memory accuracy for these images. This interpretation is in line with the idea (e.g., Kensinger and Choi, 2009) that the LH lacks specialization in emotional processing. But if the LH lacks specialization in *initially* perceiving emotions, at what point might it contribute to emotional processing? Shobe (2014) states the LH plays a role in conscious emotional processing, where it provides a 'secondary interpretation' based on information provided by the RH. This 'secondary interpretation' is positively biased and contributes to executive functioning, emotional regulation, well-being, and knowledge. For example, people who show default LH activation asymmetries to emotional stimuli demonstrate adaptive responses to social threats (e.g., the threat of social rejection; Koslov, Mendes, Pajtas, & Pizzagalli, 2011). They also have attenuated startle responses following, but not during, negative stimulus processing (Jackson et al., 2003). These examples demonstrate both the importance and the adaptive benefit of LH activation in emotional regulation, i.e., increasing or decreasing emotional intensity to maximize well-being.

We found no hemispheric differences in recognition memory accuracy for neutral images; an effect that counters existing pseudoneglect research (Della Sala et al., 2010; Dickinson & Intraub, 2009; McGeorge et al., 2007; Petrini et al., 2009). We have extended this research in several ways that could explain this discrepancy. By presenting our image pairs simultaneously—rather than centrally (e.g., Dickinson & Intraub, 2009) or to one field at a time (e.g., Kensinger & Choi, 2009)—we forced the RH and LH to initially process each image independently. Calvo et al. (2015) used a similar paradigm, presenting matched-valence image pairs simultaneously for 150 ms, and found no RH advantage for discrimination accuracy of neutral scenes. These findings make sense; if neither hemisphere is specialized for processing neutral stimuli then we should not find a RH advantage with simultaneous and brief scene presentation.

These experiments allow us to draw conclusions regarding the emotional enhancement of memory effect—that we remember emotional stimuli better than non-emotional stimuli (e.g., Kensinger, 2007). Contrary to this effect, we found higher memory accuracy for *neutral* than negative scenes, particularly when these scenes were processed by the LH. Perhaps interspersing emotional and neutral images prospectively enhanced memory for neutral images (e.g., Tambini, Rimmele, Phelps, & Davachi, 2017). Alternatively, the presence (or absence) of emotion may have changed the way our participants made memory judgments (Sharot, Delgado, & Phelps, 2004; Sharot, Verfaellie, & Yonelinas, 2007). For neutral stimuli (e.g., objects), people may rely on the recognition of visual details because they are typically simpler than negative images, thus leading to enhanced recognition memory for neutral images. For negative images, however, they may rely on arousal signals and heightened perceptual fluency at test (Sharot et al., 2004) because these images are more semantically related with recurring themes of blood/injury (Talmi, Schimmack, Paterson, & Moscovitch, 2007). If participants are choosing between two similar images and relying on arousal signals to guide recognition memory, then their ability to discriminate between those images will be reduced. This explanation is consistent with participants' slower response times on negative compared to neutral (and positive) items, suggesting they found it more difficult to distinguish between perceptually similar 'seen' and 'unseen' negative images.

Our findings do not fit with the idea that semantic relatedness should enhance memory (e.g., Talmi et al., 2007). This discrepancy can be explained by using a recognition memory test that relied on detail, rather than gist, recall (Brady et al., 2011; Talmi, 2013). It may also be explained by having participants attend to the fixation cross rather than the image pairs, thereby not giving them a choice on where to allocate their attention. Indeed, Talmi and McGarry (2012) eliminated the emotional enhancement of memory effect by asking participants to allocate their attention equally between emotional and neutral pictures. Our confidence data support these explanations. In Experiment 1, participants made similar confidence ratings for negative and neutral correct items, despite higher memory accuracy for neutral items. However, on incorrect items, participants gave higher confidence ratings for negative than neutral items. In cases where detail-based recall is required, familiarity with general themes across image sets decouples accuracy and confidence (Chandler, 1994; Voss et al., 2008). For example, a decrease in memory accuracy coupled with an increase in confidence on negative images suggests familiarity with a general 'theme' gave participants the illusion that they recalled correctly. By contrast, distinguishability among neutral images due to wider variations in content and color—e.g., animals, objects—led confidence judgments to more accurately reflect memory accuracy, in addition to aiding overall memory accuracy.

To our knowledge, no other research has examined the combined influence of hemispheric processing and emotional valence on the relationship between confidence and memory accuracy. Participants generally made low confidence ratings, presumably due to our short stimulus duration and the limited opportunity for memory rehearsal—given we integrated encoding and testing phases. We found an inconsistent, and often decoupled, relationship between confidence and accuracy. This decoupled relationship may be due to methodological factors in our adapted divided visual field paradigm. Processing two complex images simultaneously in the RH and LH and having to quickly retrieve the images on interpolated test items is a high cognitive load activity that may have made it difficult for participants to accurately reflect on the meta-components (e.g., confidence) of their memory judgments (Chua, Schacter, & Sperling, 2009). This explanation fits with data showing people can maintain high recognition memory accuracy (e.g., 80%) for complex visual stimuli (e.g., kaleidoscope images) in divided attention paradigms, despite making low confidence judgments (Voss et al., 2008). Future research should directly investigate which factors influence the relationship between confidence and memory accuracy to determine whether it is useful to measure confidence with divided visual field paradigms.

Our findings suggest that people take longer to make memory judgments for negative than neutral or positive stimuli, particularly when these stimuli are initially processed by the RH. Across both experiments, participants took approximately 300 – 500 ms longer to respond on negative than neutral or positive items, with the longest responses on negative items processed by the RH. Faster responses should reflect more effective processing. For example, in global vs. local processing (e.g., Volberg, Kliegl, Hanslmayr, & Greenlee, 2009) and low vs. high spatial frequency paradigms (e.g., Peyrin, Chauvin, Chokron, & Marendaz, 2003), the dependent variable is the time taken to identify the target stimulus. Therefore, our response time data are surprising because they inconsistently align with memory accuracy data. One possible explanation for the discrepancies between accuracy and response time is that participants' attention was automatically directed to the novel 'unseen' negative image at test, slowing their response time[20]. But this explanation does not explain the slower responses on left than right visual field negative items, a finding that future research could follow up.

We examined whether memory for negative compared to neutral (Experiment 2a) and positive (Experiment 2b) images differed depending on the hemisphere in which they were initially processed. Our findings suggest initial LH processing leads to a slight deficit in

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[20] We thank an anonymous reviewer for suggesting this possible explanation.

recognition memory for emotional images. We have extended prior visuospatial attention research (e.g., Dickinson & Intraub, 2009) by incorporating emotional stimuli. Similarly, we have extended the emotional processing literature by using naturalistic images with greater generalizability. We conclude that hemispheric asymmetries for emotional and visuospatial attention *do* influence behavioural outcomes.

5 Do People Show a Left-side Memory Bias When Freely Viewing Emotional, Compared to Neutral, Scenes?

When looking at the world around us, we do not pay equal attention to the left and right side. In fact, most people make an initial leftward eye-movement and pay more attention toward the left than the right side of space (Foulsham, Gray, Nasiopolous, & Kingstone, 2013; Nuttham & Matthias, 2013; Ossandón, Onat, & König, 2014). These leftward biases occur because visuospatial attention is a right-hemisphere (RH) asymmetry in up to 90% of people (de Schotten et al., 2011; Hervé, Zago, Petit, Mazoyer, & Tzourio-Mazoyer, 2013). But does attending more to the left side of scenes, particularly upon first encounter, lead to better memory for stimuli located in the left than the right visual field?

Existing research suggests a left-side memory bias exists for neutral stimuli including squares, digits (Petrini, Hennings, & Arendt-Nielsen, 2009), two-dimensional shapes (Della Sala, Darling, & Logie, 2010), and visual scenes (Dickinson & Intraub, 2009; McGeorge, Beschin, Colnaghi, Rusconi, & Della Sala, 2007). However, these studies do not consider that emotional valence might alter this left-side memory bias. This consideration is important because in addition to being dominant for visuospatial attention, the RH plays an important role in emotional processing, particularly in the initial processing of emotional stimuli (e.g., Gainotti, 2012, 2018; Shobe, 2014). Our earlier work (Moeck, Thomas, & Takarangi, 2018) suggests that these combined RH roles lead to a slight memory enhancement for emotional scenes encoded for 500 ms from the left compared to the right visual field. This left-side memory bias did not occur for neutral scenes. Here we wondered if—in a more ecologically valid paradigm—we would observe the same left-side memory bias for stimuli located *within* emotional, compared to neutral, scenes. We used an online free-viewing visual hemifield paradigm to answer this question.

When evaluating a scene, initial eye movements are leftward on about 60-70% of occasions (Dickinson & Intraub, 2009; Foulsham, Frost, & Sage, 2018; Foulsham et al., 2013; Nuttham & Matthias, 2014; Ossandón et al., 2014). This leftward eye-movement bias is strong; it occurs even when people are instructed to search for an object in the right side of a scene (Nuttham & Matthias, 2013). For example, Dickinson and Intraub found that when people looked at scenes with an object located in the right and left visual field, 62% of initial fixations were leftward (38% rightward). The initial leftward fixation subsides after 1-2 seconds of viewing and, in some instances, a weak rightward bias follows, and lasts for several seconds (Ossandón et al., 2014). Dickinson and Intraub investigated whether this initial leftward bias *influenced memory* for objects located on the left, compared to the right, side of neutral scenes. They presented each scene for 500 ms and found, in a surprise memory test, that participants' memory was about 5% more accurate for left than right side objects. But these scenes and objects were neutral (e.g., a washing basket), which begs the question: does this leftward bias in initial eye movements and memory vary if the scene contains an emotional stimulus, to which attending might be advantageous for survival?

From an evolutionary perspective, it is advantageous that we automatically attend to potentially threatening stimuli within the environment. Indeed, the automatic capture of attention by emotional, compared to neutral, stimuli is robust; it occurs when emotional and neutral scenes are task irrelevant distractors (see Carretié, 2014 for review) and when mixed-valenced image pairs are presented simultaneously (e.g., Calvo & Lang, 2004; Calvo, Nummenmaa & Hyönä, 2008; Nummenmaa, Hyöna, & Calvo 2006). However, Alpers (2008) suggests the automatic capture of attention by emotional over neutral stimuli may only occur when the emotional scene appears in the left visual field. Alpers tracked participants' eye movements while looking at mixed-valence image pairs presented for 8 seconds. They manipulated which visual field the emotional vs. neutral image appeared and found initial fixations went to the emotional (positive, negative) image over the neutral image *only* when the emotional image appeared on the left. Interestingly, emotional images held attention for longer than neutral images regardless of visual field, suggesting emotion influences attention capture and attention hold differently.

When people see an image pair, they may perceive the two images as independent and unrelated, allowing them to be processed separately from one another (Acunzo & Henderson, 2011). But what happens when emotional stimuli are embedded *within* a scene? When people do not view the stimuli independently from the rest of the scene, emotional attention capture is not as robust. For example, Acunzo and Henderson (2011) embedded emotional or neutral targets in naturalistic scenes. They aimed to determine if emotional targets captured attention—operationalised as how long it took the participant to fixate on the 'interest area' surrounding the target—more than neutral targets. They also aimed to determine whether attention capture depended on which side of the scene the targets appeared (right, left). The targets were gist-inconsistent, i.e., they did not fit with the rest of the scene. Participants viewed each scene for 15 seconds and believed their memory for the scene would be later tested (in reality there was no memory test). Unexpectedly, emotional targets *did not* capture attention more than neutral stimuli, regardless of side of scene. However, consistent with Alpers (2008), participants spent more time looking at emotional (3784 ms) than neutral (2464 ms) targets overall. Because the target stimuli appeared either in the right or left visual field, this experiment does not shed light on what might occur when two targets appear simultaneously in each visual field and compete for attention. Further, by not testing participants' memory (despite getting them to encode the scenes for an anticipated memory test) we do not know whether valence and visual field influence memory for stimuli embedded in naturalistic scenes. We addressed these limitations in Experiments 3a and 3b, which were largely based on Chapter 4 (Moeck et al., 2018).

As previously mentioned, our earlier work (Moeck et al., 2018) investigated the combined influence of visuospatial attention and emotional processing as RH asymmetries on memory for emotional vs. neutral scenes. We adapted a divided visual field paradigm (Bourne, 2006) and presented pairs of matched-valence scenes (Experiment 2a: negative vs. neutral, Experiment 2b: positive vs. negative) for 500 ms. For negative and positive images, participants showed higher recognition memory for left than right side images. For neutral images, we found no visual field difference. By using pairs of *matched-valence* scenes, this work overcomes a substantial limitation of prior work that has presented pairs of mixed-valence scenes or singly presented isolated objects (Kensinger & Choi, 2009). But this paradigm is not ecologically valid; in everyday-life, we do not view pairs of scenes in our periphery. We also (in general) do not view scenes for just 500 ms. Here, we sought to increase the ecological validity of our earlier experiments in two ways: (1) by manipulating the visual field of target stimuli within a single, centrally presented, scene, and (2) by using a free-viewing paradigm (where participants do not have to maintain central fixation) and presenting each scene for 3 seconds.

Increasing ecological validity decreases experimental control, particularly when measuring behavioural outcomes of hemispheric asymmetries (Bourne, 2006). However, free-viewing paradigms give rise to reliable visual field differences. Voyer, Voyer, and Tramonte (2012) meta-analysed 329 effect sizes from 112 published studies using free-viewing laterality tasks[21], defined as any task where the stimuli were presented for at least 2 seconds. These tasks included, but were not restricted to, chimeric faces (devised by Levy, Heller, Banich & Burton, 1983)—where participants see *two* composite faces (e.g., the left hemiface is smiling and the right hemiface is neutral) and have to choose which face looks happier, for example. Participants typically choose the face where the target expression is on the left side. This bias is not specific to faces; it exists for a range of other visuospatial stimuli including greyscales, dots, and shapes. For example, in the greyscales task (first developed by Mattingley, Bradshaw, Nettleton, & Bradshaw, 1994) participants are shown two bars that start as black then gradually degrade to white (or vice versa). When asked to choose which bar looks darker (or brighter), participants typically choose the bar that has the target judgment (e.g., white for brighter, black for darker) on the left. Across a wide range of tasks and judgments, Voyer et al. (2012) found a large left visual field bias (estimated $d = 1.02$), leading them to conclude that free-viewing tasks are a valid measure of hemispheric asymmetries. Therefore, we should observe a left visual field memory bias using a free-viewing paradigm, should it exist.

5.1 Experiment 3a

We presented online participants[22] with 10 negative, 10 neutral, and 10 positive scenes for 3 seconds each in a free-viewing visual hemifield paradigm. To overcome automatic orienting toward emotional over neutral stimuli (e.g., Calvo et al., 2008), we placed a matched-valence stimulus in both the right and left visual field of each scene. Based

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[21] Voyer et al. (2012) did not include any line bisection tasks, due to the extensive review by Jewell and McCourt (2000). Consistent with Voyer et al. (2012), Jewell and McCourt found a reliable leftward bias for line bisection tasks.

[22] Because we ran this experiment online, it was not possible to track participants' eye-movements.

on the emotional enhancement of memory (e.g., Kensinger, 2007), we expected target stimuli from emotional scenes (positive and negative) to be recognised better than target stimuli from neutral scenes. Because pseudoneglect influence memory for scenes (e.g., Dickinson & Intraub, 2009), we expected to find higher recognition memory accuracy for stimuli that appeared in the left than the right visual field. However, we expected this visual field difference to be larger for emotional (negative and positive) than neutral scenes, i.e., an interaction between valence and visual field.

5.1.1 **Method**

Participants. This experiment was completed online by 268 Amazon Mechanical Turk (MTurk) workers. We only wanted strongly right-handed participants, because these people should have RH dominance for visuospatial attention (Bowers & Heilman, 1980). However, unlike our lab studies, we did not deliberately recruit right handers because if potential participants knew right-handedness made them eligible, they may have adjusted their responses on the FLANDERS. Instead, we excluded anyone who did not meet the right-handed eligibility criteria (a FLANDERS score of less than +8) after they completed the survey, but before data analysis. This exclusion procedure resulted in a higher number of handedness exclusions than in our prior experiments. We excluded 68 participants (25% of the sample[23]): 53 who were not strongly right-handed, 13 for technical issues, one who failed the attention check, and 1 who reported leaving their computer during encoding. The remaining 200 participants (*M* = 9.85, *SD* = 0.48 on the FLANDERS) ranged from 20 to 72 years of age (*M* = 35.45, *SD* = 9.87) and were 42% female, 56% male, and 2% gender non-

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[23] Although higher than our lab studies, this proportion is normal for online studies where up to 30% of participants are usually excluded (Oppenheimer, Meyvis, & Davidenko, 2009).

binary.

We determined a sample size of 200 based on Kensinger and Choi (2009) who compared recognition memory accuracy (gist vs. specific) for objects encoded from the left vs. the right visual field. Using a similar 3 (valence: positive, negative, neutral) x 2 (field of presentation: left, right) within-subjects design, they found a main effect of visual field for specific recognition memory of objects, F(1, 25) = 4.29, $p < .05$, $\eta_p^2 = .18$. We entered this within-subjects ANOVA result into the Shiny Web App (Anderson, Kelley, & Maxwell, 2017), with .8 power and .5 assurance (correcting for publication bias). This sample size calculation yielded $N = 199$. Based on this estimated sample size and our own counterbalancing, we aimed to collect at least 200 participants that met inclusion criteria.

The Flinders University Social and Behavioural Research Ethics Committee approved this experiment, which we pre-registered on the Open Science Framework (see https://osf.io/v7zhy/).

Materials

Flinders Handedness Survey. We used the Flinders Handedness Survey (FLANDERS; Nicholls, Thomas, Loetscher, & Grimshaw, 2013) to assess whether participants were right-, left-, or mixed-handed. The FLANDERS is a 10-item measure where participants select the hand (left, either, right) they use to complete obvious (e.g., *'with which hand do you write?'*) and less obvious (e.g., *'in which hand do you hold the peeler when peeling an apple?'*) tasks. Scores range from -10 (strongly left handed) to +10 (strongly right handed). The FLANDERS has high split-half reliability ($\alpha = .96$) and is strongly associated with other handedness measures (e.g., Edinburgh handedness inventory; Oldfield, 1971).

Depression Anxiety and Stress Scale. We used the Depression Anxiety and Stress Scale (DASS-21; Lovibond & Lovibond, 1995) to measure participants' current symptom scores. Participants rate 21 statements (e.g., *I found it difficult to wind down*) on the extent (from 0 = *did not apply to me at all* to 3 = *applied to me very much, or most of the time*) to which each applied to them over the past week. There are seven statements per symptom subscale. Our samples showed high internal consistency (Experiment 3a: α = .96 overall, .93 for depression, .89 for anxiety and .91 for stress; Experiment 3b: α = .95 overall, .93 for depression, .87 for anxiety and .88 for stress).

Positive and Negative Affect Schedule. We used the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988) state measure to assess participants' mood before and after scene exposure. Participants rated 10 words representing positive affect (PA; e.g., *excited, enthusiastic*) and 10 words representing negative affect (NA; e.g., *irritable, scared*) on how much they reflect their current mood. Ratings range from 1 (*very slightly or not at all*) to 5 (*extremely*), resulting in scores from 10 (least PA or NA) to 50 (most PA or NA) per subscale. The PANAS has high test-retest reliability and internal consistency (Watson et al., 1988) as observed in our sample at baseline for PA (α = .92 in Experiment 3a, .91 in Experiment 3b) and NA (α = .92 in Experiment 3a, .95 in Experiment 3b).

Scenes. We sourced negative, neutral, and positive scenes from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008), the Nencki Affective Picture System (NAPS; Marchewka, Zurawski, Jednorog, & Grabowska, 2014), the Geneva affective picture database (GAPED; Dan-Glauser & Scherer, 2011), and from the publicly available Shutterstock database. We altered some of the scenes using Adobe Photoshop so that each scene had a gist-consistent stimulus (e.g., object, person, nature) clearly located in the right and the left visual field; in some cases we removed elements of the scene and in others we added new elements, sourced from Shutterstock. We pilot tested 55 scenes on

Amazon Mechanical Turk—30 altered and 25 unaltered. Each scene was rated on valence (1 = most negative to 9 = most positive) and arousal (1 = least arousing to 9 = most arousing) by 51 to 54 people. We assessed valence and arousal using the self-assessment manikin (SAM; Bradley & Lang, 1994) in response to *'How does this scene make you feel?'*. From the 55 piloted scenes, we selected 30 (10 per valence) that fit best into neutral, negative, and positive categories (see Table 5.1 for valence and arousal ratings and Appendix B for example images). We tried to balance the presence of faces/people across categories (Colden, Bruder, & Manstead, 2008). However, to maintain the similar arousal ratings between the positive and negative images, we had to make a concession to include three images with faces in the positive category and one in each of the negative and neutral categories. We created mirror-reversals of each scene; half the participants saw the scenes in their original orientation and half saw them mirror-reversed (Dickinson & Intraub, 2009). We counterbalanced orientation across participants to check if any attention-grabbing stimuli that happened to appear on the left or right side influenced any laterality effects. Participants were randomly allocated to an orientation condition (original, mirror-reversed). To counterbalance how often each side of the scene was tested, there were four versions of the experiment per orientation condition, creating eight versions in total. Each version had 15 test items sourced from the left visual field and 15 from the right visual field.

Table 5.1

Pilot ratings (M (SD)) of valence (1 – most negative to 9 most positive) and arousal (1 – least arousing to 9 – most arousing) per image category for each experiment.

	Experiment 3a (10 images per category)		Experiment 3b (12 images per category)	
	Valence	Arousal	Valence	Arousal
Positive	6.69 (1.64)	4.10 (2.28)	6.86 (1.63)	3.88 (2.23)
Negative	3.07 (1.45)	4.47 (2.29)	3.07 (1.56)	4.62 (2.23)
Neutral	5.12 (1.25)	3.07 (1.88)	5.18 (1.29)	3.10 (1.87)

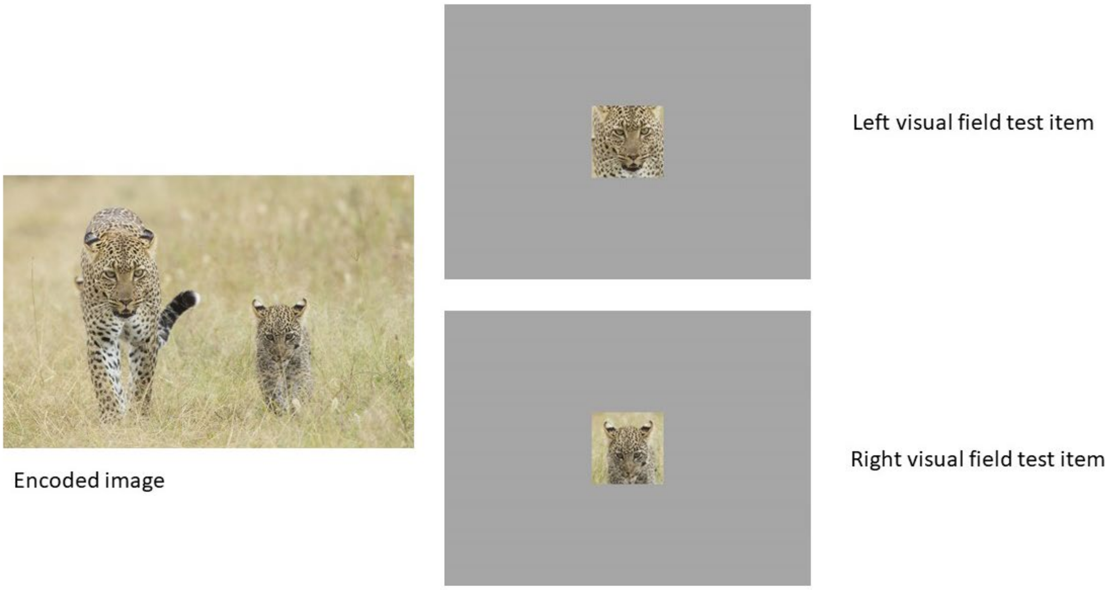

Figure 5.1. Example of an encoded positive scene (original orientation) and the test item crops. Each participant was tested on either the left or right visual field item.

Test items. We created our test items by cropping a square segment in which the right or left target stimulus (e.g., object, person, nature) was clearly identifiable (based on Dickinson & Intraub, 2009). We then placed these square crops (140 x 140 pixels) on a grey background. We tested recognition memory for *either* the right or left visual field stimulus from each scene, depending on counterbalancing. Figure 5.1 shows an example of an encoded scene and the possible test items for that scene. There were 15 filler test items (5 per valence) sourced from the same image databases. These filler items were the same for all participants, regardless of version or orientation. We tested recognition memory by asking '*Have you seen this stimulus before?'* (yes/no). Consistent with Chapter 4 (Moeck et al., 2018), participants rated retrospective confidence in their answer following each recognition memory judgment. We measured confidence by asking *'How confident are you that your response is correct?'*. Participants responded using an 11-point scale with 10% increments from 0% (*completely unsure*) to 100% (*completely sure*).

Procedure. After providing consent, participants completed demographics (sex, gender, age), FLANDERS, DASS-21, and the first PANAS. On each scene trial participants saw a central fixation cross for 2000 ms (which we instructed them to look at) and then a scene for 3000 ms (same presentation time as Calvo & Lang, 2004; Nummenmaa et al., 2006). They then made an affective judgment about the scene they just viewed (i.e., *How much do you like this scene?*; Nuttham & Matthias, 2013) of 1 (dislike), 2 (neither like nor dislike), and 3 (like). This affective judgment ensured participants actively attended to each scene and also acted as a manipulation check of our pilot tested valence categories. Participants completed two practice trials before encoding the 30 scenes in a randomised order. After encoding all 30 scenes, participants completed the second PANAS and then did Sudoku as a 10-minute filler task. We did not tell participants' that their memory would be tested until after the filler task. The recognition memory test comprised 45 randomly presented items; 30 test and 15 filler items. At the end of the study we asked two honesty questions; (1) *'Did any of the scenes in the first part of this study (before the filler task) look altered?'* (yes/no), and (2) *'At any point during the study, did you leave the task and do something else for any period of time?'* (yes/no). If participants indicated that they left the task we asked when and for approximately how long. We debriefed participants and compensated them $3.50 USD for the 35 to 40 minute session.

5.1.2 **Results and Discussion**

Manipulation check. We first examined whether exposure to negative scenes changed participants' mood by running a 2 (affect: positive, negative) x 2 (time: before, after scene exposure) repeated measures ANOVA on PANAS scores. Mood remained stable over time as indicated by no interaction between affect and time, $F(1, 199) = 1.81$, $p = .18$, $\eta_p^2 = .009$. This stability occurred for PA (before: $M = 28.27$, 95% CI [27.00, 29.54], after: $M = 27.64$, 95% CI [26.30, 28.97]) and NA (before: $M = 13.18$, 95% CI [12.44, 13.91], after: $M = 13.04$, 95% CI [12.36, 13.71]). To ensure this stability in mood was not due to the experimental participants rating scene valence differently to our pilot participants, we analysed the affective ratings for each valence set. Mean ratings for the negative images ($M = 1.27$, $SD = .28$) were close to 1 (dislike), neutral ($M = 2.25$, $SD = .30$) close to 2 (neither like nor dislike), and positive ($M = 2.73$, $SD = .27$) close to 3 (like). Importantly, negative images were disliked significantly more than neutral ($t(199) = -37.93$, $p <.001$, $d = 2.78$) and positive images ($t(199) = -50.54$, $p <.001$, $d = 3.51$), and neutral images were disliked more than positive images, ($t(199) = -24.27$, $p <.001$, $d = 1.61$). These data suggest our pilot tested valence categories matched the valence judgments made by our experimental sample. Thus, interspersing negative scenes with neutral and positive scenes—due to random presentation of the valence sets—may have stabilised mood. Alternatively, despite the experiment sample disliking the negative scenes, these scenes may not have been negative enough to reduce positive or increase negative mood.

Our honesty questions revealed a small percentage of participants (11.5%) thought at least one of the scenes looked altered. An even smaller percentage (2.5%) left the study at some point, but these instances were brief and did not occur during encoding. Given the small number of participants who answered yes to these questions, we did not account for these responses in any of our main analyses.

Participants were good at correctly identifying seen items as seen (*M* = .81, *SD* = .15) and correctly rejecting filler unseen items (*M* = .92, *SD* = .10). Participants correctly rejected positive (*M* = .94, *SD* = .14) more often than negative (*M* = .90, *SD* = .13) filler items, *t*(199) = 3.26, *p* = .001, *d* = 0.26. Correct rejection of neutral filler items (*M* = .92, *SD* = .14) was similar to negative (*t*(199) = 1.25, *p* = .21, *d* = 0.12) and positive (*t*(199) = 1.85, *p* = .07, *d* = 0.12) filler items. Because filler items have no visual field properties, we do not analyse them further; subsequent analyses focus on seen items only.

Hypothesis testing. We ran a 3 (valence: positive, negative, neutral) x 2 (visual field: left, right) repeated measures ANOVA to test our hypothesis that valence and visual field would interact to predict recognition memory accuracy[24]. We found a main effect of valence, *F*(2, 198) = 49.70, *p* <.001, $ŋ_{p}{}^{2}$ = .33; recognition memory was higher for test items from positive (*M* = .87, *SD* = .16) than negative (*M* = .78, *SD* = .19, *t*(199) = -7.50, *p* <.001, *d* = 0.58) and neutral (*M* = .78, *SD* = .19, *t*(199) = -8.56, *p* <.001, *d* = 0.65) scenes. There was no difference in recognition memory for test items from negative and neutral scenes, *t*(199) = .15, *p* = .89, *d* = 0.01. Memory accuracy was similar for left (*M* = .80, *SD* = .16) and right (*M* = .82, *SD* = .17) visual field items, indicating no main effect of visual field, *F*(1, 199) = 2.80, *p* = .10, $ŋ_{p}{}^{2}$ = .01. This similarity in memory regardless of which visual field items appeared

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[24] We analysed our results using recognition memory accuracy, i.e., the proportion of hits, rather than sensitivity (d prime) or specificity (c prime) because the filler items do not have visual field properties. Therefore, false alarm and correct rejection rates have no left or right judgments, making Signal Detection Theory an inappropriate analysis for these data.

in counters our prediction and prior work by Dickinson and Intraub (2009). There was a significant interaction with a small effect size between valence and visual field, $F(1, 199) = 4.38$, $p = .01$, $\eta_p^2 = .04$, but in the opposite direction to what we predicted. As shown in Figure 5.2, recognition memory accuracy for negative items was significantly higher when these items appeared in the *right* than the left visual field, $t(199) = -2.52$, $p = .013$, $d = 0.18$. For items from positive ($t(199) = 1.52$, $p = .13$, $d = 0.12$) and neutral ($t(199) = -1.25$, $p = .21$, $d = 0.09$) scenes, however, accuracy was similar regardless of which visual field they appeared in.

Because these results contradicted our hypotheses, we next determined if idiosyncrasies within the scenes influenced memory accuracy. Recall that participants either encoded the scenes in their original or mirror-reversed orientation. Therefore, we added orientation (original, mirror-reversed) as a between-subjects factor in the valence x visual field repeated measures ANOVA. We found a two-way interaction between orientation and visual field, $F(1, 198) = 12.28$, $p = .001$, $\eta_p^2 = .06$, and a three-way interaction, $F(2, 197) = 3.56$, $p = .03$, $\eta_p^2 = .04$. To look closer at these interactions we ran two separate repeated measures ANOVAs (see Table 5.2 for descriptive statistics).

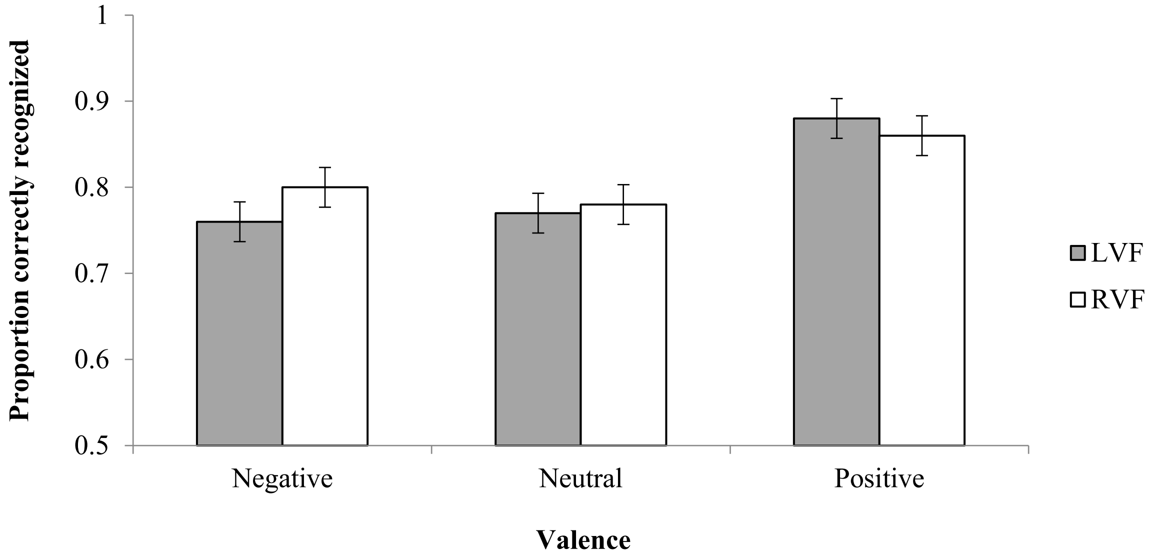

Figure 5.2. Mean proportion of test items correctly recognized in Experiment 3a depending on valence (negative, neutral, positive) and visual field (left, right). Errors bars represent 95% within-subject confidence intervals (Masson & Loftus, 2003).

Among participants who saw scenes in their *original* orientation, there was a main effect of valence with higher accuracy for positive than negative or neutral scenes (*F*(2, 99) = 27.31, *p* <.001, $\eta_p{}^2$ = .36)—an effect we found in the prior set of analyses. Participants were more accurate on right than left visual field items, a reversal of the expected main effect of visual field, *F*(1, 100) = 15.05, *p*<.001, $\eta_p{}^2$ = .13. We also found an interaction between valence and visual field, *F*(2, 99) = 7.38, *p* <.001, $\eta_p{}^2$ = 13. Paired samples t-tests showed that original-orientation participants had higher recognition memory accuracy for right than left visual field items on negative (*t*(100) = -4.30, *p* <.001, *d* = 0.40) and neutral (*t*(100) = -2.74, *p* = .007, *d* = 0.26) but not positive (*t*(100) = 1.20, *p* = .23, *d* = 0.14) scenes. Among participants who saw *mirror-reversed* scenes, there was a main effect of valence, again favouring positive over negative and neutral scenes, *F*(2, 97) = 22.74, *p* <.001, $\eta_p{}^2$ = .32. Contrary to participants who saw original orientation scenes, there was no main effect of visual field, $F(1, 98) = 1.49$, $p = .23$, $\eta_p^2 = .02$, nor an interaction between valence and visual field, $F(2, 97) = .07$, $p = .93$, $\eta_p^2 = .001$, for participants who saw mirror-reversed scenes. If idiosyncrasies within the scene made the stimuli more memorable, we would have expected the same items to lead to enhanced memory from original to mirror-reversed scenes—i.e., right side negative and neutral items in original orientation scenes and left side negative and neutral items in mirror-reversed scenes. However, we did not find this reciprocal relationship, suggesting that the orientation differences may have been due to anomalies stemming from a small number of data points per cell (i.e., 10). These anomalies likely drove the overall valence and visual field interaction found in our earlier analyses (Figure 5.2).

Table 5.2

Descriptive statistics (M (SD)) for participants who saw original vs. mirror-reversed scenes by valence and visual field in Experiment 3a. Bold indicates significant differences

	Original (*N* = 101)		Mirror-reversed (*N* = 99)	
Valence	Left visual field	Right visual field	Left visual field	Right visual field
Positive	.88 (.17)	.86 (.21)	.88 (.18)	.86 (.19)
Negative	**.75 (.22)**	**.83 (.19)**	.78 (.23)	.77 (.24)
Neutral	**.75 (.23)**	**.81 (.21)**	.79 (.26)	.77 (.24)

We next analysed confidence ratings—which participants made for each recognition memory judgment (from 0 = *completely unsure* to 100 = *completely sure*). To confirm that confidence aligned with recognition memory accuracy, we calculated each participant's resolution using Goodman and Kruskal's gamma correlation (Dunlosky & Metcalfe, 2009). This correlation is based on the number of correct vs. incorrect responses the participant provided at each of the 11 possible confidence ratings. Across our sample[25], mean within-

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[25] We could not calculate Gamma for five participants; three who rated their confidence as 100% for every answer and two who got all answers correct.

participant gamma correlation was positive and medium to high ($M = .63$, $SD = .26$). Therefore, to establish whether valence and visual field influenced participants' confidence in their recognition memory judgments, we separated confidence for correct vs. incorrect answers and ran two 3 (valence: positive, negative, neutral) x 2 (visual field: left, right) repeated-measures ANOVAs.

We first looked at confidence ratings (%) on correct answers[26]. We found a main effect of valence, $F(2, 187) = 39.93$, $p < .001$, $\eta_p^2 = .30$; in line with recognition memory accuracy, confidence ratings were higher on positive ($M = 93.73$, $SD = 8.47$) than negative ($M = 89.32$, $SD = 10.94$, $t(188) = 7.10$, $p < .001$, $d = 0.61$) and neutral ($M = 89.06$, $SD = 10.78$, $t(188) = -7.83$, $p < .001$, $d = 0.67$) correct items. There was no difference in confidence ratings between negative and neutral correct items, $t(188) = .38$, $p = .71$, $d = 0.03$. We found no main effect of visual field, $F(1, 188) = 1.13$, $p = .29$, $\eta_p^2 = .006$, nor any interaction between valence and visual field, $F(2, 187) = 1.67$, $p = .19$, $\eta_p^2 = .017$, in predicting confidence on correct answers. Due to participants' high recognition memory accuracy, the sample was too small ($n = 23$) to run the planned valence x visual field repeated measures ANOVA on confidence ratings for incorrect answers[27].

Symptom scores. Mean DASS-21 scores were "normal" according to the ranges described by Lovibond and Lovibond (1995) (depression: $M = 4.43$, 95% CI [3.73, 5.13];

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[26] These analyses include 189 participants, because 11 had incomplete data from getting no answers correct in certain valence-visual field combinations (e.g., no data were available for correct, negative, right side items).

[27] The same pattern exists when we encompass confidence ratings on incorrect answers by analyzing confidence without splitting by accuracy. Similar to recognition memory, there was a main effect of valence, $F(2, 198) = 70.93$, $p < .001$, $\eta_p^2 = .42$. Participants were more confident in their memory judgments for items from positive ($M = 90.38$, $SD = 10.30$) than negative ($M = 83.09$, $SD = 14.03$, $t(199) = -10.05$, $p < .001$) or neutral ($M = 84.25$, $SD = 12.54$, $t(199) = -10.45$, $p < .001$) scenes. Confidence on negative and neutral scenes was similar, $t(199) = -1.71$, $p = .09$. There were no differences in confidence ratings depending on visual field, $F(1, 199) = .35$, $p = .55$, $\eta_p^2 = .002$. Unlike recognition memory, we found no interaction between valence and visual field for confidence ratings, $F(2, 198) = .40$, $p = .67$, $\eta_p^2 = .004$.

normal: 0 - 7, anxiety: *M* = 3.43, 95% CI [2.84, 4.01], normal: 0 - 9; stress: *M* = 5.60, 95% CI [4.92, 6.27], normal: 0 - 14). There was a small negative correlation between anxiety symptoms and overall memory accuracy (*r* = -.18, *p* = .01), but not between depression (*r* = -.13, *p* = .08) or stress (*r* = -.09, *p* = .20) and overall memory accuracy.

5.2 Experiment 3b

Experiment 3a suggested participants were most accurate and confident in stimuli from positive than negative or neutral scenes, regardless of which visual field the stimuli appeared. Unexpectedly, we found better memory for stimuli from the right than the left visual field among negative scenes. However, the between-subjects orientation counterbalance likely drove this effect. Therefore, in Experiment 2 we changed our orientation counterbalance from between to within-subjects, to reduce the influence of this confound on our results. We also changed our recruitment strategy to reduce cost, due to the high number (*n* = 53) of participants who we still paid but excluded because of handedness. Participants were only able to access the full experiment once they first met the inclusion criteria of scoring at least +8 on the FLANDERS (Nicholls et al., 2013). We told all participants that they would complete a one-minute handedness survey (for 10 cents), and then gave participants who met inclusion criteria (e.g., +8 on the FLANDERS) the option to do another study (the rest of the experiment) for $3.40[28]. We increased task difficulty—by adding six scenes to encoding, additional filler items, and adjusting our test crops—to increase error rates. We added a Captcha, to prevent bot responses (Bai, 2018), and two additional attention checks so that we could exclude only participants who failed all three

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[28] These recruitment strategies are often used for online studies and do not break ethical guidelines, because participants consented separately to each part of the study.

attention checks (Berinsky, Margolis, & Sances, 2014). This experiment was pre-registered on the Open Science Framework (see https://osf.io/2qfgz/).

5.2.1 Method

Participants. Three hundred and seventy MTurk workers completed the FLANDERS (Nicholls et al., 2013); of those who were strongly right handed, 212 opted to complete the full experiment, meeting our target minimum sample size of 200 participants. There were 25 to 28 participants in each of the eight versions of the experiment. We excluded two people who failed all three attention checks. The remaining 210 participants (*M* = 9.78, *SD* = 0.58 on the FLANDERS) ranged from 18 to 70 years of age (*M* = 36.19, *SD* = 10.53) and were 59% female, 40% male, and 1% gender non-binary.

Materials.

Scenes. We increased the number of scenes of each valence from 10 to 12 (36 in total). These additional six scenes came from the same sources (IAPS, NAPS, Shutterstock) as Experiment 3a and were previously pilot tested (see Experiment 3a method). With 12 images per category, the mean valence and arousal ratings (see Table 5.1) were similar to Experiment 3a. There were two images with faces in the negative and neutral categories, and three in the positive category. To maintain counterbalancing, we added three new filler items (one per valence). We also increased the difficulty of test items by re-cropping, and thus adjusting the test item, for 10 scenes where mean recognition memory accuracy in Experiment 3a was 90% or higher. This adjustment aimed to reduce the number of items where memory accuracy was at ceiling. We changed our confidence scale from an 11-point Likert scale to a continuous slider. This slider had the same marked 10% increments, but participants could answer between the markers as well as on them.

Procedure. Besides the changes to our recruitment strategy and adding two more attention checks, our procedure matched Experiment 3a. Participants' completed the DASS-21, the PANAS, encoded 36 scenes presented for 3 seconds each, completed a 10-minute Sudoku filler task, the recognition memory test, and honesty questions. To reduce the number of technical issues from Experiment 3a, we changed the host of the Sudoku task.

5.2.2 **Results and Discussion**

Manipulation check. We first ran a 2 (affect: positive, negative) x 2 (time: before, after scene exposure) repeated measures ANOVA on PANAS scores. Consistent with Experiment 3a, mood remained stable over time as indicated by no interaction between affect and time, $F(1, 209) = 1.45$, $p = .23$, $\eta_p^2 = .007$. This stability occurred for PA (before: M = 28.20, 95% CI [26.99, 29.42], after: M = 27.69, 95% CI [26.39, 28.98]) and NA (before: M = 13.77, 95% CI [12.85, 14.68], after: M = 13.77, 95% CI [12.91, 14.63]). Participants' affective judgments (where 1 = dislike and 3 = like) reflected the valence category of the image sets. Mean ratings for the negative images (M = 1.26, SD = .29) were close to 1 (dislike), neutral (M = 2.24, SD = .29) close to 2 (neither like nor dislike), and positive (M = 2.75, SD = .24) close to 3 (like). As in Experiment 3a, negative images were disliked significantly more than neutral ($t(209) = -42.60$, p <.001, d = 2.96) and positive images ($t(209) = -57.67$, p <.001, d = 3.64), and neutral images were disliked more than positive images, ($t(209) = -26.97$, p <.001, d = 1.72).

The honesty questions revealed a higher percentage (24.4%) of participants[29] thought at least one of the images looked altered in Experiment 3b than Experiment 3a. Again, a

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[29] The results of the main valence x visual field analysis on recognition memory accuracy do not change when we exclude participants who thought at least one of the images looked altered.

small percentage of participants (5.8%) left and came back to the study at some point, but none of these departures occurred during encoding.

Participants were good at correctly identifying seen items as seen (*M* = .76, *SD* = .15) and correctly rejecting filler items (*M* = .84, *SD* = .10), but not as good as Experiment 3a, suggesting that we successfully increased task difficulty. Participants were better at correctly rejecting positive (*M* = .89, *SD* = .19) than negative (*M* = .75, *SD* = .19) filler items, *t*(209) = 11.21, *p* <.001, *d* = 0.78, and neutral (*M* = .87, SD = .19) than negative filler items, *t*(209) = 9.48, *p* < .001, *d* = 0.65). There was no difference in correct rejection of neutral and positive filler items, *t*(209) = 1.66, *p* = .10, *d* = 0.11. We do not analyse filler items further.

Hypothesis testing. To analyse our hypotheses, we ran a 3 (valence: positive, negative, neutral) x 2 (visual field: left, right) repeated-measures ANOVA on recognition memory accuracy. We found a main effect of valence, F(2, 208) = 13.64, *p* <.001, η_p^2 = .12; recognition memory accuracy was higher for test items from positive (*M* = .79, *SD* = .17) than neutral (*M* = .76, *SD* = .18, *t*(208) = -2.44, *p* = .016, *d* = 0.17) and negative (*M* = .73, *SD* = .18, *t*(209) = -5.23, *p* <.001, *d* = 0.37) scenes. This positive advantage is consistent with Experiment 3a, although the size of the valence main effect was smaller (Experiment 3a: η_p^2 = .33, Experiment 3b: η_p^2 = .12). Accuracy was slightly higher for test items from neutral than negative scenes (*t*(209) = 2.84, *p* = .005, *d* = 0.19). This effect is inconsistent with Experiment 3a, where there was no difference in accuracy between neutral and negative scenes. We found no main effect of visual field, *F*(1, 208) = .20, *p* = .66, η_p^2 = .001, nor an interaction between valence and visual field, *F*(2, 208) = .33, *p* = .72, η_p^2 = .003 (see Figure 5.3). This lack of interaction differs from Experiment 3a, where we attributed the significant interaction to a visual field difference for negative original orientation scenes only. Therefore, the lack of interaction in Experiment 3b suggests counterbalancing orientation within-subjects addressed the between-subject differences in orientation that may have driven the valence, visual field interaction in Experiment 3a.

To confirm that we addressed the orientation confound, we ran a 3 (valence: negative, neutral, positive) x 2 (orientation: original, mirror reversed) x 2 (field: left, right) repeated measures ANOVA. We found a two-way interaction between orientation and field, $F(1, 209) = 13.07$, $p<.001$, $\eta_p{}^2 = .06$, of the same magnitude as Experiment 3a, but driven by positive and not neutral or negative items (see Table 3). For mirror reversed scenes, participants had higher accuracy for stimuli on the right ($M = .77$, $SD = .19$) than the left ($M = .74$, $SD = .19$) side, $t(209) = -2.29$, $p = .023$, $d = 0.16$. For original orientation scenes, participants had higher accuracy for stimuli on the left ($M = .77$, $SD = .19$) than the right ($M = .74$, $SD = .18$) side, $t(209) = 2.43$, $p = .016$, $d = 0.17$. Our Experiment 2 findings suggests something within the scenes (e.g., a face, an object) increased their memorability, because the stimuli that

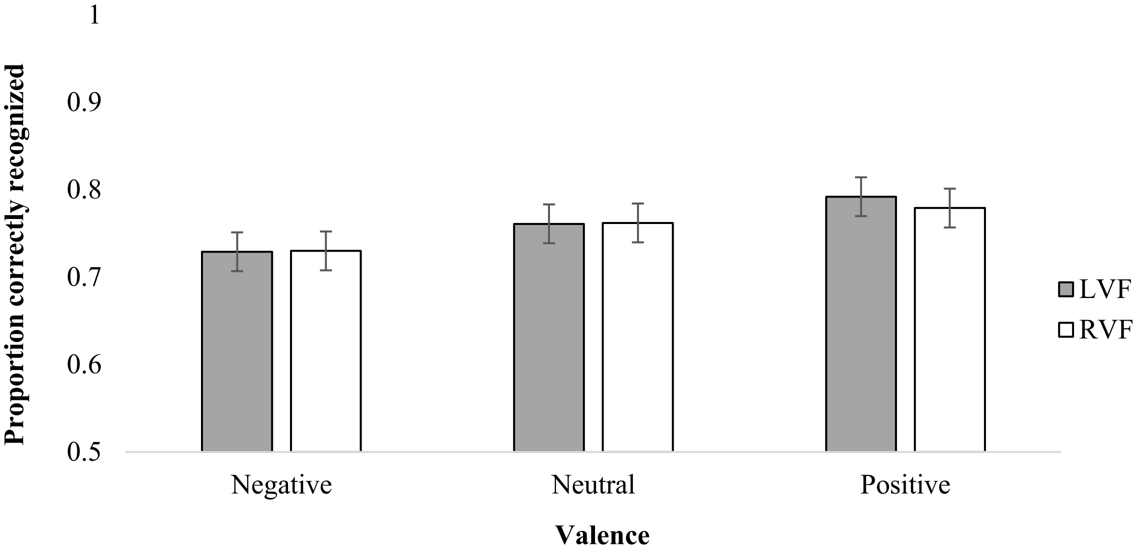

Figure 5.3. Mean proportion of test items correctly recognized in Experiment 3b depending on valence (negative, neutral, positive) and visual field (left, right). Errors bars represent 95% within-subject confidence intervals (Masson & Loftus, 2003).

appeared on the right side of the mirror reversed images are the same stimuli that appeared on the left side of original orientation images. In line with this view, there was no difference in accuracy for mirror left vs. original right items ($t(209) = .04$, $p = .97$, $d = 0.00$) and mirror right vs. original left items ($t(209) = -.19$, $p = .85$, $d = 0.02$). Taken together, these findings suggest that although idiosyncrasies exist in these scenes, accounting for them through a within-subject counterbalance reduced their effect on our primary analyses—as demonstrated by no interaction between valence and visual field in Experiment 2.

Table 5.3.

Descriptive statistics (M (SD)) for original and mirror-reversed items by valence and visual field in Experiment 2. Bold indicates significant differences.

	Original		Mirror-reversed	
Valence	Left visual field	Right visual field	Left visual field	Right visual field
Positive	**.82 (.24)**	**.76 (.27)**	**.76 (.29)**	**.80 (.25)**
Negative	.73 (.28)	.72 (.28)	.72 (.27)	.74 (.26)
Neutral	.76 (.27)	.75 (.28)	.75 (.29)	.78 (.27)

Confidence ratings. We next analysed confidence ratings—which participants made using a slider for each recognition memory judgment (from 0 = *completely unsure* to 100 = *completely sure*). Across our Experiment 2 sample, mean within-participant gamma correlation[30] was positive and moderate ($M = .57$, $SD = .21$). We analysed the influence of valence and visual field on confidence ratings using two 3 (valence: positive, negative, neutral) x 2 (visual field: left, right) repeated measures ANOVAs; one for correct and one for incorrect answers. For correct answers[31] we found a main effect of valence, $F(2, 201) = 9.84$,

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[30] We could not calculate Gamma for two participants who rated 100% confidence in every answer.

[31] These analyses include 203 participants because 7 had incomplete data due to getting no answers correct in certain valence-visual field combinations (e.g., no data were available for correct, negative, right side items).

$p = .001$, $\eta_p^2 = .09$. Consistent with Experiment 3a, confidence ratings were significantly higher on positive ($M = 90.76$, $SD = 9.00$) than negative ($M = 88.50$, $SD = 10.32$) test items, $t(202) = 4.40$, $p <.001$, $d = 0.34$). Inconsistent with Experiment 3a, participants confidence ratings were similar for correct positive and neutral ($M = 89.84$, $SD = 9.57$) items, $t(201) = -1.82$, $p =.07$, $d = 0.14$, but slightly lower on negative than neutral; $t(201) = -2.87$, $p = .005$, $d = 0.19$) correct items. Similar to Experiment 3a, we found no main effect of visual field, $F(1, 202) = .01$, $p = .92$, $\eta_p^2 = .000$, nor any interaction between valence and visual field, $F(2, 201) = 1.96$, $p = .14$, $\eta_p^2 = .02$. We found the same pattern for incorrect answers, although only 65 participants were included in this ANOVA because several participants did not have incorrect answers in all valence-visual field combinations. There was a main effect of valence ($F(2, 63) = 5.66$, $p = .005$, $\eta_p^2 = .15$) with higher confidence ratings on positive ($M = 64.34$, $SD = 21.62$) than negative ($M = 57.38$, $SD = 22.75$; $t(64) = -3.39$, $p = .001$, $d = 0.41$) and neutral ($M = 59.62$, $SD = 22.00$; $t(64) = -1.62$, $p = .019$, $d = 0.17$, $t(64) = -2.47$, $p = .02$, $d = 0.30$) incorrect items. There was no difference in confidence ratings on negative and neutral incorrect items, $t(64) = -1.62$, $p = .11$, $d = 0.21$. We found no main effect of visual field, $F(1, 64) = .04$, $p = .85$, $\eta_p^2 = .001$, nor an interaction between valence and visual field, $F(2, 63) = 1.96$, $p = .14$, $\eta_p^2 = .02$, in predicting confidence on incorrect answers[32].

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[32] When we did not split confidence for correct and incorrect answers, therefore encompassing all participants confidence ratings, we found a main effect of valence, $F(2, 208) = 24.03$, $p = .001$, $\eta_p^2 = .19$. Similar to memory accuracy, confidence ratings were higher for test items from positive ($M = 84.30$, $SD = 11.57$) than neutral ($M = 82.49$, $SD = 12.44$, $t(209) = -3.36$, $p <.001$) and negative ($M = 79.92$, $SD = 13.42$, $t(209) = -6.86$, $p < .001$) scenes. Also in line with memory accuracy for Experiment 3b, confidence ratings were higher on items from neutral than negative scenes, $t(209) = -4.91$, $p < .001$. We found no main effect of visual field, $F(1, 209) = 2.79$, $p = .10$, $\eta_p^2 = .013$, but did find an interaction between valence and visual field, $F(2, 208) = 3.56$, $p = .03$, $\eta_p^2 = .033$. This interaction is inconsistent with Experiment 3a confidence ratings. Paired samples t-tests revealed visual field differences for positive items; confidence was higher for left ($M = 85.45$, $SD = 12.35$) than right ($M = 83.15$, $SD = 13.27$) visual field items, $t(209) = 3.02$, $p = .003$. There were no visual field differences for confidence on negative ($t(209) = -.43$, $p = .67$) or neutral ($t(209) = .42$, $p = .67$) scenes.

Taken together, our Experiment 3b accuracy and confidence data largely align with one another—participants were more accurate and confident for items from positive than neutral or negative scenes and for items from neutral than negative scenes. This advantage for positive items fits with Experiment 3a, but the advantage of neutral over negative items does not.

Symptom scores. Similar to Experiment 3a, mean DASS-21 scores were "normal" (depression: *M* = 4.69, 95% CI [3.99, 5.39]; normal: 0 - 7, anxiety: *M* = 3.29, 95% CI [2.74, 3.82], normal: 0 - 9; stress: *M* = 5.88, 95% CI [5.25, 6.50], normal: 0 - 14). There were no correlations between any symptom measure and overall memory accuracy (*r* values = .02 to .09, *p* values .20 to .74), suggesting the small negative correlation between anxiety symptoms and overall memory accuracy from Experiment 3a was spurious.

5.3 General discussion

We used a free-viewing paradigm to determine whether people show a left-side memory bias for stimuli located within emotional (positive and negative)—compared to neutral—scenes. Contrary to expectations, we found no left-side memory bias overall, nor in any valence category. We found consistently higher memory accuracy for stimuli from positive than negative or neutral scenes (7 to 10% higher), accompanied by higher confidence in answers on positive items. In Experiment 3a, we found similar accuracy and confidence on neutral as negative items, but in Experiment 3b, we found higher accuracy and confidence on neutral than negative items. These results support a positive but not a negative emotional enhancement of memory effect (e.g., Kensinger, 2007). Finally, although we found an interaction between valence and visual field in Experiment 3a, differences relating to scene orientation (original vs. mirror reversed) appeared to drive this interaction. In Experiment 3b, where we made orientation a within- rather than between-subjects factor to account for this potential confound, we found no interaction. Therefore, we conclude that—contrary to expectations—valence and visual field did not have a combined effect on memory accuracy or confidence ratings.

Our lack of left side memory bias contradicts Dickinson and Intraub (2009), who found a left side memory advantage for objects embedded within neutral scenes. However, differences in presentation time and task instructions may explain this discrepancy. Dickinson and Intraub presented each scene for 500 ms and instructed participants to maintain central fixation. We presented scenes for 3000 ms and gave no instruction for where to look once the scene appeared. It is possible that 3000 ms is too long to observe any visual field differences, because after 1 to 2 seconds the leftward bias in eye movements no longer exists (Nuthmann & Matthias, 2014; Foulsham et al., 2013). In fact, with longer presentation times, people may compensate for the initial leftward bias with a weak rightward bias in subsequent eye movements (Ocklenburg et al., 2014). This compensation may have been particularly likely in our free-viewing paradigm, where—after looking at the central fixation cross before the image was presented—participants had the freedom to explore the entire scene. Therefore, although people may have fixated toward the left at first, 3 seconds provided enough time for people to compensate for this bias and look at the rest of the scene. These experiments should be replicated with eye-tracking to confirm this explanation and provide a stronger test of our hypotheses.

The lack of left side bias also contradicts the results of free viewing paradigms (e.g., Voyer et al., 2012). However, there are two key differences between our paradigm and the types of tasks included in Voyer et al. (2012) meta-analysis. First, we were interested in memory accuracy (after a delay), while most free-viewing tasks are interested in immediate preference and discrimination judgments, e.g., which of two faces looks happier? It is possible that immediate preference judgments are more likely to elicit perceptual asymmetries than higher order judgments (e.g., memory) made after a delay. Future research should investigate this possibility. Second, although Voyer et al. report an overall left visual field bias across a range of stimuli and tasks, they did find faces and timed tasks (i.e., where participants only have a certain amount of time to make a judgment) produce the largest left visual field biases. We used scenes containing a variety of stimuli, not just faces, and an untimed memory test. These two methodological differences between these experiments and typical free-viewing paradigms may explain our lack of left visual field bias.

We found no interaction between valence and visual field in predicting participants' memory for stimuli within emotional or neutral scenes. This finding opposes Moeck et al. (2018), where valence and visual field interacted to predict recognition memory of emotional vs. neutral scenes. The methodological changes made to increase ecological validity may explain the discrepancy in findings between the two studies. First, testing participants' memory for stimuli located *within* scenes, rather than memory for *entire* scenes, may have led to a mismatch in valence from encoding to test. For example, people could have rated the scene shown in Figure 1 as positive because of the combination of the cheetah cub and the fully-grown cheetah. But perhaps the crop containing the fully-grown cheetah, the test image, was not perceived as positively as the full scene containing the fully-grown cheetah and the cub, the encoded image. In Moeck et al. we tested memory for the entire scene that was encoded, ensuring a match in valence at both stages. Future research could test this explanation by matching valence ratings as closely as possible between the cropped stimuli and the original scene. Second, we lengthened presentation time to 3000 ms (from 500 ms), used a free-viewing (rather than a divided visual field) paradigm, and presented a single image (rather than a pair of images). When pairs of images are briefly presented in the left and right visual field, the RH and LH process a single image contralaterally (Bourne, 2006). Under these circumstances, the specialisations of each hemisphere will make a larger contribution to the outcome variable compared to when the two hemispheres can collaborate. According to Shobe (2014), the RH is dominant for the initial processing of emotional stimuli, particularly negative stimuli. However, when there is sufficient time for the stimuli to be transferred cross-colossally from the RH to the LH, the LH may also contribute to emotional processing. Therefore, we found no interaction between valence and visual field because 3 seconds was enough for the RH and the LH to collaborate.

Another explanation for why we found no visual field differences, nor an interaction between valence and visual field, is that participants used gist (rather than detailed) based recall cues to guide their decisions at test. Prior research suggests hemispheric asymmetries for visuospatial attention and emotional processing may have a combined influence on memory only for detailed recall (Kensinger & Choi, 2009; Moeck et al., 2018). For example, Kensinger and Choi (2009) measured general and specific recognition memory for photos of negative, positive, and neutral objects presented singly to the right and left visual field. Valence and visual field interacted to predict specific recognition memory—i.e., identifying test objects as the same as encoded objects—where memory was better for negative objects encoded from the left than the right visual field. But there was no interaction for general recognition memory—i.e., identifying a test object as the same *or* similar to an encoded object—which was higher for emotional than neutral objects regardless of visual field. Here, we presented two gist-consistent stimuli within each scene, e.g., a person on the left and a person on the right, or a tiger on the left and a tiger on the right. Therefore, our memory test measured general recognition because people could correctly determine that they had seen the stimulus before based on a general gist feeling that they saw a similar stimulus at some stage during encoding.

Using a memory test that relied on gist rather than detailed recall may explain the emotional enhancement of memory effect we found for positive images (Kensinger, 2009; Levine & Edelstein, 2009; Talmi, 2013). Alternatively, the content of the positive images was more memorable than the negative and neutral images. This explanation is plausible, because accuracy in correctly rejecting positive filler items was also higher than neutral or negative filler items. Despite trying to control for scene differences across valence types, the positive scenes contained more people and animals than the negative and neutral scenes. Although isolated faces are less memorable than scenes (Keightley, Chiew, Anderson, & Grady, 2011), when these faces occur in context—i.e., within a scene—they may become more memorable than scenes without faces. Indeed, images with people are more memorable than images without people (Hourihan & Bursey, 2015; Isola, Xiao, Parikh, Torralba, & Oliva, 2014).

Intriguingly, memory accuracy was lowest for items from negative scenes, which does not fit with the emotional enhancement of memory effect. Accuracy for negative items was significantly lower than positive items in both experiments and neutral items in Experiment 2. It is possible that our negative images were not sufficiently negative, as suggested by the lack of mood change from before to after picture viewing. We know that enhanced attention for emotional over neutral scenes is most likely when the emotional scenes involve erotica and mutilations (Calvo et al., 2015). We were unable to include these highly negative scenes when developing our stimuli set due to making a number of concessions to maintain the parameters of having a stimulus clearly located in each visual field *and* keeping arousal levels as consistent as possible between the positive and negative scenes. One of those concessions was choosing negative images that were less negative in valence and lower in arousal than we would have liked. For example, the negative images used in Experiment 2 had mean valence ratings of 3.07, which falls on the less negative end of the 1 to 4 scale (where 1 is most negative; Lang et al., 2008).

This work has limitations in addition to those already mentioned. First, the task completed during encoding (making affective judgments) did not match the actual task (memory test). There is an interaction between picture content and task type in directing eye movements (e.g., Theeuwes, De Vries, & Godjin, 2003); for example, when people view stimuli in preparation for a memory test, the first eye movement is likely to be leftward (Foulsham & Kingstone, 2010; Nuttham & Matthias, 2014). Therefore, it may be worth investigating whether telling participants at encoding that their memory would be tested later leads to the same results. Both Acunzo and Henderson (2011) and Dickinson and Intraub (2009) told participants their memory would be tested but found different results. Acunzo and Henderson found no visual field differences in attention (however, memory was never measured), while Dickinson and Intraub found a leftward bias in memory accuracy. This discrepancy highlights the need for future research using a similar method with varied task instructions. A second limitation is that we did not control for low-level differences for the images between the valence categories, including saliency of the targets or overall luminance. It is possible that these differences could have drawn participants' attention to one visual field over another (as suggested by the Experiment 3a orientation results) *or* enhanced their memory for a particular valence category. Future research should develop a better set of stimuli that matches the content within each valence category as closely as possible.

Ecologically valid experiments shed light on whether differences observed in the lab occur in the real-world. Here, we used a free-viewing paradigm to determine whether people show a leftward memory bias for stimuli embedded in naturalistic scenes and whether this bias depended on scene valence. We found no leftward memory bias, regardless of scene valence. Due to the limitations of the current work, in particular not tracking eye movements, we need more research to elucidate exactly when hemispheric asymmetries for visuospatial attention and emotional processing do and do not bias memory.

6 Using the Landmark Task to Test the Underlying Assumptions of Unilateral Contraction Research[33]

6.1 Abstract

Unilateral contraction research assumes that instructing participants to squeeze a ball with one hand (e.g., left hand) activates the contralateral hemisphere (i.e., right), thus enhancing a number of cognitive functions (e.g., global processing) specialized to the activated hemisphere. Here, we tested whether unilateral contractions influence visuospatial attention using the landmark task *following* (Experiments 1-3) and *during* (Experiments 4-5) unilateral contractions. Based on prior research, squeezing a ball with the right (or left) hand should lead baseline asymmetry scores to deviate further left (or right). We performed a meta-analysis on our five experiments to determine a precise estimate of the effect. This analysis showed unilateral contractions do not lead to observable changes in visuospatial attention, leading us to question if and how unilateral contractions activate the contralateral hemisphere.

6.2 Introduction

Unilateral contractions—i.e., the activation that occurs to squeeze a ball with one hand—reportedly enhance cognitive functions, including global/local processing (Gable, Poole, & Cook, 2013; Stankovic & Nesic, 2018), creative thinking (Goldstein, Revivo, Kreitler, & Metuki, 2010), skilled motor performance (Beckmann, Gröpel, & Ehrlenspiel, 2013; Gröpel & Beckmann, 2017), emotional state (Harmon-Jones, 2006; Propper, Dodd,

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[33] Moeck, E. K., Thomas, N. T., & Takarangi, M. K. T. (Revising following review). Using the landmark task to test the underlying assumptions of unilateral contraction research. *Laterality: Asymmetries of Body, Brain, & Cognition.*

Christman, & Brunyé, 2017; Peterson, Gravens, & Harmon-Jones, 2011), episodic recall (Propper, McGraw, Brunye, & Weiss, 2013), behavioural persistence (Schiff, Guirguis, Kenwood, & Herman, 1998; Experiment 1), aggression (Peterson, Shackman, & Harmon-Jones, 2008), semantic processing (Turner, Hahn, & Kellogg, 2017), socioeconomic decision making, (Harlé & Sanfey, 2015), and self-infiltration (Baumann, Kuhl, & Kazén, 2005). Unilateral contractions 'work' because the motor cortex of one hemisphere (e.g., left) activates to squeeze the ball with the opposite hand (e.g., right) and this neural activation spreads to surrounding cortical areas via white matter tracts (Peterson et al., 2008; Turner et al., 2017). But published papers largely *assume* that the activation spreads to surrounding cortical areas, relying on previously published or flawed behavioural manipulation checks. We seek to address this issue by using a behavioural index of visuospatial attention—the landmark task (first devised by Harvey, Milner, & Roberts, 1995; this version revised by McCourt & Jewell, 1999; McCourt & Olafson, 1997; Thomas, Loetscher, & Nicholls, 2012)—to determine whether unilateral contractions reliably activate the contralateral hemisphere. The landmark task is the perceptual version of manual line bisection (Szczepanski & Kastner, 2013), which published research has used as 'an alternative measure of hemispheric activation' (Baumann et al., 2005, p. 150).

Kinsbourne's (1970) *Activation-Orientation Account* of spatial attention led to the development of unilateral contractions as a method for increasing hemispheric activation. This account posits that each hemisphere controls an attentional gradient (i.e., the extent to which one stimulus captures attention over another; Kinsbourne, 1993). When one hemisphere is activated more than the other, the slope of the gradient increases, biasing attention toward the opposite hemispace. Hence, the activation which occurs to perform unilateral contractions aims to increase the slope of the attentional gradient and—as a byproduct—enhance other cognitive functions specialised to the activated hemisphere (Baumann et al., 2005; Beckmann et al., 2013). For example, to squeeze a ball with the left hand the right hemisphere (RH) activates, enhancing global processing (Gable et al., 2013)—e.g., the time taken to identify a large letter comprised of smaller letters, as in the Navon figure task (Martin, 1979). To squeeze a ball with the right hand, the left hemisphere (LH) activates, enhancing local processing (Gable et al., 2013; Stankovic & Nesic, 2018)—i.e., the time taken to identify the smaller letter. In a typical experiment, participants squeeze a rubber ball and *then* complete a task 'influenced' by hemispheric activation.

The unilateral contractions procedure assumes widespread activation occurs *and* that it continues once contractions have ceased. However, only three studies use any behavioural manipulation check—e.g., manual line bisection (Baumann et al., 2005 Experiment 2; Goldstein et al., 2010; Propper et al., 2017; Turner et al., 2017). But these studies administer few trials (e.g., two: Goldstein et al., 2010; Turner et al., 2017), do not measure baseline asymmetries (Goldstein et al., 2010) which show individual differences (Benwell, Thut, Learmonth, & Harvey, 2013; Learmonth, Gallagher, Gibson, Thut, & Harvey, 2015; McCourt, 2001; Szczepanski & Kastner, 2013; Thomas, Aniulis, & Nicholls, 2016; Thomas, Barone, Flew, & Nicholls, 2017), and compare line bisection scores with the outcome of interest, rather than the contraction conditions (Baumann et al., 2005). Given these methodological shortcomings, how convincing is the evidence that unilateral contractions—as a procedure—influence visuospatial attention?

When Propper et al. (2017) administered 10 line bisection trials, they found greater *ipsilateral* activation—i.e., on the same side as the contracted hand—confirmed with functional near-infrared spectroscopy following sustained hand clenching. Further, studies using electroencephalography (EEG) suggest unilateral contractions lead to area-specific contralateral activation (central-parietal, Gable et al., 2013; central-frontal, Harmon-Jones, 2006; central, Hirao & Masaki, 2018). But this contralateral activation does not always occur. Using EEG, Peterson et al. (2008) excluded one third of their sample (12 participants) who did not show the expected increased contralateral activation. Also using EEG, Hirao and Masaki (2018) found increased contralateral activation following unilateral contractions *but* only in central regions and with left, but not right, hand contractions of a 'hard' (vs. soft) ball for 90 (vs. 30) seconds. In fact, squeezing the same 'hard' ball for 30 seconds with the left hand led to increased ipsilateral as well as contralateral activation (Hirao & Masaki, 2018). These findings raise doubt about the validity and reliability of hemispheric activation following unilateral contractions, because we cannot assume contralateral activation occurs among all participants *or* in all cortical regions.

Across five experiments, we directly tested: Do unilateral contractions influence visuospatial attention in an observable and consistent manner? We chose to use the landmark task (adapted by Thomas et al., 2012) because it is computerised and allows for greater stimulus variation than manual line bisection. The landmark task has good construct validity with other measures of perceptual pseudoneglect, including the greyscales and the grating-scales task (Chen et al., 2019). In the landmark task, participants state which side of a *pre-bisected* line looks longer. Therefore, unlike manual line bisection, the landmark task allows us to measure visuospatial attention *during* (Experiments 4-5) as well as following unilateral contractions. Importantly, manual line bisection and the landmark task are underpinned by similar neural activation (Çiçek, Deouell, & Knight, 2009) and yield consistent intra-task reliability across two consecutive days (e.g., manual line bisection: r = .85, landmark task, r = .60; Learmonth et al., 2015). Hemispheric activation following transcranial magnetic stimulation shifts responses on the landmark task (Szczepanski & Kastner, 2013) and line bisection responds to changes in frontal lobe activation (Nash, McGregor, & Inzlicht, 2010) suggesting the landmark task, too, should be sufficiently sensitive to detect any changes in hemispheric activation associated with unilateral contractions.

Based on the mechanism described in published research, we predicted LH activation among participants in the right squeezing condition, shifting visuospatial asymmetries more rightward (compared to baseline). By contrast, we predicted RH activation among participants in the left squeezing condition, shifting visuospatial asymmetries more leftward (compared to baseline). We recruited a total of 141 participants and randomly allocated them to the right- (LH activation) or left- (RH activation) squeezing condition. Our experiments were initially designed as pilots, due to resource limits, hence the small sample size in each (Experiment 4a-4c: 20, Experiment 4d-4e: 40). We had difficulty anticipating estimated effect size, considering Goldstein et al. (2010)—the only unilateral contractions experiment reporting *d* for change in line bisection scores—is flawed by not measuring baseline asymmetries. According to Quintana (2017), a meta-analysis of five effect sizes, with an average sample size of *n* = 30 and moderate heterogeneity in each study, provides .85 power to detect medium effect size. If the effect exists, we would be interested in a medium (or larger) effect size. The data for all five experiments are publicly available on the Open Science Framework (http://osf.io/5t39k).

6.3 Experiment 4a

We administered the landmark task (McCourt & Jewell, 1999; Thomas et al., 2012) before and after participants squeezed a ball with their right or left hand—depending on random allocation.

6.3.1 **Method**

Participants. We recruited 20 participants from the Flinders University participant pool, who received $5 AUD for their time. Participants were strongly right-handed (*M* = 9.85, *SD* = 0.37 on the Flinders Handedness Survey [FLANDERS]; Nicholls, Thomas, Loetscher, & Grimshaw, 2013), 18 - 33 years old (*M* = 20.85, *SD* = 3.38) with 19 females and 1 male. All participants provided written informed consent before beginning these experiments, which were approved by the Flinders University Social and Behavioural Research Ethics Committee (these experiments comply with APA ethical standards).

Materials.

Flinders Handedness Survey. We administered the FLANDERS (Nicholls et al., 2013) to verify that participants were strongly right-handed and would likely demonstrate pseudoneglect—an attentional asymmetry toward the left side which reflects RH dominance for visuospatial attention (Bowers & Heilman, 1980; Çiçek,et al., 2009; see Jewell & McCourt, 2000 for review)—at baseline. The FLANDERS is a 10-item self-report measure of handedness, where participants select the hand (left, either, right) they use to complete obvious (e.g., "*with which hand do you write?"*) and less obvious (e.g., *"in which hand do you hold the peeler when peeling an apple?"*) tasks. Importantly, participants are told to select "either" only if one hand is truly no better than the other, which improves other handedness questionnaires where the number of mixed-handers is artificially inflated by "either" responses. Scores range from -10 (strongly left handed) to +10 (strongly right handed). The FLANDERS has high split-half reliability (Cronbach's alpha = .96) and is strongly associated with other handedness measures (e.g., Edinburgh handedness inventory; Oldfield, 1971).

Landmark Task. The landmark task is a reliable measure of visuospatial attention where participants judge whether the left or right side of a pre-bisected line looks longer. Due to pseudoneglect, people typically choose the left side (e.g., Nicholls et al., 2012). Each trial consisted a pre-bisected line comprising two black and two white bars, arranged by opposing polarity (equally often) and shown on a grey background. Each line was 140 mm wide, 5 mm high, and transected to the left or the right of centre equally often. In Experiments 4a and 4b, the lines were transected 0.5 mm (i.e., 0.0475°) only. In Experiments 4c - 4e, the lines were transected 0.5, 1, or 2 mm (where 1 mm represents 0.095°) to increase stimulus variability with the increased number of trials. As Figure 6.1 depicts, trials began with a fixation cross for 100 ms, a blank screen, and then a line for 250 ms. We kept presentation time short to maximise contralateral processing (Bourne, 2006) and because pseudoneglect is stronger with shorter durations (Thomas & Elias, 2011; Thomas et al., 2012). Once the line disappeared, participants had 2000 ms to indicate, by forced choice, whether the left or the right side of the line looked longer. The left-longer key was on the left, and the right-longer key on the right, to maintain the natural mapping between keys and responses (Thomas et al., 2012). We calculated participants' asymmetry scores by subtracting the number of leftward responses (i.e., choosing the left side as longer) from the number of rightward responses (i.e., choosing the right side as longer), dividing by the total number of trials and multiplying this number by100 to create a percentage. A negative score indicated a leftward asymmetry (i.e., RH activation) and a positive score indicated a rightward asymmetry (i.e., LH activation).

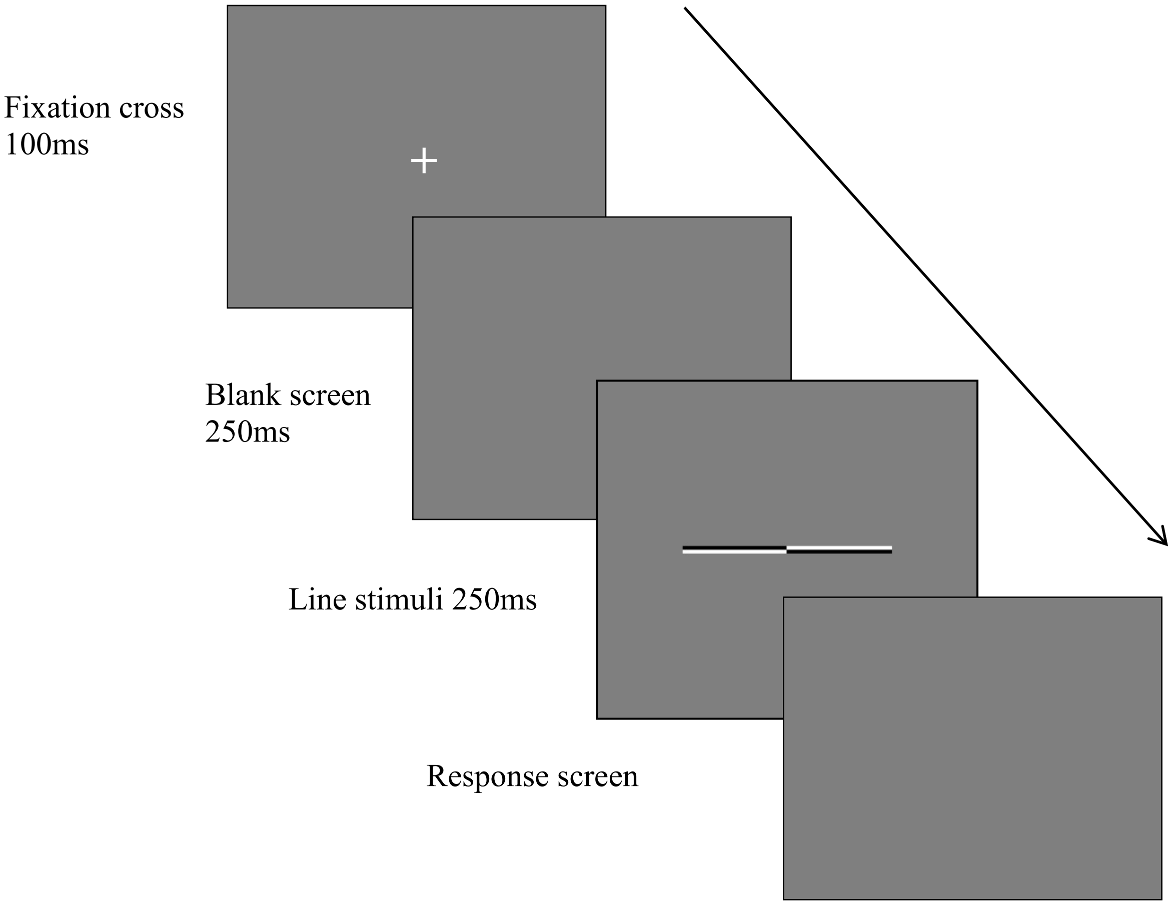

Figure 6.1. Visual depiction of a landmark task trial with an example stimulus.

Procedure. Following consent, participants completed the FLANDERS. They then completed four landmark task trials to measure baseline spatial asymmetry. We chose four trials as a starting point, doubling the number of line bisections used by Goldstein et al. (2010) and Turner et al. (2017). Next, participants completed a two-minute ball-squeezing procedure, with either the right or the left hand—depending on random allocation. We used a between-participants design to prevent possible carry over effects from squeezing with the opposite hand (Gable et al., 2013). To remain consistent with the majority of unilateral contraction research (Gable et al., 2013; Goldstein et al., 2010; Harlé & Sanfey, 2015; Harmon-Jones, 2006; Peterson et al., 2008; Propper et al., 2013; Propper et al., 2017; Stankovic & Nesic, 2018), we adapted Schiff et al.'s (1998) ball-squeezing procedure: two

45-second rounds of squeezing, each followed by a 15-second rest. We instructed participants to "*squeeze the ball on-and-off, as hard as you can*" whilst fixating their attention on a cross in the centre of the screen. To increase compliance, a researcher stayed in the room giving "start" and "stop" squeezing commands. Both hands (squeezing, non-squeezing) were resting on the table, but the non-squeezing hand was kept as still as possible with the palm facing upwards. Following the ball-squeezing procedure, participants completed another four landmark trials. Participants then sat in silence for approximately 3.5 minutes, before completing a third set of landmark trials, to establish whether changes in asymmetry scores in response to unilateral hemispheric activation could be maintained over time. Lastly, participants were debriefed and paid.

6.3.2 Results and Discussion

Overall, participants had a leftward asymmetry at baseline (Figure 6.2), which did not significantly differ between groups (independent samples t-test, $t(18) = -1.92$, $p = .07$) nor from zero (one-sample t-test, $t(19) = 1.80$, $p = .08$). We tested our hypothesis with a 2 (squeezing condition: left hand, right hand) x 3 (time: baseline, post-squeezing, post-break) mixed ANOVA to determine the influence of unilateral contractions on landmark task scores over time. Squeezing condition was a between-subjects factor and time was a within-subjects factor. As shown in Figure 6.2, participants' landmark task scores remained stable over time ($F(2, 17) = .03$, $p = .97$, $\eta_p^2 = .003$, 90% CI[34] [.00, .06]) despite our contraction manipulation. We found no interaction between time and condition, $F(2, 17) = 1.89$, $p = .18$, $\eta_p^2 = .18$, 90% CI [.00, .37]). To test evidence for the null hypothesis, we ran Bayesian analyses. A Bayesian

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[34] We report 90% CIs around η_p^2 because η_p^2, unlike *d*, can only be positive. A 95% CI could include 0, even for significant effects (http://daniellakens.blogspot.com.au/2014/06/calculating-confidence-intervals-for.html)

mixed ANOVA[35] with default Cauchy prior (Rouder, Speckman, Sun, Morey, & Iverson, 2009) confirmed these results. According to the ranges described by Wetzels and colleagues (2011), we have substantial evidence for the null hypothesis that landmark task scores remained stable over time ($BF_{10} = 0.14$), and anecdotal evidence that this stability occurred regardless of squeezing condition ($BF_{10} = 0.61$).

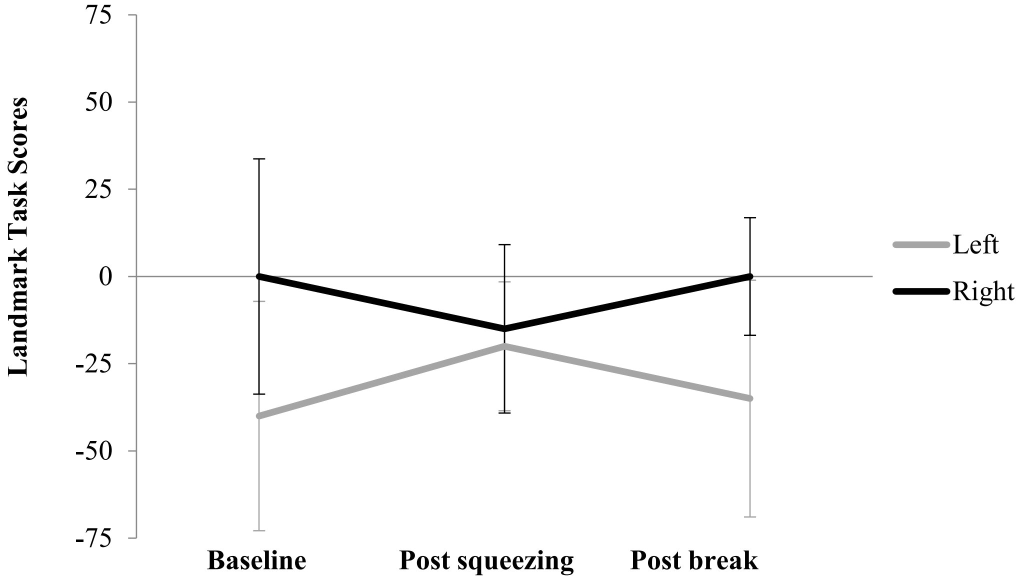

Figure 6.2. Mean landmark task scores over time for the left and right squeeze conditions in Experiment 4a (four trials per time point). Positive numbers represent a rightward asymmetry; negative numbers represent a leftward asymmetry. Error bars represent within-subject 95% confidence intervals (CIs) (Masson & Loftus, 2003).

Our Experiment 4a findings do not support our prediction; across all three time-points, there were no differences between our left and right squeezing conditions. Observed baseline differences could be due to high individual variability on the four landmark trials. Indeed, the 95% CIs were wide at baseline (Figure 6.2). Because we were interested in

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[35] We ran all Bayes analyses using JASP (2018).

change over time, it was important to reduce this individual variability, and have equitable groups at baseline. Therefore, we increased the number of trials from 4 to 12 in Experiment 4b.

6.4 Experiment 4b

6.4.1 Method

We recruited 20 strongly right-handed participants (FLANDERS: $M = 9.50$, $SD = .89$) ranging from 18 - 52 years ($M = 23.60$, $SD = 8.26$) with 13 females and 7 males. Our procedure matched Experiment 4a, except we increased the number of trials from 4 to 12 to reduce individual variation in asymmetry scores.

6.4.2 Results and Discussion

Participants had a leftward asymmetry at baseline (Figure 6.3), which did not significantly differ between groups (t(18) = -1.19, $p = .25$), nor from zero (one-sample t-test, $t(19) = 1.80$, $p = .08$). We ran a 2 (squeezing condition: left hand, right hand) x 3 (time: baseline, post-squeezing, post-break) mixed ANOVA. Similar to Experiment 4a (Figure 6.2), participants' landmark task scores remained stable over time, $F(2, 17) = 1.13$, $p = .35$, $\eta_p^2 = .12$, 90% CI [.00, .30] (see Figure 6.3). We found no interaction between time and condition in predicting landmark task scores, $F(2, 17) = .07$, $p = .93$, $\eta_p^2 = .008$, 90% CI [.00, .09]. A Bayesian mixed ANOVA with default Cauchy prior (Rouder et al., 2009) confirmed we have substantial evidence toward the null hypothesis—that landmark task scores remained stable over time ($BF_{10} = 0.30$), regardless of squeezing condition ($BF_{10} = 0.26$; Wetzels et al., 2011).

Consistent with Experiment 4a our primary prediction was not supported, increasing evidence that unilateral contractions do not observably change visuospatial asymmetries. In line with expectations, increasing trial numbers decreased the change in landmark task scores over time. However, individual asymmetry scores were still highly variable (Figure 6.3). To rule out individual variability as an explanation for our null findings, we further increased trial numbers in Experiment 4c.

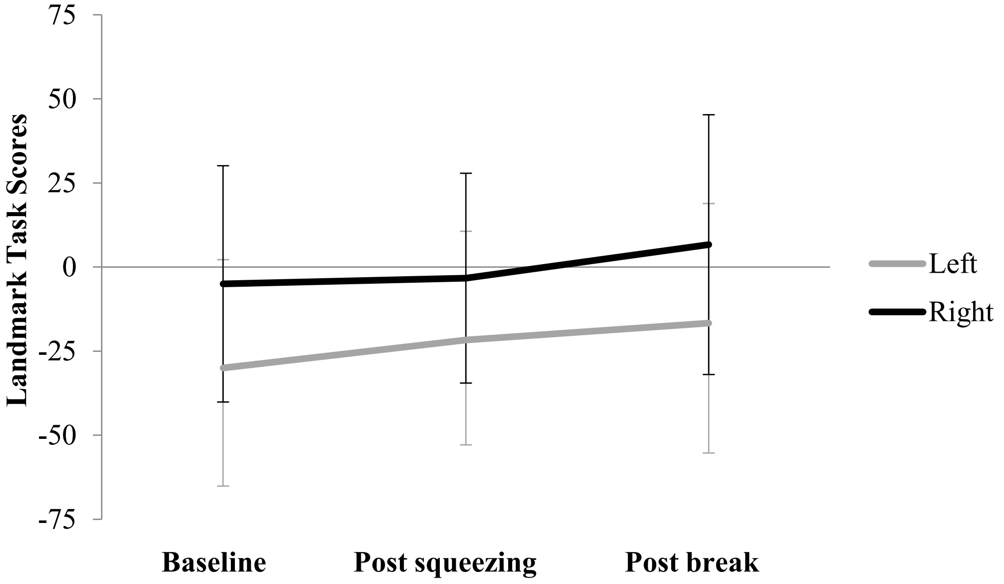

Figure 6.3. Mean landmark task scores over time for the left and right squeeze groups in Experiment 4b (12 trials per time point). Positive numbers represent a rightward asymmetry; negative numbers represent a leftward asymmetry. Error bars represent within-subject 95% CIs (Masson & Loftus, 2003).

6.5 Experiment 4c

6.5.1 **Method**

We recruited 21 participants but excluded one who stopped during the second set of line judgments. The remaining 20 participants were strongly right handed (FLANDERS: *M* = 10.00, *SD* = .00) ranging from 18 - 63 years (*M* = 26.00, *SD* = 10.75) with 14 females and 6 males.

Our procedure matched Experiments 4a and 4b, except we increased the number of trials to 144 at each time point to further reduce individual variability. We chose to use 144 trials because this number fell within the range of trial numbers in previous landmark task research (i.e., 108 and 216; Thomas et al., 2016, 2017), while allowing us to maintain a time period that did not induce fatigue. Participants completed four counterbalanced blocks of trials, each comprising 36 lines presented in random order. Due to the higher number of trials, we included lines that were transected at .5, 1, and 2 mm from centre. We counterbalanced deviation from centre as a within-subjects factor, leading to 48 trials per deviation. Although participants should find it more difficult when lines are bisected by .5, compared to 1 or 2 mm deviation, deviation does not change response asymmetry (McCourt & Jewell, 1999; Thomas et al., 2016; Thomas et al., 2017).

6.5.2 **Results and Discussion**

We ran a 2 (squeezing condition: left, right) x 3 (time: baseline, post-squeezing, post-break) x 3 (deviation: .5, 1, 2 mm) mixed ANOVA. We found no influence of deviation (*F*(2, 17) = .74, *p* = .49, $ŋ_p^2$ = .08, 90% CI [.00, .25]); as expected, participants' asymmetry scores were not affected by deviation from centre. Therefore, in line with Experiments 1 and 2, we tested our primary prediction by removing deviation as a factor. Unexpectedly, participants showed a rightward asymmetry at baseline (Figure 6.4), but this baseline asymmetry did not significantly differ between conditions (t(18) = .12, *p* = .91), nor from zero (one-sample t-test, *t*(19) = .87, *p* = .40). We tested our hypothesis with a 2 (condition: left hand, right hand) x 3 (time: baseline, post-squeezing, post-break) mixed ANOVA. We found—consistent with Experiments 4a and 4b—no effect of time (*F*(2, 17) = .81, *p* = .46, $ŋ_p^2$ = .09, 90% CI [.00, .26]), nor an interaction between time and condition (*F*(2, 17) = .63, *p* = .54, $ŋ_p^2$ = .07, 90% CI [.00, .23]) on landmark task scores (see Figure 6.4). A Bayesian mixed ANOVA with default Cauchy prior (Rouder et al., 2009) confirmed we have anecdotal evidence toward the null hypothesis—that landmark task scores remained stable over time ($BF_{10} = 0.36$), regardless of squeezing condition ($BF_{10} = 0.37$; Wetzels et al., 2011).

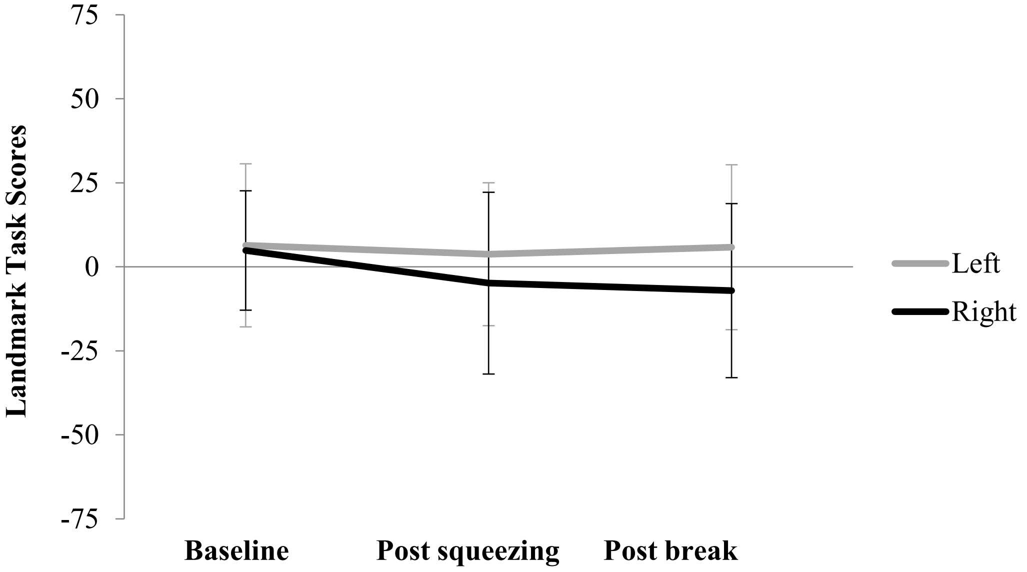

Figure 6.4. Mean landmark task scores over time for the left and right squeeze groups in Experiment 4c (144 trials per time point). Positive numbers represent a rightward asymmetry; negative numbers represent a leftward asymmetry. Error bars represent within-subject 95% CIs (Masson & Loftus, 2003).

Increasing the number of trials successfully addressed the issue of high individual variability as demonstrated by reducing the baseline 95% CI considerably. Participants' rightward asymmetry at baseline was unexpected, given healthy individuals typically show pseudoneglect (Jewell & McCourt, 2000). However, numerous studies find 5 - 50% of people show a rightward asymmetry at baseline, which suggests individual differences are important in predicting landmark scores (e.g., Benwell et al., 2013; Learmonth et al., 2015; McCourt, 2001; Thomas et al., 2016, 2017). Despite this individual difference, if unilateral contractions influence contralateral hemispheric activation we should have seen a change in asymmetries over time. But we did not.

Perhaps unilateral contractions did not influence performance because we administered the landmark task after contractions had ceased. Indeed, some EEG data suggest hemispheric activation is *depressed* (termed *relaxed* by Gröpel & Beckmann, 2017) following unilateral contractions (Cross-Villasana, Gröpel, Doppelmayr, & Bergmann, 2015). What if contralateral activation is increased during, and not after, contractions? The answer to this question is critical because researchers typically administer the 'task' that supposedly enhances contralateral activation *following* unilateral contractions. Therefore, we asked participants to respond verbally, *whilst ball squeezing*, in Experiment 4d. We also doubled our sample size to 40 participants to increase statistical power and balance baseline differences in response asymmetry scores (i.e., left- versus right-responders).

6.6 Experiment 4d

6.6.1 Method

We recruited 40 strongly right-handed participants (FLANDERS: *M* = 9.65, *SD* = .62) ranging from 18 - 50 years (*M* = 22.18, *SD* = 5.55) with 32 females and 8 males. Participants completed the FLANDERS followed by a baseline landmark task, then a 'squeezing' landmark task. To disentangle the influence of unilateral contractions and hand movements during responding, we need dependent measures that do not require lateralised motor responses (Propper et al., 2017). Therefore, participants responded to the landmark task verbally and the researcher entered their responses. To maintain task consistency, participants verbally responded during baseline and squeezing. We reduced the number of trials from 144 to 108—i.e., three blocks of 36 lines, bisected .5, 1, or 2 mm from centre—because ball squeezing whilst completing the landmark task is highly taxing. Consistent with Experiments 1-3, we instructed participants to "*squeeze the ball on-and-off, as hard as you can*" and ensured both hands were resting on the table, with the non-squeezing hand as still as possible. We removed the break, and the post-break landmark task; if contralateral activation only occurs during unilateral contractions, then there is no need to assess its maintenance over time.

6.6.2 Results and Discussion

Despite random allocation and increasing our sample size to 40, the left squeeze group demonstrated a rightward asymmetry at baseline while the right squeeze group showed a leftward asymmetry (Figure 6.5). However, one-sample t-tests showed neither of these baseline asymmetries were significantly different from zero (left squeeze: $t(19) = .91$, $p = .37$, right squeeze: $t(19) = -.76$, $p = .46$), nor from each other ($t(38) = 1.18$, $p = .25$). To test our hypothesis, we ran a 2 (squeezing condition: left hand, right hand) x 2 (time: baseline, during squeezing) mixed ANOVA. In light of our Experiment 4c results, where deviation did not influence response asymmetries, we did not include deviation as a factor. We found no influence of time in predicting landmark task scores; asymmetries were relatively consistent from baseline to squeezing, $F(1, 38) = .94$, $p = .34$, $\eta_p^2 = .02$, 90% CI [.00; .15]. This consistency over time occurred in both squeezing groups; time and condition did not interact, $F(1, 38) = 2.82$, $p = .10$, $\eta_p^2 = .07$, 90% CI [.00; .22] (see Figure 6.5). A Bayesian mixed ANOVA with default Cauchy prior (Rouder et al., 2009) confirmed we have anecdotal evidence toward the null hypothesis—that landmark task scores remained stable over time ($BF_{10} = 0.34$), regardless of squeezing condition ($BF_{10} = 0.96$; Wetzels et al., 2011).

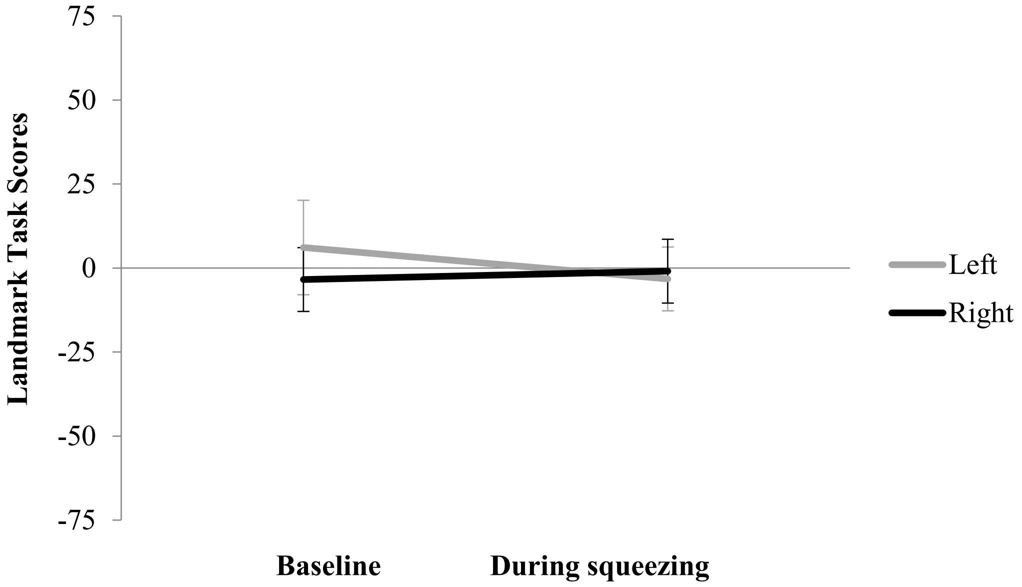

Figure 6.5. Mean landmark task scores from baseline compared to during squeezing for the left and right squeeze groups in Experiment 4d (108 trials per time point). Positive numbers represent a rightward asymmetry; negative numbers represent a leftward asymmetry. Error bars represent within-subject 95% CIs (Masson & Loftus, 2003).

The anecdotal evidence toward the null hypothesis—which Wetzels et al. (2011) defines as insufficient evidence to accept or reject the null hypothesis—prompted us to replicate this experiment with an additional categorisation block of landmark trials. Thus, in Experiment 4e we added a separate, categorization block of landmark trials (Thomas et al., 2017), enabling us to categorise participants by responder type, and control for individual differences in pseudoneglect. Controlling for these differences is important, as they influence how attention is distributed across space (Thomas et al., 2016, 2017).

6.7 Experiment 4e

6.7.1 Method

We recruited 41 strongly right-handed participants (FLANDERS: $M = 9.78$, $SD = .62$)

ranging from 18 - 48 years (*M* = 21.36, *SD* = 4.78) with 29 females and 12 males. Our procedure matched Experiment 4d, but we added a screening phase before the baseline phase. This 'screening asymmetry' measure allowed us to first categorise participants as rightward and leftward responders. We randomly allocated participants to squeeze the ball with their left, or right hand, and determined screening asymmetry pseudo-randomly, based on participants' responses to the first set of 108 landmark task trials. Time was a within-subjects factor.

6.7.2 **Results and Discussion**

We first checked for any baseline differences between our squeezing groups by comparing participants screening asymmetries (i.e., their responses to the first 108 trials). We found no significant difference in screening asymmetries between participants allocated to the left (*M* = -3.15, *SD* = 26.07) or right (*M* = -12.87, *SD* = 23.09) squeezing condition, *t*(39) = 1.27, *p* = .21, *d* = 0.40. A one-sample t-test suggested that overall, participants showed a leftward asymmetry at screening (*M* = -10.02, *SD* = 3.75) which significantly differed from zero, *t*(40) = -2.72, *p* = .01. These screening asymmetry scores show evidence for pseudoneglect and were consistent across screening and baseline landmark trials, *F*(1, 39) = .88, *p* = .35, $\eta_p^2 = .02$, 90% CI [.00; .14].

Given our groups did not differ at screening, we tested whether landmark asymmetry changed over time, depending on which hand was contracted, using a 2 (squeezing condition: left hand, right hand) x 2 (time: baseline, squeezing) mixed ANOVA. Participants' landmark asymmetry was stable over time in both the left and the right squeeze conditions, *F*(1, 39) = .005, *p* = .94, $\eta_p^2 < .001$, 90% CI [.00; .01]. In other words, squeeze condition and time did not interact to predict landmark asymmetries, *F*(1, 39) = .063, *p* = .80, $\eta_p^2 = .002$, 90% CI

[.00; .06] (see Figure 6.6). A Bayesian mixed ANOVA with default Cauchy prior (Rouder et al., 2009) confirmed we have substantial evidence toward the null hypothesis—that landmark task scores remained stable over time (BF_{10} = 0.23), regardless of squeezing condition (BF_{10} = 0.32; Wetzels et al., 2011).

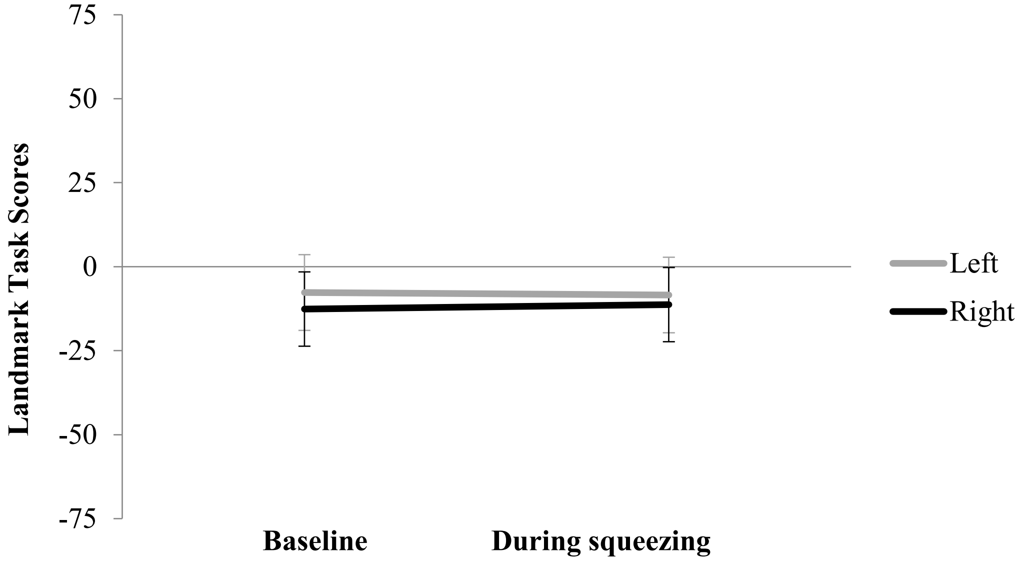

Figure 6.6. Mean landmark task scores over time for the left and right squeeze conditions in Experiment 4e (108 trials per time point). Positive numbers represent a rightward asymmetry; negative numbers represent a leftward asymmetry. Error bars represent within-subject 95% CIs (Masson & Loftus, 2003).

Our Experiment 4e findings suggest that individual differences in pseudoneglect are not a viable explanation for our null resuls. To find a precise estimate of whether unilateral contractions influence landmark asymmetry, we used Cumming's (2012) ESCI software to run a random effects model meta-analysis.

6.8 Meta-Analysis

6.8.1 Method

The random effects model compares change in landmark task scores over two time points. For consistency, we used baseline to time 1—post-squeezing in Experiments 4a to 4c and during squeezing in Experiments 4d and 4e—i.e., we did not include any post-break data.

6.8.2 Results and Discussion

Due to our small number of experiments, we had moderate heterogeneity, as indicated by $I^2 = 30.35\%$ and *tau* = 6.98, 95% CI [0, 17.46]. The CI around *tau* is wide and indicates the data are compatible with being completely homogenous (*tau* = 0) as well as heterogeneous (*tau* = 17.46), suggesting a random effects model is most appropriate. As depicted in Figure 6.7, the CI around the effect size for Experiments 4a and 4b is particularly wide, likely due to small sample sizes, few landmark trials per timepoint, and high individual variability—as previously indicated by the wide 95% CIs on mean landmark asymmetries (see Figures 6.2 and 6.3). It is for these same reasons that those two experiments contribute smaller loading to the pooled effect size than Experiments 4c to 4e. The meta-analysis provides an estimated raw effect size of 0.27 (95% CI [-11.03, 11.53], $p = .22$), evidencing no difference between the right and left squeezing groups on mean change in landmark scores. Given the CI crosses zero, we can conclude that unilateral contractions have no observable influence on response asymmetries, regardless of which hand is contracted.

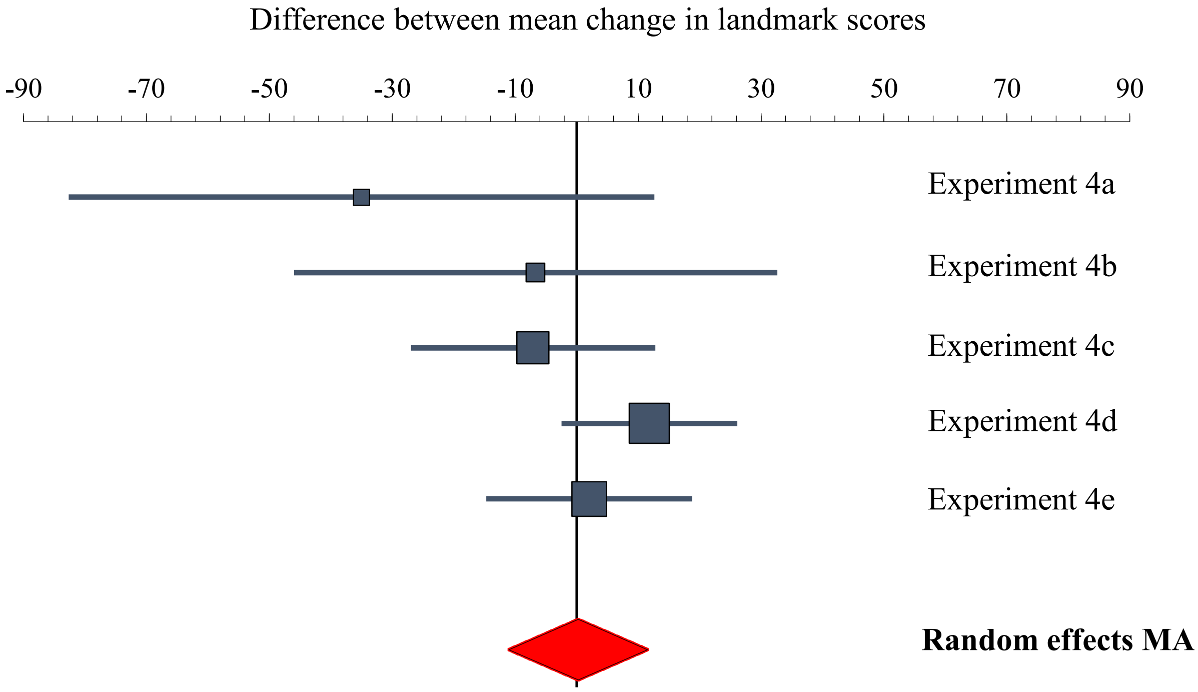

Figure 6.7. Forest plot displaying random effects meta-analysis of the effect sizes across our experiments. Each row represents a different experiment with each square representing the experiment's effect size—the difference between the mean change (Exp. 4a-4c: baseline to post squeezing, Exp. 4d-4e: baseline to during squeezing) in the left vs. right squeeze conditions. The horizontal line extending from each square represents the CI of the effect size. The size of each square represents its sample size and thus, weighting in the meta-analysis. The diamond represents the pooled effect size and its spread represents the 95% CI.

6.9 General Discussion

Published research suggests unilateral contractions enhance a wide variety of cognitive functions including global and local processing (Gable et al., 2013), creative thinking (Goldstein et al., 2010), and episodic recall (Propper et al., 2013). But, until now, their usefulness in shifting biases in visuospatial attention—which is reliably influenced by hemispheric processing—has not been directly assessed. It was important to address this gap to determine, more generally, if unilateral contractions activate the opposite hemisphere in an observable manner. Contrary to expectations, we found that intermittent unilateral contractions do not influence subsequent or simultaneous landmark task performance.

Our findings fit with Turner et al. (2017) and unpublished results from Kranz and Grimshaw. Turner et al. administered line bisection following unilateral contractions in two experiments (total $N = 119$). Averaging across all trials they found no convincing evidence that unilateral contractions altered participants' visuospatial asymmetry. In an unpublished experiment, Kranz and Grimshaw (2012) administered the greyscales task (see Nicholls, Bradshaw, & Mattingley, 1999) following unilateral contractions in a large sample (227 participants). In the greyscales task, participants choose which of two equiluminant bars looks darker; the bar that is dark on the left is most often chosen as being darker. Consistent with our data, response asymmetries did not change, regardless of hand contracted, $t(225) = .98$, $p = .328$. Turner et al. (2017), Kranz and Grimshaw's unpublished data, and our findings provide strong evidence from three different visuospatial tasks and a large cumulative sample (487 participants) to conclude: unilateral contractions may be an ineffective manipulation of visuospatial attention.

If unilateral contractions do not influence visuospatial attention, then why did Goldstein et al. (2010) find significant differences in line bisection following sustained unilateral contractions? In Goldstein et al., participants who contracted their right hand showed significantly more positive bisection scores than participants who contracted their left hand ($d = 0.74$). But this paper did not measure bisection scores at baseline, administering just two line bisections after unilateral contractions. Thus, it is possible that the observed difference was due to inherent group differences. Further, they used Israeli participants who, due to reading direction, show a central tendency in spatial attention (Turner et al., 2017).

Baumann et al. (2005) and Nicholls, Loftus, Mayer, and Mattingley (2007) measured baseline asymmetries and administered substantially more line bisection trials than Goldstein et al. (2010). However, both these studies report line bisection data in relation to their primary outcome measures; self infiltration (Baumann et al., 2005) and doorway bumping (Nicholls et al., 2007). Therefore, we cannot determine whether the reported difference (Baumann et al., 2005) or no difference (Nicholls et al., 2007) in line bisection over time were due to contraction (or unimanual activity; Nicholls et al., 2007) condition or an individual difference that also influenced the primary outcome.

Alternatively, perhaps hemispheric activation only occurs with *sustained* and not *intermittent* squeezing. Most studies that report effects of unilateral contractions on variables other than visuospatial attention have used sustained squeezing (Gable et al., 2013; Goldstein et al., 2010; Harlé & Sanfey, 2015; Harmon-Jones, 2006; Peterson et al., 2008; Propper et al., 2013; Stankovic & Nesic, 2018); only one (Gröpel & Beckmann, 2017) found effects with intermittent squeezing. We found no effect of intermittent squeezing on a landmark task, while Propper et al. (2017) found no effect of sustained squeezing on a line bisection task. Thus, we need additional research to clarify whether these mixed findings are due to measure (i.e., visuospatial attention vs. other cognitive functions) or clenching type. The issue of clenching type is particularly pertinent, because Hirao and Masaki (2018) found contraction strength and duration influence motor-related brain activity. Therefore, future research should compare the effects of sustained vs. intermittent squeezing on the landmark task within one experiment.

It is possible that the influence of unilateral contractions on cognitive functions may be domain specific. Our findings suggest unilateral contractions do not influence visuospatial attention. But for other cognitive domains, published research suggests contracting one hand may lead to improvements, even though contracting the other hand leads to no, or an inverse, effect. For example, left, but not right, hand contractions reduce choking under pressure leading to improvements in sporting performance (Beckmann et al., 2013; Gröpel & Beckmann, 2017). Yet, left hand contractions do not drive all effects. According to Stankovic and Nesic (2018), right hand contractions enhance local processing, but left-hand contractions made no difference to global processing. However, none of these studies included a manipulation check, suggesting future research should comprehensively test this counterintuitive explanation.

Another explanation for our results is that the landmark task is insensitive to changes in hemispheric activation resulting from unilateral contractions. According to published literature, the unilateral contractions procedure enhances lateralised processing by eliciting widespread increases in activation from the motor cortex to surrounding cortical regions, including visuospatial regions (Hellige, 1993; Peterson et al., 2008; Turner et al., 2017). Following this rationale, the landmark task, which responds to changes in hemispheric activation following transcranial magnetic stimulation (Szczepanski & Kastner, 2013), should be sufficiently sensitive. Further, researchers claim unilateral contractions enhance 'choking' under pressure (Beckman et al., 2013), behavioural persistence (Schiff et al., 1998), social economic decision making (Harlé & Sanfey, 2015), and self-infiltration (Baumann et al., 2005), which are *not* influenced by hemispheric asymmetries. Therefore, this explanation is unlikely.

Finally, could landmark asymmetry scores be fixed, leading to no change as a result of unilateral contractions? This explanation seems unlikely because we know the leftward bias in pseudoneglect is sensitive to unimanual responding (e.g., McCourt, Freeman, Tahmahkera-Stevens, & Chaussee, 2001), visual (e.g., Thomas, Castine, Loetscher, &

Nicholls, 2015) and auditory (e.g., Thomas et al., 2017) distractors, cues (e.g., McCourt, Garlinghouse, & Reuter-Lorenz, 2005), and time on task (e.g., Benwell et al., 2013) manipulations. For example, McCourt et al. (2001) had participants respond with the computer mouse in their left vs. right hand on different blocks of a landmark task. They varied response condition within-subjects and found that landmark task responses became *more* leftward when participants responded with their left compared to their right hand. Further, using eight blocks of 132 landmark task trials, Benwell et al. (2013) found participants with an inherent leftward asymmetry experienced a significant rightward shift over time, while participants with an inherent rightward asymmetry experienced a significant leftward shift. Therefore, it seems unlikely that we failed to observe changes in landmark asymmetries because this asymmetry is fixed. After considering these counter-explanations, we believe the landmark task is sufficiently sensitive to detect changes in hemispheric activation, should unilateral contractions actually elicit such changes.

Our experiments have limitations. First, the success of our manipulation relies on participants ‘squeezing the ball as hard as you can’. Hemispheric activation following unilateral contractions is often measured using neuroimaging, typically EEG (Cross-Villasana et al., 2015; Gable et al., 2013; Harmon-Jones, 2006; Hirao & Masaki, 2018; Peterson et al., 2008; Peterson et al., 2011). Unfortunately, we had no access to neuroimaging, leading us to rely on visual observation. In cases where neuroimaging is unavailable, asking participants if they squeezed as hard as possible could prove useful; however, this question relies upon self-report. Second, due to initially designing this line of research as pilot experiments, our first three experiments may be underpowered. The small sample sizes (*N* = 20, 10 per condition) of Experiments 4a-4c decrease their reliability; however, we believe conducting the meta-analysis addresses this limitation. Third, there were several methodological changes across our experiments, including the number of landmark trials and how to account for baseline differences in asymmetries. We also had no control group; it may be worthwhile for future research to use bilateral squeezing as a control condition, as in Nicholls et al. (2007). Fourth, we had participants rest their non-squeezing hand with the palm facing upwards, instead of downwards. Although unlikely, this unintentional methodological departure from prior studies (e.g., Goldstein et al., 2010) may have altered the effectiveness of our manipulation. However, if this slight change alters the effectiveness of the manipulation, then it is not a strong manipulation.

We conclude that unilateral contractions do not influence visuospatial attention, leading us to question the underlying explanation of how unilateral contractions 'work'. Although inconsistent with some prior research, this conclusion fits with findings where hemispheric activation is explicitly and appropriately measured (e.g., EEG; Peterson et al., 2008; Propper et al., 2017). Unilateral contraction researchers should clarify the basic mechanism underlying their effects, as our data suggest it is not due to widespread activation across *all* cortical regions. Our findings also speak to a larger issue; we must be cautious of using manipulations without checking whether they work with basic behavioural indices. This issue could be contributing to published false-positives, which, in the era of reproducibility (Lindsay, 2015), open science, and psychology's renaissance (Nelson, Simmons, & Simonsohn, 2017), we must address now, more than ever before.

7 Does Hemispheric Processing Influence the Development, Persistence, and Characteristics of Intrusions for Traumatic Images?

Following a traumatic event, it is normal to experience intrusive memories or future trauma-related thoughts that subside over time (Galatzer-Levy et al., 2013; Marks, Franklin, & Zoellner, 2018). However, persistent and distressing intrusions are a hallmark symptom of Post-Traumatic Stress Disorder (PTSD; e.g., Hackmann, Ehlers, Speckens, & Clark, 2004). The factors that make intrusions persistent and distressing remain unclear (Marks et al., 2018); but visuospatial attention appears to be one factor (e.g., Meyer, Krans, van Ast, & Smeets, 2017). Indeed, intrusions are often visual (e.g., Marks et al., 2018). For most people, the right hemisphere (RH) of the brain is dominant for visuospatial attention (e.g., de Schotten et al., 2011). Interestingly, greater activity in the left, compared to the right, frontal cortex is associated with *decreased* PTSD symptoms, including intrusions (e.g., Meyer et al., 2018) suggesting functions localised to the RH may be involved in PTSD symptoms. Given the RH's dominance for visuospatial attention, we wondered: does the RH play a role in intrusion development, persistence, and characteristics? We addressed this question here by manipulating hemispheric activation during encoding of traumatic images.

It is well accepted that visuospatial attention plays a role in intrusion development (e.g., Bourne, Frasquilho, Roth, & Holmes, 2010). Completing visuospatial tasks—e.g., pattern-tapping—during or directly after watching a trauma film reduces intrusion frequency in the subsequent week, compared to completing no task (Bourne et al., 2010; Deeprose, Zhang, DeJong, Dalgleish, & Holmes, 2012; Holmes, Brewin, & Hennessy, 2004; Holmes, James, Coode-Bate, & Deeprose, 2009; Holmes, James, Kilford, & Deeprose, 2010; Krans, Näring, Holmes, & Becker, 2010a; Stuart, Holmes, & Brewin, 2005). But several studies show that verbal tasks (e.g., counting backwards) lead to a similar reduction in intrusions (Brewin & Saunders, 2001; Krans, Langner, Reinecke, & Pearson, 2013; Krans, Näring, Holmes, & Becker, 2010b; Logan & O'Kearney, 2012), suggesting *any* concurrent task during or directly after encoding might reduce intrusions.

In real-life, people are unlikely to receive an intervention during or immediately after trauma. Thus, whether this reduction in intrusions is unique to intervention at *encoding* is an important applied issue. According to the *memory reconsolidation hypothesis* (Nader & Einarsson, 2010), reactivating a memory leaves it malleable for change (for review, see Scully, Napper, & Hupbach, 2017). Indeed, after reactivating participants' memory for a trauma film participants had watched 24-hours earlier, James et al. (2015) found that playing *Tetris* led to a significant intrusion reduction compared to reactivation, *Tetris* only, or no task (see Iyadurai et al. (2018) for a replication with motor accident victims). But when Hagenaars, Holmes, Klaasen, and Elzinga (2017) directly compared a verbal and visual task following reactivation, both tasks equally reduced intrusions, suggesting this reduction is not exclusive to visual tasks. Thus, an alternate possibility is that the role of visuospatial attention in intrusion formation depends on individual differences.

Meyer et al. (2017) provide support for this possibility, suggesting individual differences in visuospatial attention *efficiency* may predict intrusion development. Processing efficiency is the ability to bind specific memories to their original visuospatial context (e.g., binding a car crash memory to a specific road) and to develop separate memory representations, even for similar events—termed contextual embedding. Intrusions often occur out-of-the-blue (Ehlers, Hackman, & Michael, 2004), triggered by non-trauma-related cues (e.g., driving *any* road triggers an intrusive memory). Indeed, the lack of context associated with intrusions—alongside "nowness" and distress—strongly predicts PTSD diagnosis (Michael, Ehlers, Halligan, & Clark, 2005). In theory, when encoding the visuospatial elements of a trauma is *inefficient*—*poor* contextual embedding—memory is less context-dependent and intrusions are more likely to occur out of context. Meyer et al. tested whether visuospatial attention efficiency predicts intrusion development: Participants encoded neutral and emotional objects on neutral backgrounds and were tested on new objects, and old objects presented on either the same background as encoding or a new background. Meyer et al. operationalised stronger memory contextualisation as better discrimination of old or new objects on the same background as encoding versus a new background. Participants then watched a trauma film and reported subsequent intrusions. Memory contextualisation scores negatively correlated with intrusion frequency, distress ratings, and analogue PTSD symptoms, suggesting visuospatial attention efficiency relates to intrusion development.

Taken together, we know completing a concurrent task whilst viewing, or following reactivation of, traumatic footage reduces intrusions, and visuospatial attention efficiency influences intrusion development. But existing studies have not acknowledged the potential role of the RH—which is dominant for visuospatial attention (de Schotten et al., 2011)—in this process. We propose that functions localised to the RH may be involved in traumatic intrusions because in addition to being dominant for visuospatial attention, the initial and automatic processing of negative emotion is a RH function (e.g., Gainotti, 2012; Gainotti, 2018; Shobe, 2014). To date, no empirical work has investigated whether hemispheric asymmetries in visuospatial attention and emotional processing influence *involuntary* memory, including traumatic intrusions. We manipulated hemispheric activation during encoding of traumatic images. We focused on manipulating encoding, for two reasons: (1) because neural activation at the time of viewing a trauma film differentiates the scenes that return as intrusions from the scenes that do not (Bourne, Mackay, & Holmes, 2013; Clark, Holmes, Woolrich, & Mackay, 2016) and (2) because a person's experience during and immediately after a traumatic event (termed peri-traumatic processing) is a primary predictor of developing PTSD (e.g., Ozer, Best, Lipsey, & Weiss, 2003).

Research with PTSD samples supports the possibility that the RH may be involved in the development and maintenance of traumatic intrusions. Specifically, abnormalities in the RH have been linked with PTSD diagnosis and symptoms (Anders et al., 2015; Asbjornsen, 2011; Christova, James, Engdahl, Lewis, & Georgopolous, 2015; Davenport, Lim, & Sponheim, 2015; Engdahl et al., 2010; Hampstead, Briceno, Mascaro, Mourdoukoutas & Bikson, 2016; James et al., 2013; McDermott et al., 2016; Meyer et al., 2015; Nilsen et al., 2016). These RH abnormalities are characterised by miscommunication between right temporoparietal cortices and other cortical areas. Because stimulating the lateral temporal cortex elicits multisensory autobiographical "flashbacks" (Penfield & Perot, 1963), Engdahl et al. (2010) proposed that these abnormalities relate to intrusive PTSD symptoms. Furthermore, research using EEG has established a difference in activation over the right vs. left frontal cortex. In relation to PTSD, greater left than right frontal activity during symptom provocation (e.g., viewing a negative photograph) predicts fewer PTSD symptoms (Meyer et al., 2018; Rabe, Beauducel, Zöllner, Maercker, & Karl, 2006; Rabe, Zöllner, Beauducel, Maercker, & Karl, 2008). This effect is consistent with increased left frontal activity relating to psychological resilience and increased right frontal activity relating to psychopathology vulnerability (Harmon-Jones, Gable, & Peterson, 2010).

Due to our interest in behaviour, rather than neuroimaging, we used an experimental trauma analogue to identify whether initially activating one hemisphere more than the other during encoding influences intrusion development or persistence. Because Chapter 6 questioned unilateral contractions as an effective manipulation of hemispheric activation, we instead manipulated hemispheric activation by biasing which visual field we presented the majority of the images to. We biased image presentation across three conditions: (1) leftward (RH processing), (2) rightward (left hemisphere [LH] processing), and (3) none (equal RH/LH processing). We measured intrusions directly after encoding—to examine their development—and over three days following the lab session (Chun, 2016)—to examine their persistence. Participants rated their intrusions on characteristics (e.g., vividness, distress), which are stronger predictors of problematic intrusions than frequency (Ashbaugh, Marinos, & Bujaki, 2018; Michael et al., 2005). We predicted participants in the leftward presentation bias condition would report more intrusions of longer duration and more intense characteristics compared to participants in the rightward or no presentation bias conditions.

As a subsidiary aim, we assessed associations between initial emotional reaction (lab measures) and intrusion persistence (diary measures). Accumulating evidence with both positive (Clark, Mackay, & Holmes, 2013) and negative (e.g., Rattel et al., 2018) films suggests that the more emotionally intense people find stimuli during encoding, the more intrusions they will have. Therefore, we expected stronger emotional reactions (e.g., decrease in mood) in the lab would be associated with more persistent and intense diary intrusions.

7.1 Method

7.1.1 Participants

We recruited 170 strongly right-handed participants from Flinders University and the Adelaide community. Participants received course credit or $20.00AUD. We used Precision for Planning (Cumming, 2012) to determine our sample size. Due to software limitations, we generalized the minimum sample size (n = 44 per group) from two independent groups (target margin of error = .5, level of confidence = 95, level of assurance = 99) to three (*n* = 50 per group). We reasoned the recommended sample size for two independent groups was a suitable basis because our planned comparisons were for two groups. We removed and replaced 20 participants: 3 for not completing the diary phase and 17 for technical issues[36]. Our analyses focus on the target sample of 150 (50 per condition; 69% female, 31% male). These participants were 18-53 years (*M* = 23.57, *SD* = 6.84), had normal or corrected-to-normal vision, and were strongly right-handed (*M* = 9.77, *SD* = 0.67 on the FLANDERS; Nicholls, Thomas, Loetscher, & Grimshaw, 2013). The Flinders University Social and Behavioural Research Ethics Committee approved this experiment. Deidentified data are available on the Open Science Framework (https://osf.io/f462u/).

7.1.2 Materials

Depression Anxiety and Stress Scale. We used the Depression Anxiety and Stress Scale (DASS-21; Lovibond & Lovibond, 1995) to establish baseline symptoms and determine any effect on intrusions. Participants rated statements relating to the depression, anxiety, and stress subscales on a 4-point scale from 0 *(did not apply to me at all*) to 3 *(applied to me very much, or most of the time),* resulting in a total score between 0 and 63 (0 - 21 per subscale). Our sample had high internal consistency overall (.92), and per subscale (depression: .87, anxiety: .81, stress: .82).

Positive Affect Negative Affect Schedule (PANAS). We used the PANAS to determine whether participants' mood changed after image exposure (Watson, Clark, &

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[36] We had a recurring issue with E-Prime crashing during the thought-monitoring phase, despite our and E-Prime technicians' best efforts to resolve the issue while we were running the experiment.

Tellegen, 1988). The PANAS includes 10 positive (e.g., *excited*) and 10 negative (e.g., *scared*) words. Participants rated, from 1 (*very slightly or not at all*) to 5 (*extremely*), how each word reflected their current mood. Higher scores represent more Positive (PA) or Negative (NA) Affect. The PANAS yielded high internal consistency (.90 for PA, .89 for NA).

Frequency of Involuntary Thoughts Scale (FITS). We used this scale (Appendix H) to establish whether participant's propensity to experience involuntary thoughts in everyday life was related to the frequency, duration and characteristics of intrusions they experienced in the current study. Developed by Hyman et al. (2015), the FITS is an 8-item measure that asks participants to rate how often they experience different types of involuntary thoughts (e.g., *music (a song stuck in your head), thoughts about the future, thoughts about money)*) from 1 (*never*) to 6 (*constantly)*. Score on the FITS ranges from 8-48, with lower numbers representing less frequent involuntary thoughts. The scale has good internal consistency (Cronbach's alpha .748). It also yields good convergent validity, correlating strongly (r = .481) with the White Bear Suppression Inventory (Wegner & Zanakos, 1994), a measure of individual differences in thought suppression.

Images. Traumatic images induce comparable stress to trauma films (Uhrig et al., 2016) and their use as a trauma analogue is supported (e.g., Krans et al., 2013; Oulton, Takarangi, & Strange, 2016; Takarangi, Oulton, Green, & Strange, 2015). We selected 100 International Affective Picture System images (Lang, Ohmann & Vaitl, 1988), rated 1.31 to 2.45 on valence (1= most negative; M = 1.95, SD = .004) and 4.00 to 7.29 on arousal (9 = most arousing; M = 6.19, SD = .017). We created 5 sets of 20 images (see Appendix C) and matched the sets within 0.012 on valence, and 0.045 on arousal. Each set contained original and mirror-reversed versions of the images, to rule out left-right idiosyncracies (Dickinson &

Intraub, 2009). We ensured an even distribution of content (human face, human non-face, animals, inanimate objects) across image sets because content can influence affect ratings (Colden, Bruder & Manstead, 2008). The majority of images in each set (85 - 95%) included human content, particularly faces (65%), because these images are highly negative and arousing.

We manipulated how many images appeared in each visual field[37]. For leftward and rightward presentation bias conditions, we presented four sets in the biased visual field (80 images) and one set (20 images) in the opposite visual field. We used an 80:20 ratio, rather than placing all images in the biased visual field, to prevent habituation to presentation location. We counterbalanced image set order and which set appeared in the opposite visual field to create five versions per condition. For the no bias condition, the images appeared equally in the left and the right visual fields (50:50 ratio). We created two sets of 50—matched on valence, arousal and category—counterbalanced five times.

Intrusion Monitoring. We measured immediate intrusions with a five-minute thought-monitoring phase (Kubota, Nixon, & Chen, 2015; Oulton et al., 2016), wherein we instructed participants to think about anything they liked and press the spacebar anytime an involuntary thought or image about the photos came to mind. Participants held the spacebar until the intrusion passed, providing intrusion duration and frequency measures. Participants then completed an Intrusion Characteristics Questionnaire (ICQ; Appendix I) in relation to the thought-monitoring phase that asked whether they re-experienced one or multiple images and to describe the most frequently re-experienced image. They rated how often they found themselves thinking, to any degree, about the images (self-rated frequency: 1 = *almost never,*

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[37] We manipulated hemispheric activation via image presentation, because Chapter 6 found unilateral contractions an ineffective method for activating the contralateral hemisphere.

5 = *very frequently*), level of distress associated with the intrusions (distress: 1 = *not at all distressing*, 5 = *extremely distressing*), how vivid they were (vividness: 1 = *not at all vivid*, 5 = *extremely vivid*), and how hard they tried to push them out of their mind (suppression attempts: 1 = *not at all,* 5 = *completely*).

Participants recorded intrusions over the next three days in a paper diary (Appendix J). We assessed distress, vividness, and suppression for each intrusion using the same questions as in the lab. In line with other spontaneous cognition research (Berntsen & Hall, 2004; Kvavilashvili & Schlagman, 2011; Moeck, Takarangi, & Hyman, 2018; Schlagman & Kvavilashvili, 2008; Vanucci, Pelagatti, Hanczakowski, Mazzoni, & Paccani, 2015), we calculated mean characteristic ratings per participant by aggregating vividness, distress, and suppression ratings across each person's diary intrusions. We asked for a brief description, the time/place the intrusion occurred, and whether it was a thought, image, or thought/image.

7.1.3 **Procedure**

Laboratory. After providing consent, participants completed the FLANDERS, DASS-21, FITS, and PANAS, then encoded the images. During encoding, a chin rest ensured the head maintained a fixed position, 500 mm from the screen, to avoid changes in visual angle (Bourne, 2006). To maximize contralateral processing, we presented each image for 250 ms, 5 times, resulting in 1250 ms total encoding time per image. Participants stared at a fixation cross[38] while the images flashed in their left and right visual fields. No responses were required during encoding, which lasted 2.5 minutes. Participants completed the PANAS again, then the thought-monitoring phase, after which the researcher re-entered the room and

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[38] They eye-tracking data from Chapter 4 (Moeck et al., 2018) suggests participants reliably fixate on the cross rather than attending to the images.

gave participants the ICQ. Paper diary instructions concluded the 20-minute session.

Diary. This phase began after participants left the lab. A text message reminded them to log their entries online at 18:00 each day, to increase compliance and ensure we did not lose data from unreturned paper diaries. This log meant that if participants forgot to record intrusions as they occurred, they only reflected on one day, reducing the influence of retrospective reporting biases (Trull & Ebner-Premier, 2009). Participants then returned their diary, received payment, and were debriefed.

7.2 **Results**

We compared conditions using one-way ANOVAs (unless otherwise specified) and followed-up significant effects with Tukey HSD tests. We report Bayes Factors (BF_{10}) with default Cauchy prior (Rouder, Speckman, Sun, Morey, & Iverson, 2009) for all main results, interpreted according to the ranges described by Wetzels and colleagues (2011) (evidence for the hypothesis [strong: $BF_{10} = 10 – 30$, substantial: $BF_{10} = 3 – 10$, anecdotal: $BF_{10} = 1 – 3$], no evidence [$BF_{10} = 1$], and evidence for the null hypothesis [anecdotal: $BF_{10} = 0.3 – 1$, substantial: $BF_{10} = 0.1 - 0.3$, strong: 0.03 - 0.1]).

Manipulation checks. To examine whether image viewing worsened participants' mood, we ran a 3 (presentation bias: right, left, none) x 2 (affect: PA, NA) x 2 (time: pre, post) repeated-measures ANOVA on PANAS scores. We found a main effect of time, $F(1, 147) = 4.88$, $p = .03$, $\eta_p^2 = 03$; participants reported a significant decrease in PA ($M = 20.92$, $SD = 7.83$), accompanied by a significant increase in NA ($M = 19.87$, $SD = 7.36$), compared to their baseline mood (PA: $M = 27.17$, $SD = 7.61$, $t(149) = 14.73$, $p < .001$; NA: $M = 14.91$, $SD = 5.65$, $t(149) = -10.44$, $p < .001$). Time and presentation bias did not interact, $F(1, 147) = 1.08$, $p = .34$, $\eta_p^2 = 01$, indicating mood consistently worsened in each condition.

Intrusion frequency and duration. Our paradigm induced a high frequency of immediate intrusions[39]; on average participants experienced 9.95 (*SD* = 9.47) intrusions in the thought-monitoring phase, each lasting approximately 2.16 s (*SD* = 3.27 s). Across conditions, participants reported similar immediate intrusion frequency, *F*(2, 141) = .67, *p* = .52, ŋ^2 = .009, BF$_{10}$ = 0.12 (Table 7.1). Consistent with this objective intrusion frequency measure, presentation bias did not influence self-rated frequency, *F*(2, 128) = 1.06, *p* = .35, ŋ^2 = .02, BF$_{10}$ = .20. Among participants who experienced intrusions (87% of participants), average intrusion duration[40] was similar for each presentation bias, *F*(2, 129) = .69, *p* = .50, ŋ^2 = .01, BF$_{10}$ = 0.12. Cumulative duration, i.e., total time spent 'intruding', also followed this pattern. Although means suggested participants in the leftward presentation bias spent longer 'intruding' than participants in the other conditions, these differences were not significant, *F*(2, 129) = .97, *p* = .38, ŋ^2 = .01, BF$_{10}$ = 0.17.

Table 7.1.

Frequency and duration (average, total) of immediate intrusions

Presentation Bias	Intrusion frequency	Self-rated frequency	Average duration (seconds)	Cumulative duration (seconds)
Leftward	8.69 (8.65)	2.95 (1.22)	2.48 (3.26)	31.15 (60.30)
Rightward	10.78 (9.51)	3.13 (.97)	2.32 (3.40)	22.94 (43.00)
None	10.39 (10.29)	2.77 (1.29)	1.70 (3.15)	16.74 (38.96)

What about intrusion frequency outside the lab[41]? Participants reported 205 intrusions

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[39] We removed six participants who did not understand the thought-monitoring instructions (four reported no intrusions but responded in the ICQ that they had experienced intrusions, and two reported intrusions but responded in the ICQ that they did not experience intrusions) leaving 144 useable participants.

[40] To reduce variability in the duration data, we removed any intrusions 2SD outside an individual's mean intrusion duration.

during the 3-day diary ($M = 2.46$, $SD = 2.40$, range: 0 – 12). Most of these intrusions contained imagery; participants classified 37% as an image, 36% as a thought/image, and 27% as a thought only. We used a 3 (day: 1, 2, 3) by 3 (presentation bias: leftward, rightward, none) repeated-measures ANOVA for diary intrusion frequency (Figure 7.1). We found a main effect of time; intrusion frequency decreased over the three days, $F(2, 146) = 45.88, p < .001, \eta_p{}^2 = .32, \mathrm{BF}_{10} > 30$, but no main effect of presentation bias, $F(2, 146) = 1.29, p = .28, \eta_p{}^2 = .02, \mathrm{BF}_{10} = 0.13$. The similarity in intrusion frequency across conditions held for each day of the diary; time and presentation bias did not interact, $F(4, 294) = 2.29, p = .06, \eta_p{}^2 = .03, \mathrm{BF}_{10} = 0.11$. Taken together, these findings suggest biased presentation of highly negative scenes to the right and left visual field did not affect intrusion frequency or duration. But intrusion characteristics may better predict persistent intrusions.

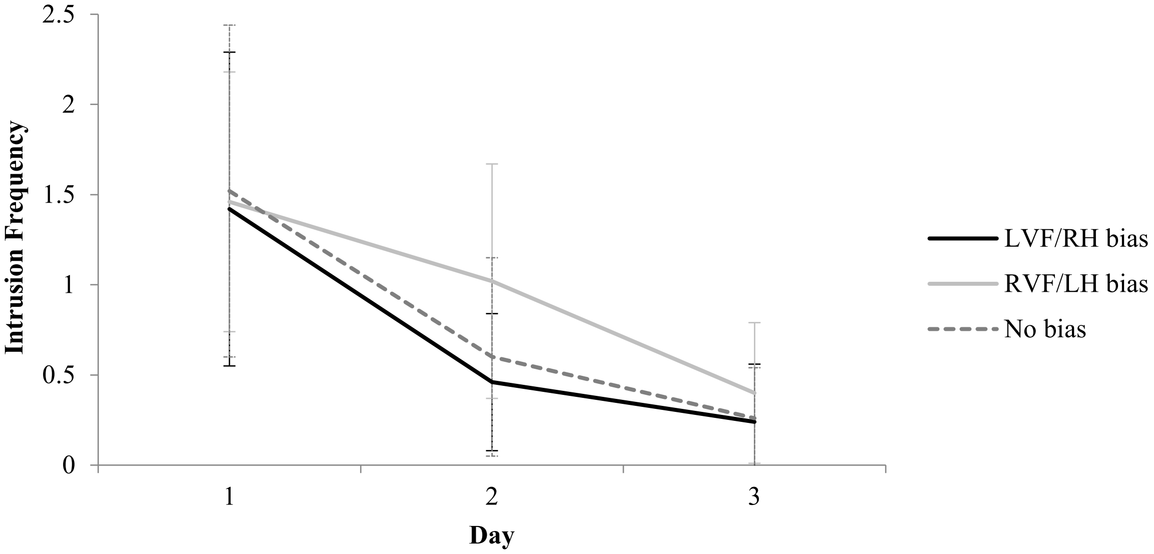

Figure 7.1. Intrusion frequency on each day of the diary depending on presentation bias condition. Error bars represent between-subject 95% CIs.

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[41] Our diary data includes participants who we excluded from our immediate intrusion data analyses because their thought-monitoring data did not match their ICQ data. Therefore, these analyses focus on all 150 participants (50 per condition).

Intrusion characteristics. We next examined whether intrusion characteristics differed depending on presentation bias. For immediate intrusions, we found a small effect of presentation bias on vividness, $F(2, 128) = 2.57, p = .046, \eta^2 = .05, \mathrm{BF}_{10} = 1.01$. Participants in the rightward bias condition rated their intrusions as more vivid than participants in the no bias condition ($M_{\text{diff}} = .56, p = .037$). There were no differences in vividness ratings between participants in the leftward and rightward ($M_{\text{diff}} = -.33, p = .33$) or the leftward and no ($M_{\text{diff}} = .23, p = .58$) bias conditions. Presentation bias did not influence distress ratings ($F(2, 128) = 2.57, p = .08, \eta^2 = .04, \mathrm{BF}_{10} = 0.60$) or suppression attempts ($F(2, 128) = .66, p = .52, \eta^2 = .01, \mathrm{BF}_{10} = 0.13$).

Table 7.2.

Characteristics Ratings of Immediate and Diary Intrusions by Presentation Bias Condition

Presentation Bias	N	Distress	Vividness	Suppression
Immediate intrusions				
Leftward	40	2.52 (1.04)	2.80 (1.09)	3.65 (1.19)
Rightward	47	2.85 (1.27)	3.13 (1.03)	3.68 (1.07)
None	44	2.30 (1.19)	2.56 (1.08)	3.41 (1.39)
Diary Intrusions		Distress	Vividness	Suppression
Leftward	38	2.29 (1.02)	2.69 (1.02)	3.04 (1.27)
Rightward	43	2.57 (1.08)	2.64 (.80)	3.22 (1.18)
None	42	1.93 (.92)	2.33 (.95)	3.00 (1.31)
‘Worst’ diary intrusion		Distress	Vividness	Suppression
Leftward	38	2.58 (1.17)	3.14 (1.20)	3.38 (1.38)
Rightward	43	2.99 (1.23)	3.30 (1.19)	3.42 (1.50)
None	42	2.29 (1.15)	2.63 (1.02)	3.58 (1.31)

We averaged distress, vividness, and suppression ratings for the 123 participants who reported diary intrusions. Presentation bias influenced distress ratings, $F(2, 120) = 4.37, p =$

.015, $\eta^2 = .07$, $BF_{10} = 2.86$ (Table 7.2). Participants in the rightward bias condition made higher distress ratings than those in the no bias condition ($M_{\text{diff}} = .64$, $p = .011$). There was no difference in distress ratings between the leftward and rightward ($M_{\text{diff}} = -.29$, $p = .40$) or the leftward and no ($M_{\text{diff}} = .35$, $p = .23$) bias conditions. Presentation bias did not predict vividness ratings, $F(2, 120) = 1.84$, $p = .16$, $\eta^2 = .03$, $BF_{10} = 0.36$, or suppression attempts, $F(2, 120) = .36$, $p = .70$, $\eta^2 = .005$, $BF_{10} = 0.11$.

Next, we looked at the characteristics of participants' 'worst' diary intrusion; determined as the intrusion with the highest total distress, vividness, and suppression ratings. Isolating participants 'worst' intrusion allows us to compare characteristics ratings equated for frequency, unlike average ratings where the denominator varied from 1 to 12 intrusions[42]. In line with average characteristics, presentation bias did not influence suppression attempts, $F(2, 120) = .25$, $p = .78$, $\eta^2 = .004$, $BF_{10} = 0.10$, but did influence distress, $F(2, 120)$ 3.76, $p = .026$, $\eta^2 = .05$, $BF_{10} = 1.74$. Distress was higher for participants in the rightward bias than the no bias condition ($M_{\text{diff}} = .70$, $p = .02$), but there was no difference between the leftward and rightward ($M_{\text{diff}} = .41$, $p = .26$) or the leftward and no ($M_{\text{diff}} = .29$, $p = .27$) bias conditions. Unlike average vividness, presentation bias *did* influence how vivid participants rated their worst intrusion, $F(2, 120) = 4.01$, $p = .02$, $\eta^2 = .06$, $BF_{10} = 2.13$. Similar to distress ratings, vividness was higher for participants in the rightward than the no bias condition ($M_{\text{diff}} = .67$, $p = .02$), but there was no difference between the leftward and rightward ($M_{\text{diff}} = .16$, $p = .25$) or the leftward and no ($M_{\text{diff}} = .29$, $p = .27$) bias conditions.

Correlations between lab and diary intrusions and symptom scores. A subsidiary aim was to assess associations between initial reactions (lab measures) and intrusion

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[42] Three paired samples t-tests confirmed that average characteristic ratings were lower than participants 'worst' intrusion characteristics (*t* values -.65 to -8.10, *p* values <.001).

persistence (diary measures). Stronger emotional reaction to initial intrusions was associated with the presence of, and stronger reaction to, diary intrusions (Table 7.3). What about emotional intensity experienced during initial *encoding* (Clark et al., 2013; Hall & Berntsen, 2008; Rattel et al., 2018)—operationalized as the change in PA and NA over time (pre, post image exposure)? Change in NA positively correlated with intrusion frequency (immediate: $r = .26$, $p = .001$, diary: $r = .35$, $p < .001$) and all characteristics ratings (immediate: r values = .31 to .57, p values <.001, diary: r values = .21 to .51, p values <.02). We found a negative correlation between change in PA and diary intrusion frequency ($r = -.20$, $p = .02$) and all characteristics (immediate: r values = -.17 to -.19, p values <.05, diary: r values = -.18 to -.24, p values <.05). Change in PA did not correlate with immediate intrusion frequency ($r = -.08$, $p = .31$).

Table 7.3.

Correlations Between Frequency and Characteristics of Immediate and Diary Intrusions

	Diary intrusion frequency	Diary average distress	Diary average vividness	Diary average suppression
Lab intrusion frequency	.47**	.17	.03	.08
Lab self-rated frequency	.49**	.37**	.22*	.28**
Lab distress	.32**	.73**	.42**	.52**
Lab vividness	.30**	.50**	.48**	.45**
Lab suppression	.14	.38**	.18	.58**

** correlation significant at .01 level, * correlation significant at .05 level

Finally, we examined associations between symptom scores and intrusion measures. Depression, anxiety and stress symptoms were normal (depression: $M = 4.01$, $SD = 3.8$; normal: 0 - 7, anxiety: $M = 3.41$, $SD = 3.57$, normal: 0 - 9; stress: $M = 5.91$, $SD = 3.94$, normal: 0 – 14; Lovibond & Lovibond, 1995). Immediate intrusion frequency positively correlated with anxiety (*r* = .24, *p* = .003) and stress (*r* = .23, *p* = .004), but not depression (*r* = .10, *p* = .25) symptoms. Immediate intrusion distress also positively correlated with anxiety (*r* = .24, *p* = .006) and stress (*r* = .24, *p* = .005) symptoms. These correlations did not last over the diary phase (*r* values = -.02 to .18, *p* values > .05).

Contrary to our expectations, the Frequency of Involuntary Thoughts Scale (Hyman, 2015) did not correlate with immediate or diary intrusion frequency (*r* values < .14, *p* values >.10).

7.3 **Discussion**

We sought to determine whether biasing hemispheric activation during encoding of traumatic images influenced intrusion development, persistence, and characteristics. Counter to our expectations that RH processing would lead to more frequent and problematic intrusions, biased presentation of negative scenes in the right and left visual field did not influence intrusion frequency, or duration, either immediately, or in the subsequent three days. However, participants who initially processed the majority of images in the *LH* rated their immediate and ‘worst’ diary intrusion as slightly more vivid, and their diary intrusions as slightly more distressing, than participants who processed the images equally in both hemispheres. Despite these higher vividness and distress ratings, we found no difference in suppression attempts.

Our finding that LH processing induced slightly more distressing and vivid intrusions than equal RH and LH processing does not fit with research suggesting increased LH activation indicates PTSD resilience, or with neuroimaging data suggesting abnormalities in the RH are associated with intrusions (e.g., Davenport et al., 2015). We speculate two reasons for this discrepancy. First, hemispheric differences could relate to *retrieval* and not encoding processes. We manipulated hemispheric processing during encoding to remain consistent with most intrusion research and because peri-traumatic processing is one of the strongest predictors of developing PTSD (e.g., Ozer et al., 2003). However, there are a number of higher order neurological processes involved in the development and maintenance of intrusions that are not encompassed by an encoding manipulation. For example, Clark and Mackay (2015) propose intrusive memories occur as a result of heightened involvement of five cognitive processes—attention hijacking, emotional processing, involuntary recall, mental imagery, and autobiographical memory—each of which has a different neural underpinning. Further, crucial processes predicting the maintenance of intrusions may occur *after* encoding. Indeed, Marks et al. (2018) suggests negative appraisals of intrusions are crucial to whether these intrusions will recur and become problematic. Future research could manipulate hemispheric processing after encoding, e.g., by using a divided-visual field symptom provocation task, to better encompass hemispheric contributions at other processing stages. This suggestion is supported by the Hemispheric Encoding/Retrieval Asymmetry model (HERA; Tulving, Kapur, Craik, Moscovitch, & Houle, 1994) which posits hemispheric differences in encoding *and* retrieval.

The HERA model posits that the left pre-frontal cortex (PFC) is more involved than the right PFC during episodic memory encoding. The pattern reverses during memory retrieval, where the right PFC is more involved than the left PFC. To test the HERA model, visual field needs to be manipulated at encoding *and* retrieval because the key comparison is activation differences between these two processing stages (Habib, Nyberg, & Tulving, 2003). The majority of support for the HERA model comes from verbal stimuli, though according to Habib et al. (2003) the model holds for non-verbal stimuli. But does the HERA model predict behavioural responses? Macbeth and Chiarello (2019) tested this question using non-verbal stimuli in two experiments. Participants viewed unfamiliar Chinese characters for 150ms in a unilateral divided visual field paradigm (i.e., a single stimulus appeared in the left OR the right visual field). At test, the stimulus appeared in the same visual field as encoding (to elicit *intra*hemispheric processing) or in the opposite visual field as encoding (to elicit *inter*hemispheric processing). If the HERA model holds for this task, we would expect superior memory accuracy when the stimuli was encoded from the RVF (LH processing) and retrieved from the LVF (RH processing) than in any other encoding-retrieval combination. Instead, participants showed a 6-10% advantage when the stimuli were encoded and retrieved by the same hemisphere than when they were encoded and retrieved by opposite hemispheres. Future research should test whether these results hold with more complex non-verbal stimuli, like the images used in the current study.

Second, hemispheric asymmetries may influence healthy, compared to clinical populations, differently. We chose a non-clinical sample for three reasons: (1) to establish whether/how hemispheric asymmetries influence healthy emotional processing, (2) because a similar network of cortical regions is active during involuntary retrieval for PTSD and trauma exposed controls (Hall, Gjedde, Kupers, 2008), and (3) to infer causality. Our findings suggest that in a healthy population, preferential LH processing may lead to slightly more vivid and distressing intrusions than processing equally with both hemispheres. Interestingly, Kühn, Vanderhasselt, De Raedt, and Gallinat (2014) found, also in a healthy population, that connectivity in the putamen-left inferior frontal gyrus is associated with self-reported frequency of unwanted thoughts. Based on our finding that biased LH processing led to slightly more vivid and distressing intrusions, we speculate that in non-clinical populations, LH processing may lead to poor contextual embedding (Meyer et al., 2017) of trauma because the LH is not specialized for visuospatial or initial emotional processing (Shobe, 2014). By contrast, RH processing may lead to more efficient contextual embedding of the trauma, due to the specialization of this hemisphere in visuospatial attention and emotional processing. In a clinical population, neural abnormalities could lead the RH to behave similarly to the LH in a healthy population, i.e., giving rise to distressing and vivid intrusions. Future research should recruit trauma-exposed participants with and without PTSD or, at a minimum, measure PTSD symptoms among a non-clinical population—to test this speculative explanation.

There area number of limitations to this experiment. First, we cannot rule out that the null results, particularly for frequency and duration, were caused by ineffectively manipulating hemispheric processing. We presented each image for 250 ms, which is longer than the 180 ms ideal presentation recommended by Bourne (2006) for divided visual field paradigms. Because participants maintained central fixation with 500 ms in Experiment 2a and 2b—where we found visual field differences in a bilateral divided visual field paradigm—we were confident that 250 ms was an appropriate choice of presentation time. However, without eye-tracking participants in this experiment, which also differed from Experiments 2a and 2b, through using a unilateral divided visual field paradigm, we cannot confirm they maintained central fixation. Second, our measure of intrusion duration was limited. Asking participants to respond when their intrusion ended is problematic because the moment people signal a thought has ended (by releasing the spacebar), they are experiencing the thought in some form (Purdon, Gifford, McCabe, & Antony, 2011). Future research should identify whether intrusion duration is a useful measure, considering intrusions are typically brief but intense and vivid recollections of the trauma (e.g., Marks et al., 2018). Intrusions may be even more fleeting following trauma analogues than real-life trauma, because analogues are substantially less intense (Rattel et al., 2018). Third, viewing traumatic images in the lab is not the same as a real-life trauma. Future research could use virtual reality, which leads to emotionally intense personally relevant memories (Schweizer et al., 2018) that are more akin to real-life trauma than passively viewing images. Importantly, virtual reality maintains experimental control; we could manipulate hemispheric processing by tracking eye movements and placing target stimuli in each visual field. Fourth, our self-rated intrusion frequency measure unintentionally encompassing voluntary thoughts. We asked participants "how often did you find yourself thinking to any degree about the images"; the term 'to any degree' may have led them to include voluntary and involuntary thoughts. Because the vividness, distress, and suppression ratings followed this question, it is possible that participants continued to reflect on voluntary and involuntary thoughts throughout the ICQ. However, participants lab-based and diary (where we did not assess self-rated frequency) intrusions were strongly correlated and voluntary retrieval of trauma is typically associated with enhanced involuntary recall (Hall & Berntsen, 2008; Rubin, Berntsen, & Johansen, 2008), decreasing our concern that this limitation influenced our results.

Currently, PTSD diagnosis and treatment rely on self-report measures (Rosen & Lilienfeld, 2008), which are prone to biases and memory distortions, prompting researchers to search for alternative treatments. For example, Hampstead et al. (2016) proposed transcranial direct current stimulation to inhibit function of the *right* lateral temporal cortex as a treatment option for PTSD. Before we can develop treatment options targeting one particular hemisphere, we must know the role of each hemisphere in PTSD symptomology. This experiment is the first to investigate hemispheric processing in the development, persistence, and characteristics of intrusions. Our findings suggest that in a non-clinical population *LH* processing slightly increases intrusion vividness and distress. Because of the small Bayes factors, these unexpected findings warrant replication, ideally alongside a measure of PTSD symptoms. The correlations between initial intrusions and intrusion persistence add to a growing body of work suggesting it is not *if* intrusions develop following a trauma, but *how* they are experienced that influences their persistence.

8 General Discussion

8.1 Summary of aims and findings

The right and left hemispheres contribute uniquely to cognitive functions, including visuospatial attention and emotional processing. This thesis aimed to determine whether these hemispheric asymmetries bias how we attend to and remember emotional (vs. neutral) images. I achieved this aim by establishing right and left hemisphere contributions to three behavioural outcomes: (1) disengaging from emotional distractors to detect neutral targets (Chapter 3), (2) recognition memory of emotional vs. neutral images (Chapters 4 & 5), and (3) involuntary memories for negative images (Chapter 7). My findings suggest asymmetries for visuospatial attention and emotional processing *do* influence these behavioural outcomes, but not in one consistent direction. The direction in which these asymmetries influence memory depends on task type, whether contralateral processing is maintained, and the type of memory measured (i.e., voluntary vs. involuntary). As a subsidiary aim, I investigated the utility of unilateral contractions for manipulating hemispheric activation (Chapter 6). A meta-analysis of the results of five experiments demonstrated that intermittent unilateral contractions do not alter visuospatial attention biases, suggesting they may be an ineffective manipulation of hemispheric activation.

Hemispheric processing some, but not other, behavioural outcomes. In Chapter 3, right hemisphere (RH) processing improved the detection of left visual field targets—presumably due to visuospatial attention being a RH function, but I found no hemispheric differences in emotion induced blindness. Despite visuospatial attention and emotional processing asymmetries not having a combined influence on attention capture by emotional distractors, these asymmetries *did* influence recognition memory. Specifically, in Chapter 4 I found a *left hemisphere* memory deficit in recognising emotional, but not neutral, images. I did not replicate this LH memory deficit in Experiment 3a or 3b (Chapter 5), where there was no influence of visuospatial attention and emotional processing asymmetries on recognition memory for stimuli located *within* scenes. However, several methodological differences—including increased presentation time and the use of a free-viewing paradigm—between the experiments in Chapter 4 vs. 5 could explain this lack of replication. Finally, in Chapter 7 there were no hemispheric differences in intrusion frequency and duration, though slight LH enhancement of intrusion characteristics. There are three key factors that help explain the discrepancies in findings between these chapters: task type, contralateral processing, and the type of memory being measured.

8.1.1 **The role of task type.**

The comparison between Chapters 3 and 4 highlights that task type may be a critical factor in how hemispheric asymmetries influence behavioural outcomes, because of the relative contribution of component processes involved in each task. The influence of hemispheric asymmetries on behaviour will depend on where each component process is localised, and how important the component processes are to each task. In Chapter 3, I predicted that participants would show more EIB with RH than LH processing because increased attention toward the left makes people more susceptible to attention capture on the left (Du & Abrams, 2010) and, despite their differences, emotional processing theories generally agree that the RH is dominant for the automatic processing of emotion upon first perception (Davidson & Fox, 1982; Gainotti, 2012; Gainotti, 2018; Shobe, 2014). Because participants viewed each image for just 100 ms, I predicted the RH would be more ‘caught up’ by the negative distractors than the LH, impairing left visual field target detection.

However, the lack of hemispheric difference in EIB makes sense if we also consider the RH's dominance for visuospatial attention, another component process involved in EIB. Visuospatial attention is a well-supported RH asymmetry that leads to a slight leftward bias in attention (e.g., Bowers & Heilman, 1980). In line with this leftward bias in attention, participants showed superior left side target detection, particularly on trials without distractors, suggesting visuospatial attention biased this task. Therefore, perhaps there was a combined influence of these RH processes, but we did not observe it behaviourally because they cancelled each other out.

In Chapter 4, visuospatial attention and emotional processing asymmetries led to an observable difference on recognition memory. I may have observed a difference on recognition memory but not disengaging from emotional distractors because of a difference in the relevance of emotion to each task. Ocklenburg et al. (2016) posits that emotional processing asymmetries influences judgments when emotion is task relevant—i.e., integral to the main task judgment—but not when it is irrelevant. Indeed, emotional processing asymmetries influence people's ability to discriminate emotional from neutral images (Calvo et al., 2015), where emotion is relevant to the task judgment, but not people's ability to inhibit responses in a go/no-go task where some of the no-go trials are emotional (Ocklenburg et al., 2016). Free-viewing paradigms also support this proposition; there is a stronger left visual field bias when judging the emotion of a face vs. making a judgment not explicitly related to emotion, like the gender of the face (Voyer et al., 2012). Future research could test the role of task relevance for emotion by replicating Experiment 1b with task-relevant emotional distractors, e.g., by adding a memory test for the emotional distractors at the end of each block and informing participants about this memory test (Kennedy et al., 2018).

8.1.2 **The importance of contralateral processing.**

Chapter 4 and 5 focused on the same behavioural index—recognition memory for emotional vs. neutral scenes—but had discrepant findings. This discrepancy suggests visuospatial attention and emotional processing asymmetries only influence recognition memory when contralateral processing is maintained. In Chapter 4, I isolated the processing of stimuli by each hemisphere by presenting image pairs for 500 ms in a divided visual field paradigm and having participants maintain central fixation. To increase ecological validity, in Chapter 5 I presented entire scenes for 3000 ms in an online free-viewing paradigm and did not ask participants to maintain central fixation. Taken together, these findings suggest that unless contralateral processing is maintained (e.g., through short presentation times and central fixation) the LH memory deficit found in Chapter 4 does not occur. Future research could clarify the role of contralateral processing in recognition memory for objects within emotional scenes by replicating Experiment 3b with reduced presentation time (e.g., 500 ms) and overlaying the scenes with a fixation cross (as in Dickinson & Intraub, 2009).

8.1.3 **Voluntary vs. involuntary memory.**

My findings suggest emotional processing asymmetries may influence voluntary and involuntary memory differently. I found no hemispheric differences in the development and persistence of intrusions in Experiment 5, inferred by similar intrusion frequency in all three processing conditions. Yet, I found a LH *deficit* for recognition—a form of voluntary memory—of negative images in Experiment 2a. According to Rubin et al. (2008), trauma memories that are readily available lead to increased PTSD symptoms—like intrusions. If we view the negative images used in both chapters as a trauma analogue (as in Krans et al., 2013 for example), then—counter to Rubin et al. (2008)—LH processing decreased the accuracy of trauma memories but had no effect on intrusion availability. A selective effect on one type of memory and not the other is not unique to my findings. For example, cognitive interventions that successfully reduce the occurrence of traumatic intrusions (involuntary memory) often spare voluntary memory (Deeprose et al., 2012; Holmes et al., 2009; Holmes et al., 2010; James et al., 2015). Indeed, it is crucial for these interventions to leave voluntary memory intact because, when a trauma is a crime, the victim may need to recall the event in court. If interventions can affect involuntary memory but spare voluntary memory for trauma, then it is feasible that hemispheric processing may influence the two types of memory differently. But this feasibility does not explain why hemispheric processing, specifically, influenced the two types of memory differently.

One possible explanation is that the two ‘tests’ used in these experiments differed on the presence, or absence, of retrieval cues. Retrieval is more likely when there is overlap between retrieval and encoding (Tulving & Thomson, 1973). The forced choice recognition test used in Chapter 4 provided a high degree of overlap between encoding and retrieval, because test items comprised an encoded and a filler image. In Chapter 7, participants were recalling memories without any overlap between encoding and retrieval because the thought monitoring phase had no cues. Therefore, we may only see hemispheric differences in memory when there is overlap between encoding and retrieval. This possibility is supported by frontal asymmetry research, where hemispheric differences related to PTSD diagnosis only emerge during symptom provocation, a task that provides a retrieval cue (e.g., Meyer et al., 2018) and the HERA model (Tulving et al., 1994). Future research could test this possibility by incorporating cues into the thought monitoring phase using an intrusion provocation task. In this task, participants would view blurred versions of the traumatic images they previously encoded and record descriptions of any involuntary memories that arise (Krans et al., 2016; Krans et al., 2010a; Lang et al., 2009). Trauma researchers have used intrusion provocation methods to investigate the neural processes underlying flashbacks in people with PTSD (e.g., Hughes & Shin, 2011), demonstrating their potential utility for investigating hemispheric processes involved in the disorder.

In addition to making the two tests more comparable in terms of retrieval cues, if participants describe their intrusions then we could infer which hemisphere processed which intruding image. This methodological change would overcome a substantial limitation of Experiment 5; that the intrusion measures do not allow us to determine which hemisphere processed the intruding image(s). To avoid habituation to presentation location, I manipulated hemispheric processing by presenting 80 images in the biased visual field and 20 images in the other visual field (note that each image was presented five times, resulting in a 400:100 presentation bias). Although each *image* was processed by either the RH or the LH, in all conditions both hemispheres initially processed some images. The fact that both hemispheres processed some images is problematic, because people usually experience intrusions for specific 'hotspots' of a traumatic event (e.g., Holmes, Grey, & Young, 2005). For example, imagine that a participant who initially processed the majority of the images with the RH (i.e., someone in the leftward presentation bias condition) reported 10 intrusions, but these intrusions were all of a 'hotspot' image that was processed by the LH (i.e., one of the 20 images presented in the right visual field). In this case, manipulating presentation bias without tracking intrusions back to specific images could have led to an incorrect assumption that the intrusions were of images presented in the left visual field. My measure of intrusion frequency does not allow us to determine if or when this type of situation may have occurred. To overcome this limitation, future research should present images equally often to the RH and LH (50:50; as in our no presentation bias condition) and get participants to provide a brief description of each intrusion. These descriptions could then be coded and tracked back to the hemisphere that initially processed the image. Trauma film analogues use a similar method to identify the scene from which the intrusion originated; an analogue ‘hotspot’ (Clark & Mackay, 2015).

Despite not influencing intrusion frequency, predominant LH processing led to slightly *more* vivid and distressing intrusions than equal LH and RH processing. Why did hemispheric processing influence intrusion characteristics, but not intrusion frequency? While intrusion frequency is attributed to memory availability, intrusion characteristics may relate to people’s appraisals of their intrusions (Marks et al., 2018). If the LH does have a deficit for processing and remembering negative images, then perhaps LH processing made intrusions more distressing because participants could not recall all details of the intruding image—an appraisal that increased the distress of the intrusion—and by trying to recall more details, the intrusion became more vivid. Of course, these reasons for why LH processing led to a deficit in voluntary memory, did not influence intrusion frequency, but intensified intrusion characteristics, are highly speculative; the Bayes factors for intrusion characteristics were small and there were a number of methodological differences between Chapter 4 and 7. These differences (respectively) include bilateral vs. unilateral image presentation, 500 vs. 250 ms presentation time, and, most significantly, lower valence and arousal ratings in Chapter 4 than Chapter 7. To determine whether hemispheric processing influences voluntary and involuntary recall for negative images differently, future research should control these methodological differences and measure recognition memory and intrusions within the same experiment (as in Bourne et al., 2010; Krans et al. 2010).

8.2 Theoretical implications

The results of my thesis experiments inform theories on the lateralisation of visuospatial attention and emotional processing. They also offer general insight to emotional memory, including the circumstances where emotion does and does not enhance memory.

8.2.1 **Visuospatial attention asymmetries.**

In most people, the RH is dominant for visuospatial attention—an asymmetry that is not debated. Although my primary focus was to elucidate what happens when visuospatial attention and emotional processing asymmetries are simultaneously elicited, my experiments also advance our understanding of how visuospatial attention as a RH asymmetry influences behaviour, irrespective of emotion. For this discussion, I focus on the non-emotional trials of my thesis experiments—the baseline and neutral distractor trials in EIB (Chapter 3), the neutral trials in Chapter 4 and 5, and participants' baseline responses on the landmark task (Chapter 6). Recall, most people pay slightly more attention to the left side of space (termed pseudoneglect), because the RH is dominant for visuospatial attention. In this thesis, basic pseudoneglect was demonstrated in Chapter 6, where—pooled across all participants baseline responses ($N = 141$)—I found a leftward bias (negative numbers indicate leftward and positive numbers indicate rightward bias) on the landmark task ($M = -7.11$, $SD = 34.52$). The overall leftward bias fits with the decisive evidence that a leftward bias exists for the landmark task reported in Brederoo et al.'s (2019) replication of Linnel et al. (2014). Counter to this evidence, some of my sub-samples (e.g., Experiment 4c) showed a baseline rightward bias, demonstrating individual differences do influence the extent of pseudoneglect (Benwell et al., 2013; Learmonth et al., 2015; Thomas et al., 2016, 2017).

But how does this overall leftward attention bias influence more complex behaviours than line bisection? Chapter 3 (Experiments 1a-1b) suggest it enhances the detection of left side targets. Participants showed superior detection of left than right visual field targets, an effect that was strongest on baseline trials, which have no distractors, and when the distractor-target relationship was predictable in Experiment 1a. This novel finding fits with superior detection of left than right side targets in a visual search task (Mulckhuyse et al., 2017; Nicholls et al., 2017). It also fits with attentional blink data, where people are better at detecting the second target when it appears in the left than the right visual field (e.g., Asanowicz et al., 2013). Interestingly, this left side advantage disappeared in Experiment 1b, where distractor-target relationship was unpredictable. This finding contradicts what we know from attentional blink research, where left side superiority in detecting the second target is *greater* when target location is *uncertain*, than when it is certain. What might explain this contradiction in the role of certainty and left side advantage in target detection between attentional blink and EIB?

The larger left side advantage when target location is uncertain than when it is certain is attributed to spatial orienting of attention being a RH function (Corbetta et al., 2008). It was surprising, therefore, that this same effect—i.e., greater left side advantage when target location is uncertain—did not occur with EIB. However, unlike attentional blink, which involves top-down processes of searching for the targets, EIB involves a complex interaction between bottom-up and top-down processes. In EIB, the distractor automatically captures attention (bottom up process), particularly when it is emotional, and interrupts the process of searching for the rotated target image (top down process) (McHugo et al., 2013). Thus, in EIB the dorsal and ventral stream interact, because the ventral stream detects the distractor while the dorsal stream continues to look for the target. The dorsal stream is bilateral, while the ventral stream is lateralised to the RH for particular functions. For example, the right ventral frontoparietal network directs attention toward unexpected stimuli (Corbetta & Shulman, 2002). When the distractor-target relationship is certain (i.e., they always appear in the same location), the RH may be superior at detecting the target because after detecting the distractor there is no need to shift attention away from this unexpected stimulus toward the target. When the distractor-target relationship is uncertain (i.e., they can appear in the same or opposite location), however, the RH processes the distractor *and*, on half the trials, shifts attention away from the distractor; leaving no capacity for superior target detection. Therefore, perhaps uncertainty does not increase the left side advantage in EIB in Experiment 1b because the RH detects and automatically orients attention toward the unexpected stimulus (which is not present in attentional blink), making it difficult to re-orient attention toward the target. Mulckhuyse et al.'s (2017) data supports this proposition. They found that the right posterior parietal cortex is involved in disengaging and reorienting attention, particularly from emotional stimuli.

Another explanation for why the relationship between visual field and certainty is inconsistent across attentional blink and EIB is that mental resources may be more sensitive to certainty manipulations than perceptual resources. In attentional blink, participants have to report the first *and* the second target. Having to remember the first target taxes mental resources, leading to an 'attentional bottleneck,' which limits the resources available to detect the second target (Chun & Potter, 1995). Wang et al. (2012), among others, disregard the attentional bottleneck explanation for EIB, because in EIB participants do not need to remember the distractor (unlike the first target in attentional blink). Therefore, any impairment in detecting the target in EIB cannot be due to a bottleneck of attentional resources. Instead, researchers attribute EIB to perceptual competition between the distractor and the target, where emotional distractors are automatically prioritised during initial perception (Most & Wang, 2011; Wang et al., 2012). Interestingly, this attribution is based primarily on the finding of larger EIB when the distractor and target appear in the same spatial location than when they appear in different spatial locations (e.g., Kennedy et al., 2017). However, this explanation for the inconsistent relationship between visual field and certainty for EIB vs. attentional blink is weakened, because I did not find spatially localised EIB in Experiment 1b. Thus, EIB may be due to more than just perceptual competition between the target and the distractor. Clearly, we need future research to compare the relationship between visual field and uncertainty for attentional blink and EIB within the same sample.

My thesis experiments advance our understanding of how lateralised processes influence the relationship between attention and memory. Prior studies (e.g., Della Sala et al., 2010; Dickinson & Intraub, 2009; McGeorge et al., 2007; Petrini et al., 2009) report that pseudoneglect results in a leftward memory enhancement for neutral stimuli. Unexpectedly, I did not replicate this effect; there was no left side enhancement for remembering entire neutral scenes (Experiment 2a) or stimuli within neutral scenes (Experiments 3a, 3b). Thus, presentation time, central fixation, and independent or collaborative hemispheric processing seem to alter whether this left side memory bias exists. When two scenes are presented simultaneously for 500 ms (Experiment 2a) or when objects are presented singly for 250 ms (Kensinger & Choi, 2009) in the right and left visual field, the LH and RH independently process the stimuli, respectively. With brief and isolated processing, there are no visual field differences because neither hemisphere is specialised for initially processing neutral information (e.g., Shobe, 2014). With central presentation, both hemispheres contribute to processing different aspects of the same scene, leading to neglect of the right side and increased attention to the left side of the scene. This increased attention to the left results in better memory for left side objects (Dickinson & Intraub, 2009). The findings of Experiments 3a and 3b, where I presented salient stimuli on the left and right side of scenes, suggests this left side advantage only occurs with short presentation time, e.g., 500 ms (Dickinson & Intraub, 2009), and central fixation. With longer presentation times and no instruction to maintain central fixation, participants can move their eyes and encode scene elements using both hemispheres. Here, the salience of stimuli within the scene may influence the attention-memory relationship more than hemispheric based processes.

8.2.2 **Emotional processing asymmetries.**

There are a vast number of conflicting theories and findings regarding the lateralisation of emotional processing. Traditional theories—namely the *right-hemisphere hypothesis* (Gainotti, 1972), the *valence-specific hypothesis* (Davidson & Fox, 1982), and the *circumplex model* (Heller, 1993)—searched for a basic dichotomy, but these views are problematic (Miller et al., 2013) because they do not consider that emotional processing asymmetries may differ depending on stage of processing (e.g., Shobe, 2014) or the task being completed (e.g., Grimshaw & Carmel, 2014). Another limitation with traditional theories is that they have been primarily informed by neuroimaging on clinical populations. The data from these studies is inherently noisy and confounded (e.g., from co-morbid disorders). As a result, we know surprisingly little about how the RH and LH contribute to healthy emotional processing and *if* and *how* these contributions influence behaviour. This thesis began to address this gap.

My findings suggest emotional processing asymmetries do not influence people's ability to disengage from emotional distractors, though it is possible that if the distractors were task relevant they would (Ocklenburg et al., 2016). By using an EIB paradigm, I expected to be able to determine whether a RH preference for processing emotion means faster processing of emotion, or increased difficulty disengaging from emotion. Because I found no hemispheric differences in EIB, my results do not inform this query.

Emotional processing asymmetries *did* influence people's recognition memory for emotional scenes. At first glance, Chapter 4 appears to support the right-hemisphere hypothesis because RH processing enhanced recognition memory for emotional (both positive and negative, to a similar extent) over neutral images. However, RH processing enhanced recognition memory for negative images so that it was *similar* to neutral images. With LH processing, however, recognition memory for negative images was significantly worse than neutral images. Hence, I interpreted these findings as a LH deficit for emotion, rather than a RH enhancement predicted by the right-hemisphere hypothesis. This interpretation raises an important theoretical consideration—we are constantly talking about one hemisphere being *superior* or show an *advantage* over the other for various tasks. Do we need to start considering implications of hemispheric *inferiority* or *deficits*? Here I have demonstrated how a LH deficit can influence recognition memory, which has practical implications. For example, imagine that someone was driving and looking at the road ahead when a crash occurred in their right periphery. The driver is likely to quickly look toward the crash, because we are automatically drawn to emotional stimuli. But those initial moments *before* looking directly at the crash may be crucial for a witness, because it is during those moments where any wrongdoing is likely to have occurred, e.g., if someone driving through a red light caused the crash. What if the witness's memory for the crucial events before the crash occurred, e.g., who was at fault, is worse because these events were processed by the LH? Future research could investigate this possibility by using a divided visual field paradigm with crime videos, rather than images, and test participants memory for crucial events in the video. To simulate driving, participants could simultaneously perform a task that requires central fixation, e.g., pressing a key every time the cross is replaced by a circle. If there are differences in participants' memory depending on which visual field the crime occurred, then perhaps we need to consider the vantage point of a witness when judging their reliability. Researching vantage point from a visual field perspective would advance research investigating variations in distance on eyewitness identification accuracy (e.g., Lindsay, Semmler, Weber, Brewer, & Lindsay, 2008).

How does my thesis inform our understanding of hemispheric contributions to processing positive emotions? Recall, the valence hypothesis predicts that the LH is specialised for processing positive emotions and the RH for processing negative emotions. I found no evidence for this hypothesis from Experiments 2b, 3a, or 3b; there was no difference in recognition memory of positive and negative images with RH or LH processing. Shobe's *Hemispheric Independence and Collaboration Model* (2014) predicts that the RH and LH can independently process positive emotions. If this prediction is correct, then I should have observed similar recognition memory for positive images processed by the RH and the LH. Instead, I found worse recognition memory for positive images processed by the LH than the RH. Future research should clarify how the RH and LH process positive emotion and whether hemispheric processing influences memory for positively valenced stimuli, e.g., by replicating Experiment 2b with neutral, as well as positive and negative, images.

8.2.3 Emotional enhancement of memory effect.

Because I compared memory for emotional with neutral images in Experiments 2a to 3b, my findings shed light on the circumstances where the emotional enhancement of memory effect may and may not occur. This effect—where emotional (positive and negative) stimuli are remembered more vividly (e.g., Todd et al., 2012) and more accurately (e.g., LaBar & Cabeza, 2006) than neutral stimuli—is robust, particularly for negative stimuli (e.g., Kensinger, 2009). Therefore, it was surprising that I found approximately 4% *better* recognition memory for *neutral* than negative images in Experiment 2a. In Experiment 2b, I found no difference in recognition memory between the positive and negative images. Although I did not compare positive with neutral images within the same experiment, we can infer that recognition memory was higher for neutral than emotional images. In Experiments 3a and 3b, however, I found a large emotional enhancement favouring recognition memory of stimuli from *positive* over neutral and negative scenes. The comparison between stimuli from negative and neutral scenes was less consistent than the enhancement of stimuli from positive scenes; in Experiment 3a I found no difference in recognition memory for stimuli from negative and neutral scenes, but in Experiment 3b recognition memory was higher for neutral than negative stimuli. What might explain these inconsistent findings for the emotional enhancement of memory effect?

Researchers have attributed the emotional enhancement of memory effect to the hormonal and cognitive activation that occurs when we view or experience something emotional (Talmi, 2013). Hormonally, emotional stimuli increase physiological arousal, which leads to cortisol and adrenaline being released (McGaugh, 2004). This process activates the amygdala, which is involved in consolidating emotional memory (McGaugh, 2004). Memory consolidation takes time, hence emotional enhancement of memory is typically greater after a delay (e.g., for recognition memory of scenes from 1 day vs. 14 days delay; Anderson, Yamaguchi, Grabski, & Lacka, 2006). But it still occurs with minimal delay (e.g., 30 minutes; Blake, Varnhagen, & Parent, 2001) leading Talmi et al. (2007) to investigate cognitive factors at encoding which can explain the effect. Cognitively, emotional stimuli enhance attention more than neutral stimuli and recruit cognitive functions associated with distinctiveness—i.e., where an emotional image stands out when presented alongside a neutral image—and organisation—i.e., where emotional images are more thematically related to one another than neutral images (Talmi et al., 2007).

There are several reasons—based on these hormonal and cognitive factors—for why I did not find an emotional enhancement of memory effect in Experiment 2a. First, encoding and testing occurred in one phase, leaving no delay for the amygdala to better consolidate memory for the negative than the neutral images. Further, any hormonal effects would have likely occurred for the neutral images as well, because they were interspersed with the negative images (Talmi, 2013). Second, enhanced attention to emotional over neutral images only occurs when the two are presented together. Therefore, it is unlikely to have occurred in Experiments 2a and 2b because I presented valence-matched image pairs. Using valence-matched image pairs also means there were no differences in distinctiveness within each trial. Fourth, although the negative images were more thematically related than the neutral images (e.g. recurring themes of blood, injury), our test relied on distinguishing between two images of the same valence. Therefore, using thematically related would have *reduced* recall in this study, because it would have made it harder to distinguish between a seen and unseen negative image at test. Conversely, it would have been easier to distinguish between a seen and unseen neutral image at test, because there was a greater variety of neutral images and therefore less thematic relatedness among them. Using a test that favoured distinguishability rather than thematic relatedness provides one explanation for recognition memory of neutral images being better than negative images in Study 2a. However, this unexpected finding warrants replication. It may be particularly worthwhile to see if this effect occurs with a free-recall memory test, which relies less on detailed and more on gist recall, to determine if the effect is due to hemispheric processing or test-type.

In Experiments 3a and 3b, memory for stimuli within positive scenes was 7 to 10% better than memory for stimuli within neutral or negative scenes. There are three explanations for this large positive enhancement of memory effect. First, while negative emotion enhances memory for details, positive emotion enhances memory for gist (Kensinger, 2009; Levine & Edelstein, 2009). Although I tested participants' memory for stimuli located within scenes, i.e., the scene's detail, the recognition test relied on gist more than detailed recall. Therefore, using a test that relied on gist recall may have benefitted memory for stimuli from positive over negative and neutral scenes. Second, despite my best efforts to equalise the number of people across valence categories (in light of Colden et al., 2008), there were more people in the positive than the neutral or negative scenes, particularly in Experiment 3a. Images containing people are more memorable than images without people, e.g., landscapes (Hourihan & Bursey, 2015; Isola et al., 2014). Although I tried to equate the number of people, I did not try to equate the number of animals across valence categories. There was a substantially higher proportion of animals in the positive than the negative or neutral scenes. To my knowledge, no one has directly investigated the memorability of pictures with vs. without animals. Considering pictures containing animals are rated similarly on valence and arousal to pictures containing people (e.g., in the NAPS; Marchewka et al., 2014), it is plausible that a greater representation of people *and* animals led to the large positive enhancement of memory found in Experiments 3a and 3b. Third, I may not have found a negative enhancement of memory because I matched the arousal ratings of the negative and positive scenes. In these experiments, I wanted to control arousal and isolate the effect of valence. However, this methodological decision came at a cost of the valence of the negative images; I could not use highly negative images, because they were too arousing. Therefore, perhaps my negative scenes were simply not negative enough. The similarity in content (e.g., a high number of objects) between the negative and neutral scenes supports this possibility and suggests why I found mixed results between Experiments 3a and 3b for the memory of neutral vs. negative stimuli.

8.3 Methodological implications

My thesis experiments advance and inform existing methods for studying the influence of hemispheric asymmetries on behaviour. I made four important advances to the divided visual field paradigm. First, to my knowledge, I am the first to combine the EIB and divided visual field paradigms. I found a reliable EIB effect with dual horizontal streams, showing EIB is not restricted to central streams (e.g., Most et al., 2005) or vertically placed dual streams (e.g., Most & Wang, 2011). Future research could use this method as an alternative to a lateralised no-go task (e.g., Ocklenburg et al., 2017) to understand LH and RH contributions to disengaging from emotional distractors. Second, I demonstrated the utility of the divided visual field paradigm for testing memory for bilaterally presented naturalistic scenes. This method advances the complexity of stimuli used in most divided visual field experiments; predominantly faces (e.g., Prete et al., 2018), letters or numbers (e.g., in attentional blink; see Verleger & Smigasiewicz, 2015 for review), or isolated objects (e.g., Kensinger & Choi, 2009). It also shows that participants can make higher-order judgments for complex stimuli presented in a divided visual field paradigm, advancing prior work that focused on simple judgments (e.g., discriminating whether scenes are emotional or not, Calvo et al., 2015). Third, my eye-tracking data shows that participants, when instructed, *can* maintain central fixation with 500 ms presentation time. This finding suggests the divided visual field paradigm can be used for studying higher-order processes that may require longer presentation times than what Bourne (2006) states are optimal. Fourth, presenting negative images unilaterally for 250 ms in a divided visual field paradigm may be a promising method for inducing a high number of analogue intrusions. In Experiment 5, participants reported a mean of 9.95 immediate intrusions, which is higher than the average of 5-6 reported by Clark et al. (2015) in a meta-analysis of 16 trauma film studies.

In a free-viewing paradigm—defined as presenting stimuli for at least two seconds—there is a larger left visual field bias with faces compared to other stimuli (Voyer et al., 2012). The mechanism underlying this stimulus-dependent difference in effect size is unclear. Voyer et al. (2012) argued that faces lead to a strong left visual field bias because the judgment relates to emotion of the stimulus, which increases the contribution of the RH. With stimuli other than faces, the judgments relate to functions that are less strongly lateralised including numerosity (e.g., Ashwin, Wheelwright, & Baron-Cohen, 2005) or brightness (e.g., Bellgrove et al., 2004). In Experiments 3a-3b, I extended this method by testing recognition memory for objects within emotional and neutral scenes. There are two explanations for the lack of left visual field bias: first, perhaps we did not find a left visual field bias because the judgment participants made was not about the emotion of the stimulus. Second, naturalistic scenes may be too complex to observe laterality effects in a free-viewing paradigm. I chose to use a free-viewing paradigm because they give rise to left side biases for visual stimuli, particularly when presentation time is controlled (Voyer et al., 2012). However, stimulus type may moderate this left side bias for free-viewing tasks, with a more reliable left side bias for faces than other stimuli, including grayscales and shapes. In Voyer et al.'s meta-analysis, none of the 244 effect sizes came from studies using naturalistic scenes. Thus, Experiments 3a and 3b makes an important advance to the free-viewing literature by suggesting that naturalistic scenes do not produce the left side bias observed, most reliably, with faces.

The most important methodological implication comes from Experiments 4a-4e, which questioned whether intermittent unilateral contractions are an appropriate manipulation of hemispheric activation. Unilateral contractions ‘work’ because squeezing a ball activates the contralateral motor cortex, and this activation then spreads to surrounding cortical areas (Peterson et al., 2008; Turner et al., 2017). If this mechanism is accurate, then biases in spatial attention should move in the same direction as the hand that squeezes the ball. However, I found—by running five experiments and meta-analysing the difference in landmark task scores depending on which hand participants contracted—that unilateral contractions did not influence spatial attention biases. This finding suggests that unilateral contractions may be an ineffective method for increasing activation in the RH or the LH. This starkly different conclusion to published studies—which claim that unilateral contractions enhance a number of lateralised cognitive functions, including global vs. local processing (e.g., Gable et al., 2013), episodic recall (Propper et al., 2013), and aggression (Peterson et al., 2008)—suggests that this field may have been affected by psychology’s high rate of false positives (e.g., Lindsay, 2015).

If unilateral contractions are ineffective, what is an alternative method that future research could use to manipulate hemispheric activation? Transcranial Magnetic Stimulation (TMS) is a well-supported non-invasive method of brain stimulation that is becoming increasingly feasible to use in a lab setting (Tully, 2018). In TMS, a brief high-intensity magnetic field passes through a magnetic coil placed on the scalp (Hallet, 2000). This magnetic field excites or inhibits the cortical area below the magnetic coil. Unlike unilateral contractions, TMS can target specific cortical areas. Therefore, these methods may be particularly useful for investigating emotional processing asymmetries, given the emerging view that specific lateralised areas are responsible for specific processes (e.g., dlPFC for inhibiting emotional distractors, Grimshaw & Carmel, 2014). Indeed, researchers have begun to use TMS to disentangle the contribution of areas localised to the RH and LH for specific aspects of emotional processing (e.g., dlPFC, Notzon, Steinber, Zwanzger, & Junghofer, 2018; Sagliano, D'Olimpio, Panic, Gagliardi, & Trojano, 2016). TMS has been used to investigate visuospatial attention asymmetries for several years. For example, Müri et al. (2002) established the role of the RH in visuospatial attention by pulsing the right vs. left parietal lobe whilst participants did a spatial attention task. Therefore, TMS is a promising method for investigating the interaction between visuospatial attention and emotional processing asymmetries on behaviour.

8.4 Limitations and Future Directions

There are important limitations to this thesis. I designed my thesis experiments to assess the influence of hemispheric asymmetries on behavioural outcomes. This choice was deliberate; work on hemispheric asymmetries—like most areas of neuropsychology (Krakauer et al., 2017)—is dominated by neuroimaging data from which we cannot infer causality. However, because I did not accompany my behavioural measures with any neuroimaging measures, I had to infer underlying neural processes from existing research. These inferences limit the strength of my conclusions regarding which cortical area drove which effects. For example, I suggested that in EIB, the left dlPFC is involved in inhibiting negative distractors. Although this suggestion is speculative, because I cannot confirm left dlPFC activation without EEG (or any other imaging measure), it does provide an important starting point for future research to investigate if dlPFC is activated during EIB.

My thesis experiments assumed that manipulating visual field is sufficient to observe hemispheric differences in processing and that any visual field effects are due to distinctions in hemispheric functioning (Bourne, 2006). These assumptions are well-founded; they have been drawn since the 1980s, when research began focusing on hemispheric differences in non-clinical populations rather than inferring hemispheric function from people with asymmetric brain damage. Across this thesis, I adapted the methods of visual field paradigms to suit the aims of each chapter. For example, due to measuring recognition memory, in Experiments 2a and 2b I used 500 ms presentation time in an adapted divided visual field paradigm. This departure from the shorter presentation times typically used in these paradigms (e.g., 100-180 ms) was necessary to achieve above-chance memory accuracy. These changes to the strict methodological controls known to increase the likelihood of contralateral processing (e.g., central fixation cross, short presentation time, backward masking, immediate responding; Bourne, 2006) were necessary. However, they do make it difficult to compare my results with other studies that did maintain these controls.

Across my experiments, I did not match the proportion of male and female participants. Sex is known to influence some of the cognitive processes investigated in this thesis, including memory. For example, a recent meta-analysis showed sex differences may influence episodic memory depending on material type (Asperholm, Hogman, Rafi, & Herlitz, 2019). Females show better episodic memory on verbal tasks and for nameable images, locations, and faces, while males show better episodic memory for spatial tasks including abstract images and routes. Of greater relevance are sex differences in hemispheric asymmetries. We know that males show slightly stronger hemispheric asymmetries than females across several laterality tasks and neuroimaging techniques (see Hirnstein, Hugdahl, & Hausmann, 2018, for review). However, this robust difference is small (estimated d = 0.05-0.15) and may only be detected with large samples or using meta-analysis (Hirnstein et al., 2018). Therefore, hemispheric differences due to sex were unlikely to have influenced my results, especially due to using randomly allocation to conditions in all experiments. Another limitation is that these experiments did not consider any role of motivation in hemispheric asymmetries for emotional processing. This consideration may be important for future work, given the *approach-avoidance* hypothesis (Harmon-Jones, 2003) focuses on hemispheric asymmetries related to motivation, rather than emotional valence, and we know that motivation alters the influence of attention on memory (e.g., Kaplan, Van Damme, & Levine, 2012).

My primary aim was to investigate the influence of hemispheric asymmetries on behaviour in a healthy population. To confirm that I had a healthy population, I measured self-reported symptoms of depression, anxiety, stress (Chapter 3, 4, 5, 7), and PTSD (Chapter 3, 4), which confirmed mean symptom scores were "normal" in all my samples. Dysfunctional hemispheric asymmetries are related to psychological disorders, including depression and panic disorder (Heller et al., 1998). For example, depressed people show disordered emotion regulation, which is a LH function (Jackson et al., 2003; Koslov et al., 2011). Indeed, depression is associated with LH hypoactivity (Henriques & Davidson, 1991), which leads to reduced motivation (e.g., Caeiro, Ferro, & Costa, 2013). Panic disorder is similarly associated with both LH hypoactivity and RH hyperactivity (Akiyoshi, Hieda, Aoki, & Nagayama, 2003). This RH hyperactivity is linked with two key symptoms of panic disorder: increased frequency of fear and anxiety responses (e.g., Wilhelm, Trabert, & Roth, 2001), and an attentional bias toward threat information (e.g., McNally, Riemann, & Kim, 1990). Indeed, pharmacological treatments for panic disorder simultaneously decrease RH and increase LH activity (Prasko et al., 2004). Extensively reviewing the literature on hemispheric differences associated with psychological disorders is beyond the scope of this thesis. However, because of the potential link between asymmetries and clinical disorders, I correlated participants' self-reported symptoms with each key dependent variable. By relying on correlation, my conclusions regarding any relationship between hemispheric asymmetries and clinical disorders are substantially limited; however, there were some correlations that future research should follow-up.

In Experiments 2a to 3b, I found no correlation between symptom scores and recognition memory for emotional images, nor any change in correlations depending on which hemisphere processed the images. In Experiment 5, anxiety and stress, but not depression, correlated with overall intrusion frequency, though these correlations did not change depending on hemispheric processing. The most promising clinical avenue to follow up came from Experiment 1a. I found significant negative correlations between *all* symptom measures and participants' ability to identify a neutral target image when a negative distractor appeared two items prior. Interestingly, these correlations only occurred for right side items, suggesting a relationship between LH processing and difficulty disengaging from negative distractors. Indeed, work with clinical populations shows that people with depression and anxiety have reduced activity in their left frontal cortex, which is associated with difficulty disengaging from negative information (Eysenck et al., 2007; Cisler & Koster, 2010; De Raedt & Koster, 2010; Gotlib & Joormann, 2010). Future research should try to replicate the correlations from Experiment 1a to determine whether the EIB paradigm may be a useful behavioural measure for identifying reduced activity in the left frontal cortex associated with depression and anxiety. This replication should use a larger sample size of 150-250 participants to ensure the correlations are stable (Schönbrodt & Perugini, 2013). Although I did not find the correlations in Experiment 1b, I recommend replication, rather than concluding the correlations are spurious, because the Experiment 1a correlations were consistent across symptoms of PTSD, depression, anxiety, *and* stress. Further, EIB may be a promising predictor of psychological disorders in general.

EIB is a promising behavioural measure of vulnerability to disorders that are associated with enhanced attention to threat, e.g., anxiety (Eldar, Yankelevitch, Lamy, & Bar-Haim, 2010) and PTSD (Fani et al., 2011). The link between enhanced attention to threat and anxiety disorder led to the development of attentional bias modification procedures, including the dot-probe task, emotional cueing task, and visual search task (see Mogoase, David, & Koster, 2014, for a meta-analysis). The general aim of these tasks is to reduce symptoms by moving people's automatic biases away from threat stimuli. But the benefit of these procedures for reducing anxiety symptoms is small, with limited evidence of any therapeutic benefit for other psychological disorders (Mogoase et al., 2014). This lack of benefit led Onie and Most (2017) to suggest EIB may be a more suitable tool for assessing and treating emotional disorders. Onie and Most (2017) directly compared the most popular attentional bias modification procedure—the dot-probe task—with EIB for predicting negative affect. Negative affect was a composite variable of depression, anxiety, and stress symptoms, state worry, and rumination. They found that EIB was a better predictor than the dot-probe task of persistent negative thought that, in turn, predicted negative affect. Onie and Most thus suggested training interventions may be more effective if they focus on reducing the "lingering prioritization" of negative stimuli that is captured by EIB (p. 891).

Olatunji et al. (2013) make the same suggestion for PTSD, concluding that treatments should focus on reducing attentional biases toward trauma-related stimuli. Olatunji et al. used EIB to predict PTSD diagnosis in a sample of veterans with PTSD, veterans without PTSD, and healthy nonveteran controls. Participants completed an EIB task, where they detected a rotated landscape image after either a combat-related, disgust-related, positive, or neutral distractor image. Veterans with PTSD showed impaired target detection following combat-related distractors, relative to veterans without PTSD and controls. There were no differences in target detection following the other types of distractors, suggesting heightened attention to trauma-related distractors in people with PTSD. Taken together, the correlations from Experiment 1a, along with the findings from Onie and Most (2017) and Olatunji et al. (2013), suggest future research should use a horizontal stream EIB paradigm with distractors relevant to specific clinical populations. These types of studies will allow us to determine whether hemispheric dysfunction contributes to enhanced attention to threat. If we found that hemispheric processes *did* contribute to enhanced attention to threat, then localising treatments for these attentional biases to one hemisphere over the other may be worthwhile.

8.5 Conclusion

Emotional processing occurs due to complex interactions between several cortical areas, some of which are lateralised to the right and left hemisphere. But limited research has evaluated how the lateralised aspects of emotional processing could bias our behaviour, or how they interact with other known hemispheric asymmetries. This thesis focused on the combined influence of visuospatial attention and emotional processing, on attention to and memory for emotional images. My findings suggest, when contralateral processing occurs, there is a left hemisphere deficit for recognition memory of emotional images. However, I found no behavioural difference depending on hemispheric processing for disengaging from emotional distractors. Thus, I conclude that the influence of asymmetries for emotional processing on behaviour is sensitive to task requirements. Future research should combine behavioural measures with neuroimaging to elucidate how different tasks activate lateralised functions involved in emotional processing.

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Appendix A – IAPS and NAPS images used in Chapter 4

Experiment 2a: negative IAPS images

3000	3350	9140	9340	2710	2688
3064	9325	2375.1	2799	9043	6550
3080	3016	3500	9500	3550	8485
3063	6350	6021	9050	6570.1	3300
3131	2703	6415	2141	9830	2981
9410	3030	9326	6260	9000	6530
3120	3101	6360	2900	9419	9491
3168	3180	9322	3017	9905	9909
3130	6520	9332	6510	9320	9922
3266	2205	2345.1	7380	9425	3212
3001	3191	3150	9520	9432	4664.2
9940	9571	9181	9900	9250	9280
9570	6313	9300	2053	2717	3185
9183	9252	9301	9184	6311	6825
3069	9253	9435	6263	6300	6830
3010	3230	9901	6312	6831	9415
9413	9800	3181	9600	9265	9925
6563	9921	9911	3220	9423	2456
2800	3195	6315	6231	2683	6571
2095	9220	9420	9007	3160	9342
3110	9414	3061	9400	6250.1	9331
3068	9910	9302	9920	9430	9424
3301	3103	6243	9340	2276	9290
3530	2352.2	9902	2799	2751	9330
3225	9810	9006	9500	9429	9427
3261	9163	9908	9050	9561	9610
9405	9560	3400	2141	6242	6213
9412	6022	3550.1	6260	6370	6834
3140	6560	9903	2900	9620	9941
9433	2811	6230	3017	6200	7359
3062	6540	9295	6510	9611	9291
3071	6212	9904	7380	9927	9530

Experiment 2a: neutral IAPS images

2351	2870	7090	7484	8466	7590
4573	2191	7017	7041	4230	2830
2575	7058	2880	7012	6570.2	7180
2372	1908	7043	7161	2512	2383
2720	7242	5920	2397	8475	7150
4274	7550	7182	7035	2704	1112
7710	7062	2122	7002	7184	2279
5500	7080	1122	7185	5534	2446
2305	7830	7207	7235	2190	2210
2273	8065	7014	9422	4000	2458
2357	1350	5510	2002	2026	7044
7033	2381	7170	7034	2493	7030
7546	7249	2038	2890	7032	7040
7061	7100	7233	7950	7038	1303
2445	7632	8160	7010	7217	9468
5040	2635	8232	7009	7491	2441
7512	2308	7255	7050	7211	9411
5530	2495	7056	7059	5535	8121
7026	2850	2411	3550.2	7018	7186
8312	7053	7187	7487	7037	9260
1820	1616	7179	4770	1726	2410
7057	2702	7247	2396	2200	1230
4613	5471	2749	2840	2690	1310
7506	7547	7004	2516	2570	1945
2499	5740	2220	7055	2780	4233
7500	7365	7160	2309	7287	7595
7052	2487	9070	1935	7130	7110
5520	2385	2214	2595	9700	9150
7001	7497	2484	7036	2480	2230
6910	2211	7003	7006	7705	9401
2745.1	5532	7000	2393	6900	9210
5533	2377	1645	7175	7016	7011

Experiment 2a: Negative images

IAPS				**NAPS**		
2095	3131	9265	9900	Animals_001_h	Faces_271_h	Objects_232_h
2205	3140	9280	9902	Animals_025_h	Faces_284_h	Objects_233_h
2345.1	3168	9290	9908	Animals_027_h	Faces_285_h	Objects_243_h
2352.2	3180	9291	9910	Animals_037_h	Faces_291_h	Objects_275_v
2455	3191	9300	9940	Animals_041_h	Faces_296_h	People_002_v
2703	3195	9301		Animals_050_h	Faces_300_h	People_012_h
2710	3266	9302		Animals_054_h	Faces_303_h	People_020_h
2800	3301	9322		Animals_060_h	Faces_362_v	People_024_v
2811	3350	9325		Animals_064_v	Faces_369_v	People_070_v
3000	3530	9326		Animals_065_h	Landscapes_005_h	People_082_h
3001	6350	9330		Animals_067_h	Landscapes_011_h	People_085_h
3010	6415	9332		Animals_071_h	Landscapes_026_h	People_088_v
3016	6520	9342		Animals_078_h	Landscapes_068_h	People_098_h
3019	6560	9405		Animals_084_h	Landscapes_118_v	People_119_h
3030	6563	9410		Faces_003_h	Landscapes_139_h	People_137_h
3062	6571	9412		Faces_007_h	Objects_039_h	People_144_h
3063	9000	9413		Faces_012_v	Objects_088_h	People_156_h
3064	9006	9414		Faces_018_h	Objects_109_h	People_204_v
3068	9007	9423		Faces_035_h	Objects_110_v	People_210_h
3069	9140	9432		Faces_041_h	Objects_111_h	People_212_h
3071	9163	9433		Faces_148_h	Objects_114_h	People_228_h
3080	9180	9520		Faces_150_h	Objects_120_h	People_230_h
3101	9181	9560		Faces_153_v	Objects_123_h	
3103	9183	9570		Faces_158_h	Objects_142_h	
3110	9220	9810		Faces_170_h	Objects_151_h	
3120	9250	9830		Faces_173_v	Objects_158_h	
3130	9253	9832		Faces_174_h	Objects_170_v	

Experiment 2b: Positive images

IAPS				**NAPS**		
1650	4623	7270	8185	Animals_002_v	Faces_348_h	People_193_h
1710	4626	7405	8186	Animals_102_h	Faces_352_h	People_196_h
1720	4628	7451	8191	Animals_106_h	Faces_359_h	
1722	4641	7499	8193	Animals_165_h	Faces_361_v	
2045	4643	7501	8200	Animals_175_h	Objects_078_h	
2075	4645	7502	8206	Animals_176_h	Objects_080_h	
2155	4656	7515	8210	Animals_178	Objects_104_v	
2208	4664	7570	8251	Animals_179_h	Objects_171_h	
2209	4676	7650	8260	Animals_198_h	Objects_290_h	
2216	4677	7660	8300	Faces_004_h	Objects_301_h	
2300	4687	8001	8340	Faces_090_v	Opposite-sex_couple_002_h.jpg	
2303	4698	8021	8370	Faces_096_h	Opposite-sex_couple_015_h.jpg	
2345	5215	8030	8380	Faces_116_h	Opposite-sex_couple_016_v.jpg	
2347	5260	8031	8400	Faces_120_h	Opposite-sex_couple_020_h.jpg	
2389	5270	8034	8420	Faces_132_h	People_029_h	
4007	5450	8040	8470	Faces_134_h	People_030_h	
4090	5460	8041	8490	Faces_136_v	People_096_h	
4225	5470	8080	8492	Faces_141_v	People_130_h	
4505	5480	8090	8496	Faces_234_h	People_160_h	
4525	5621	8116	8499	Faces_240_h	People_171_v	
4597	5623	8130	8500	Faces_245_v	People_175_h	
4598	5626	8158	8501	Faces_261_v	People_177_h	
4599	5628	8161	8503	Faces_282_h	People_178_h	
4609	5629	8163	8531	Faces_313_h	People_180_h	
4610	5700	8178	9156	Faces_321_h	People_180_h	
4611	5833	8179		Faces_322_v	People_183_h	
4617	5910	8180		Faces_347_h	People_185_h	

Appendix B – Example images used in Chapter 5

Negative

Neutral

Positive

Appendix C – IAPS images used in Chapter 7

Set 1	Set 2	Set 3	Set 4	Set 5
2095	2730	2900	2352.2	2703
2205	3016	3000	2800	2799
2811	3061	3001	3005.1	3015
3010	3062	3063	3059	3060
3017	3080	3068	3064	3069
3030	3100	3131	3071	3102
3053	3101	3150	3140	3130
3120	3103	3168	3230	3195
3181	3110	3180	3266	3261
3225	3170	3500	3530	3350
3400	3191	6360	6313	6315
6540	3301	6563	6520	6415
9040	6021	6570	9050	6560
9183	6022	6821	9140	9075
9414	6212	9187	9181	9163
9433	9252	9220	9410	9185
9560	9254	9253	9420	9332
9635.1	9413	9405	9421	9412
9901	9570	9571	9902	9435
9921	9903	9911	9910	9908

Appendix D – Depression anxiety and stress scale (DASS-21)

Please read each statement and circle a number 0, 1, 2, or 3 which indicates how much the statement applied to you over the past week. There are no right or wrong answers. Do not spend too much time on any statement.

The rating scale is as follows:
0 Did not apply to me at all
1 Applied to me to some degree, or some of the time
2 Applied to me to a considerable degree, or a good part of the time
3 Applied to me very much, or most of the time

1	I found it hard to wind down	0	1	2	3
2	I was aware of dryness of my mouth	0	1	2	3
3	I couldn't seem to experience any positive feelings at all	0	1	2	3
4	I experienced breathing difficulty (e.g. excessively rapid breathing, breathlessness in the absence of physical exertion)	0	1	2	3
5	I found it difficult to work up the initiative to do things	0	1	2	3
6	I tended to over-react to situations	0	1	2	3
7	I experienced trembling (e.g. in the hands)	0	1	2	3
8	I felt that I was using a lot of nervous energy	0	1	2	3
9	I was worried about situations in which I might panic and make a fool of myself	0	1	2	3
10	I felt that I had nothing to look forward to	0	1	2	3
11	I found myself getting agitated	0	1	2	3
12	I found it difficult to relax	0	1	2	3
13	I felt down-hearted and blue	0	1	2	3
14	I was intolerant of anything that kept me from getting on with what I was doing	0	1	2	3
15	I felt I was close to panic	0	1	2	3
16	I was unable to become enthusiastic about anything	0	1	2	3
17	I felt I wasn't worth much as a person	0	1	2	3
18	I felt that I was rather touchy	0	1	2	3
19	I was aware of the action of my heart in the absence of physical exertion (e.g. sense of heart rate increase, heart missing a beat)	0	1	2	3
20	I felt scared without any good reason	0	1	2	3
21	I felt that life was meaningless	0	1	2	3

Appendix E – Flinders Handedness Survey (FLANDERS)

The ten questions below ask which hand you prefer to use in a number of different situations. Please tick one box for each question, indicating whether you prefer to use the left-hand, either-hand, or the right-hand for that task. Only tick the ‘either’ box if one hand is truly no better than the other. Please answer all questions, and even if you have had little experience in a particular task, try imagining doing that task and select a response.

		Left	**Either**	**Right**
1	With which hand do you write?			
2	In which hand do you prefer to use a spoon when eating?			
3	In which hand do you prefer to hold a toothbrush when cleaning your teeth?			
4	In which hand do you hold a match when you strike it?			
5	In which hand do you prefer to hold the rubber when erasing a pencil mark?			
6	In which hand do you hold the needle when you are sewing?			
7	When buttering bread, which hand holds the knife?			
8	In which hand do you hold a hammer?			
9	In which hand do you hold the peeler when peeling an apple?			
10	Which hand do you use to draw?			

Handedness score (please don’t fill this out)	

Appendix F – Positive and negative affect schedule (PANAS)

This scale consists of a number of words that describe different feelings and emotions. Read each item and then circle the appropriate answer next to that word. Indicate to what extent you currently feel this way.

Use the following scale to record your answers.

(1) = Very slightly or not at all (2) = A little (3) = Moderately (4) = Quite a bit (5) = Extremely

	Very slightly or not at all	A little	**Moderately**	**Quite a bit**	Extremely
Interested	1	2	3	4	5
Distressed	1	2	3	4	5
Excited	1	2	3	4	5
Upset	1	2	3	4	5
Strong	1	2	3	4	5
Guilty	1	2	3	4	5
Scared	1	2	3	4	5
Hostile	1	2	3	4	5
Enthusiastic	1	2	3	4	5
Proud	1	2	3	4	5
Irritable	1	2	3	4	5
Alert	1	2	3	4	5
Ashamed	1	2	3	4	5
Inspired	1	2	3	4	5
Nervous	1	2	3	4	5
Determined	1	2	3	4	5
Attentive	1	2	3	4	5
Jittery	1	2	3	4	5
Active	1	2	3	4	5
Afraid	1	2	3	4	5

Appendix G – Posttraumatic Checklist (PCL – 5)

Many people have lived through or witnessed a very stressful and traumatic event at some point in their lives. We would like you to recall the worst stressful/traumatic event you have experienced and briefly describe the event (using one sentence) in the following space:

____

____

____

If the event you experienced is too personal and you would prefer not to disclose it please tick this box: ☐

Below is a list of problems that people sometimes have in response to a very stressful experience. Keeping your worst event in mind, please read each problem carefully and then circle one of the numbers to the right to indicate how much you have been bothered by that problem in the past month.

No.	Response:	Not at all	A little bit	Moderately	Quite a bit	Extremely
1.	Repeated, disturbing, and unwanted memories of the stressful experience?	1	2	3	4	5
2.	Repeated, disturbing dreams of the stressful experience?	1	2	3	4	5
3.	Suddenly feeling or acting as if the stressful experience were actually happening again (*as if you were actually back there reliving it*)?	1	2	3	4	5
4.	Feeling very upset when something reminded you of the stressful experience?	1	2	3	4	5
5.	Having strong physical reactions when something reminded you of the stressful experience (*for example, heart pounding, trouble breathing, sweating*)?	1	2	3	4	5
6.	Avoiding memories, thoughts, or feelings related to the stressful experience?	1	2	3	4	5

7.	Avoiding external reminders of the stressful experience (*e.g., people, places, conversations, activities, objects, or situations*)?	1	2	3	4	5
8.	Trouble remembering important parts of the stressful experience?	1	2	3	4	5
9.	Having strong negative beliefs about yourself, other people, or the world (e.g., *I am bad, there is something seriously wrong with me, no one can be trusted, the world is completely dangerous*)?	1	2	3	4	5
10.	Blaming yourself or someone else for the stressful experience or what happened after it?	1	2	3	4	5
11.	Having strong negative feelings such as fear, horror, anger, guilt, or shame?	1	2	3	4	5
12.	Loss of interest in activities that you used to enjoy?	1	2	3	4	5
13.	Feeling distant or cut off from other people?	1	2	3	4	5
14.	Trouble experiencing positive feelings (*for example, being unable to feel happiness or have loving feelings for people close to you*)?	1	2	3	4	5
15.	Irritable behaviour, angry outbursts, or acting aggressively?	1	2	3	4	5
16.	Taking too many risks or doing things that could cause you harm?	1	2	3	4	5
17.	Being “super alert” or watchful or on guard?	1	2	3	4	5
18.	Feeling jumpy or easily startled?	1	2	3	4	5
19.	Having difficulty concentrating?	1	2	3	4	5
20.	Trouble falling or staying asleep?	1	2	3	4	5

Appendix H – Frequency of Involuntary Thoughts Scale (FITS)

Many people have a variety of thoughts come to mind throughout the day. Sometimes these thoughts come to mind without you choosing to think about them. Please mark the box that indicates how often the following types of involuntary thoughts happens to you.

	1 Never	2 Almost never	3 A few times per month	4 A few times per week	5 A few times each day	6 Constantly
Music (a song stuck in your head)						
Visual images						
Memories						
Thoughts about the future						
Romantic relationship thoughts						
Thoughts about other relationships						
Work thoughts						
Thoughts about money						

Appendix I – Intrusion characteristics questionnaire

Please circle your answers.

1. **Did you report any involuntary thoughts of the images during the monitoring phase you just completed?**

   YES NO

If yes, please continue. If no, please ring the bell to let the experimenter know you have finished.

2. **Did one image continuously recur, or were your thoughts about multiple images during this time?**

   ONE MULTIPLE

3. **Please give a brief description (one sentence) of the image that most frequently intruded your thoughts during the monitoring phase.**

____

____

____

4. **How often did you find yourself thinking to any degree about the images you just viewed?**

1	2	3	4	5
Almost never				Very frequently

5. **On average, how vivid were your thoughts about the images?**

1	2	3	4	5
Not at all vivid				Extremely vivid

6. **On average, how distressed were you when the thoughts came to mind?**

1	2	3	4	5
Not at all distressed				Extremely distressed

7. **To what extent did you try and push the images out of your mind?**

1	2	3	4	5
Not at all				Completely

Appendix J – Intrusion Diary

Day: Participant ID:

Describe the content of the intrusion. Record the place and time it occurred.

____

____

____

____

____

____

____

____

____

____

____

What kind of intrusion was it?

Thought	Image	Combination
☐	☐	☐

How distressing was the intrusion?

1	2	3	4	5
Not at all distressing				Extremely distressing

How vivid was the intrusion?

1	2	3	4	5
Not at all vivid				Extremely vivid

To what extent did you try and push the intrusion out of your mind?

1	2	3	4	5
Not at all				Completely