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Influences on cognition:Emotion, social cues, context

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Influences on Cognition: Emotion, Social Cues, Context

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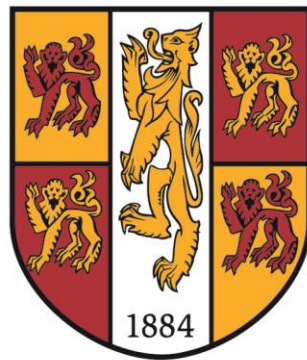
Abstract

People encounter a wide range of objects in the visual environment. Some of these are important and others are unimportant. Given that limitations on both attention and memory constrict people's ability to process everything in an environment, they must somehow prioritize important over unimportant objects. One suggestion as to how people do this is that the contents of working memory (WM), likely pertinent to current objectives, bias attention to environmental stimuli with which they share features. This suggestion has received mixed support in the literature. The degree to which stimuli in WM bias attentional deployment may relate their task relevance, that is, their pertinence to one's present activity. However, considering that emotional stimuli appear to command attention preferentially, this thesis asks how the presence of emotional stimuli, specifically expressive faces, bias attentional deployment.

Research in the area of emotion-attention interactions suggests that emotions of different valence have distinct effects on attention. Positive emotion leads to a broader, more efficient, allocation of attention than negative emotion. Thus, emotion-related WM-attention interactions may result in distinct patterns of attention capture depending on the valence of the emotion involved.

We tested whether this account describes the interaction between the emotion on a face held in WM and visual attention during the performance of a subsequent task involving emotional schematic faces. Consistent with expectations, emotion in WM influenced attention. Specifically, positive emotion led to a broader attentional focus than negative emotion. Importantly, emotion only influenced attention when it was task-relevant (Chapter 2). Event-Related Potential data indicated that when emotion was not task-relevant, participants processed WM-matching expressions more superficially than non-matching expressions, suggesting that WM-matching contents are dismissed more quickly when not task-relevant. Nonetheless, these stimuli interfered with visual processing; a result that may explain observed discrepancies in WM-attention interactions with non-task-relevant stimuli (Chapter 3).

Finally, we extend the finding that positive emotion leads to faster target processing, to the concept of value. Here, we examined how the intrinsic value of an emotional expression related to its ability to capture attention. Research shows that people are willing to give up money for the chance to see genuine smiles. Thus, we hypothesized that a

genuine smile's subjective value would predict attention capture for genuine-smile targets in a flanker task. Results confirmed this prediction, suggesting that an expression's intrinsic value also drives attention capture and may therefore have implications for how people navigate social interactions (Chapter 4).

Together, these results suggest that emotion in WM biases attention in a manner that is sensitive to the demands of a current task. Specifically, whereas task-relevant positive emotion results in more efficient orienting of attention than task-relevant negative emotion, non-task-relevant emotion receives demoted priority in visual processing. These results extend to an item's value, such that higher-value stimuli receive priority processing. This research extends our understanding of WM-attention and value-attention interactions to include long-term semantic associations as a factor. Collectively, the results of this research suggest that the allocation of attention to social stimuli is determined based on social implications, with positive implications having particular influence.

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Chapter 1

General Introduction

Introduction

The visual environment is extremely rich, containing a wide range of complex objects. In order to make sense of such environments, the brain must deploy attentional resources that focus processing on particular stimuli (Colman, 2006), thereby allowing those stimuli to be resolved. However, one problem with this process is that attentional resources are limited such that people cannot generally process all the information available in a natural environment (Lavie, 2005; Lavie & De Fockert, 2003; Rauss, Pourtois, Vuilleumier & Schwartz, 2008). Examples of attentional limitations include impaired detection of a subsequent target following the presentation of an initial target (Dell'Acqua et al., 2015; Raymond, Shapiro & Arnell, 1992; Shapiro, Arnell & Raymond, 1997). There are also costs in speed and accuracy when people attempt to shift attention between objects (Duncan, 1984; Iani, Nicoletti, Rubichi & Umiltà, 2001; Lappin, 1967), and similar costs when parsing the features of an object (Bombari et al., 2013; Navon, 1977, 1981). Thus, attentional limitations in the moment-to-moment deployment of attention mean that some information from the visual environment is necessarily lost.

We need also consider capacity limits on WM, as they influence the deployment of attention. As an example of a WM limitation, the more objects an individual must maintain, the greater the costs for recognition accuracy (Fougnie & Marois, 2006; Fukuda, Awh & Vogel, 2010; Oberauer & Eichenberger, 2013). Additionally, the process of switching between tasks incurs costs in speed and accuracy (Biederman, 1972; Monsell, 2003; Wylie & Allport, 2000), as does performing two tasks simultaneously (Gade, Druey, Souza & Oberauer, 2014; Luck, 1998; Pashler, 1994). These limitations have implications for the deployment of attention, as research shows that people's WM capacity, their ability to store and manipulate information (Baddeley, 2000; Baddeley & Hitch, 1974), correlates with their speed in locating a search target (Anderson, Vogel & Awh, 2013). Additionally, both WM capacity and load correlate with the efficient rejection of distracting stimuli (Ahmed & de Fockert, 2012). Given these limitations, how do individuals prioritise certain stimuli for further processing?

Given these limitations on attention and WM, it is not surprising that a number of factors modulate the deployment of attention to environmental stimuli. Most prominently, people prioritise task-relevant stimuli (e.g., Kim, Kim, Yoon & Jung, 2008; Lamy, Leber & Egeth, 2004; Lavie & De Fockert, 2003; Potts & Tucker, 2001; Rauss, Pourtois, Vuilleumier &

Schwartz, 2008; Visser, Bischof & Di Lollo, 2004). Recently activated information is likely to be relevant to current behaviour (e.g., Baddeley, 2000; Baddeley & Hitch, 1974), for this reason, WM could be one such factor modulating attention. When examining how people marshal their attention to emotional stimuli, we must also consider that different emotional evaluations are associated with unique sets of responses (e.g., Lazarus, 1982; Leventhal & Scherer, 1987; Scherer, 1987, 2001). Additionally, each individual is likely to arrive at different appraisals of the same emotional stimulus (e.g., Averbeck & Duchaine, 2009; Deci, 1971; Forbes et al., 2010; Shore & Heerey, 2011). Thus, the interaction that we observe between emotional objects in WM and emotional stimuli under perception may be distinct in nature from the interaction between non-emotional objects, primarily due to long-term semantic associations. In order to investigate how attention and WM interact with emotional evaluations to manage the deployment of attention, we will first summarise the current understanding of attention, WM and emotion. We will then consider the literature as it pertains to the interaction between these facets and formulate predictions based on this evidence.

Review of Attention

Selective attention is the act of focusing attention on a single object to the exclusion of other objects present (Colman, 2006). One example of this is when one attends to the departure time and platform number of their train on a train station display, whilst ignoring information pertaining to other trains. There has historically been some disagreement as to how this process occurs. One disagreement concerns the structure of attention, that is, its spatial characteristics. Theorists first conceived of visual attention as a spotlight that the perceiver could shift from one location to another (e.g., James, 1890). Later models sought to describe other features of this spotlight, such as its breadth (e.g., LaBerge, 1983; Turatto et al., 2000). Another concerns attention generally as a process, that is, how perceived stimuli are dealt with on a moment-to-moment basis. For example, whilst early models suggested that selecting stimuli involved the filtering of other stimuli (e.g., Broadbent, 1958), other theorists presented evidence in favour of the notion that the attention system attenuates unselected stimuli, but these are not completely filtered (Treisman, 1960). The current section will detail these positions in this order, but will also include other features of visual attention.

Theorists have long likened visual attention to a spotlight, possessing a focus, margin and fringe, with decreasing visual acuity being associated with greater distance from the focus (James, 1890). Cuing paradigms demonstrate that the further from a target the experimenter presents the cue, the longer it takes participants to attend to the target (Posner, Nissen & Ogden, 1978). Additionally, the number of errors made in visual search increases with the distance of a target from the centre of a display (Carrasco, McLean, Katz & Frieder, 1998), demonstrating that stimuli outside of focal attention are processed with less acuity. Another implication of this research is that attention is temporarily limited to one location people must shift their focus to resolve stimuli in other locations.

The spotlight model was however incomplete, as it did not address whether the breadth of this spotlight is static or dynamic. Research suggests that the spotlight has a dynamic focus. For example, experimenters observed that when they instructed participants to attend to the central letter of a word, their reaction times (RT) slow the further from the centre the probe appears (LaBerge, 1983). However, when they instructed participants to attend to the whole word, their RTs do not differ by probe location (LaBerge, 1983), suggesting that participants' attention encompassed differing amounts of the display depending on task requirements. Additionally, participants detect targets more efficiently when located within a small circular cue than when located within a large circular cue (Turatto et al., 2000), demonstrating that a person can increase their available attentional resources by minimizing the size of the spotlight. This suggests that the breadth of the spotlight is under voluntary control depending on the requirements of the visual search, much like a zoom lens.

Although the updated spotlight model addresses the spatial structure of visual attention, it does not address how people select stimuli for further processing. Models that scientists had devised to describe this process relied primarily on evidence from auditory attention studies. They had previously found that a participant could report the physical characteristics of two messages each entering an ear, but could only report the meaning of one message (Cherry, 1953). Based on this observation, Broadbent (1958) posited that a filter directly after sensory registration prevents unattended stimuli from entering short-term memory based on its physical characteristics (see Figure 1). However, this claim was inconsistent with later observations that participants could recognise their own name in the unattended ear (Moray, 1959), suggesting that some of the meaning of the unattended

message must have passed the sensory register. Researchers needed another model to explain how people limit the amount of information that undergoes later processing.

One suggestion was that rather than unattended objects being filtered out completely, they are attenuated such that they less likely to enter short-term memory (Treisman, 1960, see Figure 1.1). Using a similar dichotic listening paradigm, Treisman (1964) demonstrated that bilingual participants are able to determine that an unattended message is identical in content to an attended message even when they were in a different language, suggesting that participants had access to the meaning of the unattended message even though they had different physical characteristics. These findings extend to visual attention, as the naming of shapes is less accurate when presented with the name of a different shape nested within them, demonstrating that task-irrelevant but semantically associated information affected cognition (Flowers & Stoup, 1977). An important implication of this model is that people can process unattended stimuli at a reduced level of acuity as long as they meet some criterion of importance (e.g., they have personal relevance).

Figure 1.1: Schematic depictions of the filter and attenuation models of selective attention, adapted from Davey (2004); arrow size represents input strength.
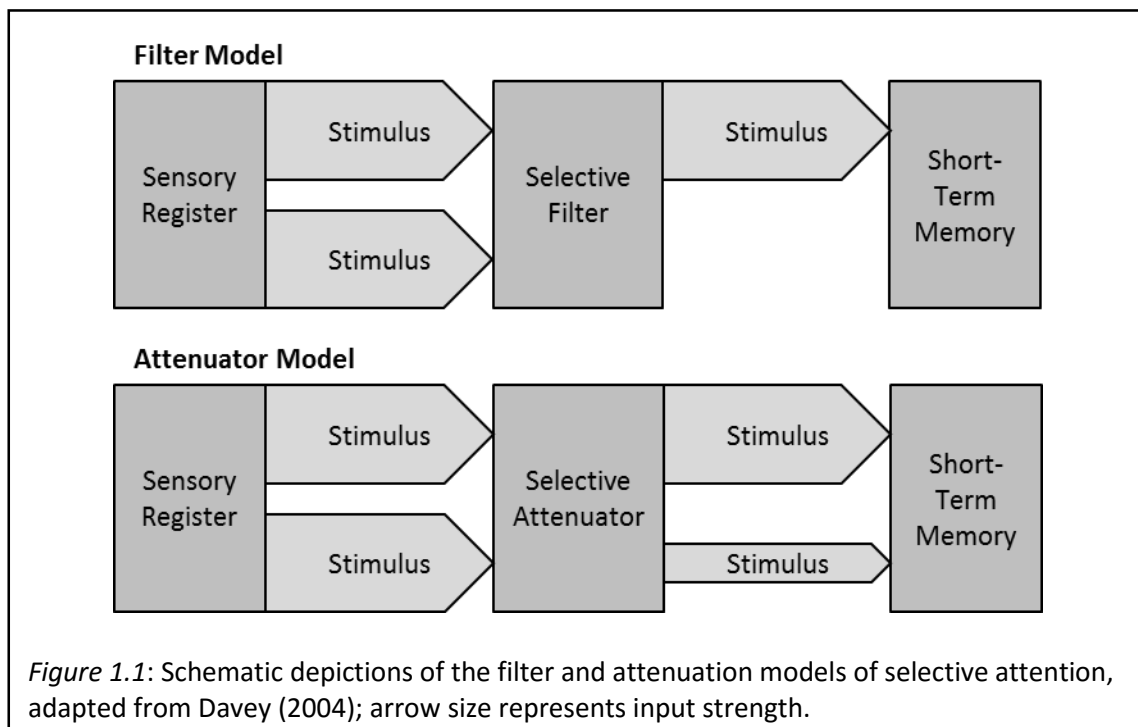
Focussed attention as it specifically pertains to the visual modality has also been theorised to be the mechanism by individuals integrate features into whole objects. Feature integration theory suggests a pre-attentive stage at which individuals automatically examine

features across the visual field, and subsequently combine the features into an object during focussed attention (Treisman & Gelade, 1980). Given that the combination of features would require more effort on the part of the perceiver than the identification of a single feature, the observation that visual searches for a feature target (e.g., a square) are more rapid than visual searches for conjunctions of multiple features (e.g., a red square) is consistent with this theory (Scialfa & Joffe, 1998; Treisman, 1982). Another aspect of this theory is that once combined, conjunctions of features are stored in memory (Treisman & Gelade, 1980). For example, search for words is more rapid than search for non-words (Gilford & Juola, 1976), as participants are more likely to have previously encountered words than non-words. Other researchers have found similar effects with other objects such as faces (Persike, Meinhardt-Injac & Meinhardt, 2013; Tong & Nakayama, 1999). This theory establishes the role of focussed attention in object resolution, and additionally implicates top-down factors in the process.

Whilst the previous models mentioned describe the structure of visual attention in both spatial and temporal terms, the capacity model (Kahneman, 1973) augmented these models by attempting to describe how four primary factors determine the allocation of resources between stimuli competing for resources (see Figure 1.2). These factors are arousal; current demands, dispositional biases and situational intentions.

Figure 1.2: The capacity model of attention, adapted from Kahneman (1973).
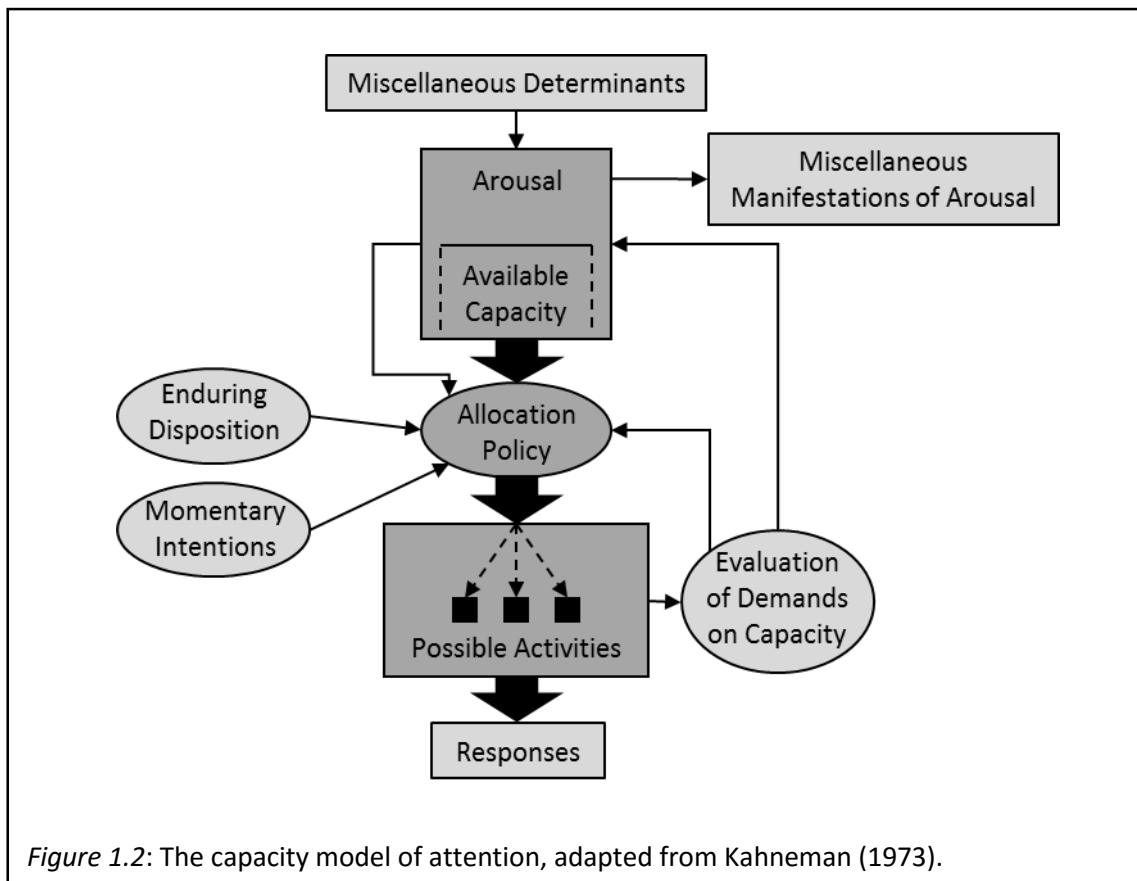
The capacity model claims that attentional resources are marshalled in distinct ways under conditions of high and low arousal (Kahneman, 1973). In support of this, Hockey (1970a) found that monitoring of peripheral visual cues during the performance of a central pursuit-tracking task was less accurate under conditions of arousal induced by a loud noise stimulus than in silence. A subsequent study (Hockey, 1970b) found arousal induced central focus only when signals had a higher probability of occurring in the pursuit-tracking task than in the monitoring task than when the experimenters balanced probabilities between the two tasks. This latter finding indicates that it is performance of a primary task that improves under arousal, and not merely the processing of centrally located stimuli. This research suggests that under conditions of high arousal, people prioritise primary task related stimuli for selective attention, and as a result, fewer resources are available to process less important stimuli.

Current demands refers to how available attentional resources are allocated based on the requirements of the demands of a given task or set of tasks (Kahneman, 1973). One study (Cosman & Vecera, 2009; Experiment 2) found that vertically flanking letters that were

distinct from a target letter elicited slower responses than flanking letters identical to the target. However, when the target (designated by a pre-cue) was embedded in a horizontal array of six letters, this facilitation disappeared. This suggests that the flanking letters only captured attention when the task was relatively undemanding. That is, participants only committed resources to the processing of the flankers when they had a surplus of attentional capacity. Additionally, it is well-documented that the attention given to an initial target can determine the detection of a subsequent target (Dux & Marois, 2009), suggesting that this rule also applies to the allocation of attention on a serial basis. These studies illustrate that the attention system allocates resources depending on the extent to which resources are available.

Dispositional biases are rules governing the allocation of attention that are enduring and involuntary in nature (Kahneman, 1973). One example of such a rule is the tendency to detect moving targets more efficiently at the onset of movement than during continuous movement (Abrams & Christ, 2003; Experiment 1a). Another study (Turatto & Galfano, 2000) examined the effect of presenting a target stimulus embedded within shapes that differed from others in the array on either colour, form or luminance. The authors found that responses were faster to this target than targets that embedded in the homogenous shapes, regardless of the dimension on which it differed, suggestive of a bias toward visual discontinuity. As can be seen from this research, a number of stimulus characteristics determine the allocation of attention.

Situational intentions are momentary objectives that relate to the fulfilment of current task requirements (Kahneman, 1973). One study found that faces elicited faster responses than objects when the former were more predictive of subsequent target location than the latter (Bindemann, Burton, Langton, Schweinberger & Doherty, 2007; Experiment 2b). However, when objects had greater predictive value than faces, responses were faster to targets cued by objects than targets cued by faces (Bindemann, Burton, Langton, Schweinberger & Doherty, 2007; Experiment 2c). This finding suggests that the tendency for certain stimuli to capture attention depends on their current utility to the achievement of task objectives. Furthermore, when experimenters asked participants to respond to a red letter rather than a green letter, a preceding cue produced an electrophysiological marker of attention only when it matched the target colour (Lien, Ruthruff, Goodin & Remington, 2008; Experiment 2). This suggests that stimuli that are

congruent with some aspect of current goals capture attention even if they do not actually aid in attainment of this goal. We can infer from this evidence that an individual's current objectives also determine which stimuli consumes their attentional resources. Working memory, being "a temporary store for recently activated items of information" (Colman, 2006, p. 819), may be one such situational influence.

Review of Working Memory

The concept of short-term memory, and by extension working memory, stemmed from the necessity to account for the functioning of patients with neurological impairments affecting their long-term memory. Specifically, whilst individuals with anterograde amnesia lack the ability to form new memories subsequent to brain damage, their ability to retain information on a temporary basis remains intact (Markowitsch & Staniloiu, 2012; Sidman, Stoddard & Mohr, 1968; Wickelgren, 1968). This suggests that their ability to store information for a short period is separate from their ability to store information more permanently. Additionally, healthy participants recall items presented earlier and later in a string of items with more accuracy than items presented in the middle of a string (Glanzer & Cunitz, 1966; Murdock, 1962; Skoff & Chechile, 1977), known respectively as the primacy and recency effects. The primacy effect presumably occurs because participants can study early items for longer than later items, and are therefore more likely to be in long-term memory. Supporting this interpretation, brain areas associated with long-term memory demonstrate greater activation to early items compared to late items (Talmi, Grady, Goshen-Gottstein & Moscovitch, 2005). In light of phenomena such as these, a partitioning of human memory into multiple functions has become a plausible model.

One influential early model of working memory characterised human memory as consisting of three structural components and attendant control processes (Atkinson & Shiffrin, 1968). The first proposed structure was the sensory register, which acts as an information store for a matter of milliseconds, after which the information decays (Estes & Wessel, 1966). The person then selects contents of the register using a range of strategies. For example, participants switch between scanning whole arrays of letters, only a row of which they will be required to recall, to trying to anticipate which row will be selected order to improve their recall (Sperling, 1960). Selected information then passes to a short-term store that is subject to decay with time (Peterson & Peterson, 1959). Rehearsal, for example

by repeating letters subvocally, is one method of preserving information whilst in the short-term store (Hintzman, 1965). People can transfer information from the more permanent long-term store to the short-term store, one strategy being to attend to cues associated with the memory searched for (Atkinson & Shiffrin, 1968). Additionally, individuals remember a sequence of numbers with greater success if the experiment requires the participant to make an overt response, rather than viewing them passively (Cohen & Johansson, in press), demonstrating control processes that transfer information from the short-term store to the long-term store.

One assumption that we can derive from Atkinson and Shiffrin's (1968) model is that the storage of information should impair concurrent complex cognitive operations. However, the observation that participants can hold between one and three objects in memory whilst suffering no performance decrement in reasoning tasks called in to question this notion of a unitary store working memory (Baddeley & Hitch, 1974). Additionally if the short-term store is solely responsible for transferring information to long-term memory, patients with an impaired short-term memory should show dramatically impaired learning, which is not the case (Shallice & Warrington, 1970). Baddeley & Hitch (1974) proposed a refined multi-component model that could account for these contradictions. Their alternative model initially consisted of a short-term store and processer known as the central executive, a visual buffer called the visuo-spatial scratchpad, and an auditory buffer called the phonological loop.

In this model, the central executive represents both a processor and workspace (Baddeley & Hitch, 1974). One process it is responsible for is the managing of information drawn from both the phonological loop and the visuo-spatial scratchpad. For example, participants performing both a digit-span recall task and a reasoning task recalled more numbers when the experimental instructions placed emphasis on the recall task than when the instructions indicated an equal importance for either task (Baddeley & Hitch, 1974; Experiment 2). This is evidence for a system that can allocate between different functions depending on situational requirements. The executive is also responsible for strategies that aid in the recall of information from the other stores, and chunking is one such strategy. For example, one can improve their digit span of a binary numerical sequence by converting it into a shorter sequence of decimal numbers prior to recall (Miller, 1956).

The tripartite model also alleges the existence of a dedicated store for verbal information called the phonological loop (Baddeley & Hitch, 1974). There is evidence that that noise has a smaller disruptive effect on the recall of digits than nonsense syllables and words (Salamé & Baddeley, 1982), supporting the suggestion that this is a dedicated verbal store. Three main limitations of the phonological loop are its capacity, duration and the effect of stimulus similarity. In regards to capacity, the percentage of words correctly recalled reduces as the number of syllables comprising each word increases (Baddeley, Thompson & Buchanan, 1975). Additionally, the ability to retain verbal information decreases over time. For example, compared to participants tested on recall for a list of words immediately, participants tested after a twenty-second delay recalled fewer words (Baddeley & Hitch, 1974; Experiment 10). The similarity of memorised stimuli is another limitation, as it is more difficult to remember phonologically similar compared to phonologically dissimilar information (Conrad & Hull, 1964).

The tripartite model also identifies a separate temporary store for visual and spatial information known as the visuo-spatial scratchpad (Baddeley & Hitch, 1974). This store is considered separate from the phonological loop based on evidence that participants can store both visual letters and phonemic information without a significant decrement in performance (Baddeley, Grant, Wight & Thompson, 1975). The visuo-spatial scratchpad is characterised by similar limitations to that of the phonological loop. As with verbal information, the complexity of the stimuli limits visuo-spatial capacity. For example, it is more difficult to remember a path through a matrix of three-dimensional blocks than through a matrix of two-dimensional blocks (Cornoldi, Cortesi & Preti, 1991). As with verbal information, visual information is also subject to decay over time. Memory for the features of a shape becomes less accurate with an increasing retention period (Zhang & Luck, 2009). The detrimental effect of similarity on remembering is apparent in the observation that the presence of shared elements between Chinese characters impairs recall accuracy (Hue & Ericsson, 1988).

Since Baddeley and Hitch originally authored the tripartite model, some have argued for a fractionation of the phonological loop and visuospatial scratchpad into passive storage mechanisms and active rehearsal mechanisms. The storage mechanisms are the phonological store and visual cache and the earlier part of this section described their characteristics. The novel fraction of this component is an active rehearsal process, which

serves to refresh representations held in the phonological store (Baddeley & Logie, 1999). One rehearsal mechanism may be subvocal speech, as instructing participants to repeat irrelevant words or sequences of numbers (i.e., articulatory suppression), which preoccupies this process, impairs memory performance for verbal information (Baddeley, 1983; Baddeley, Lewis & Vallar, 1984; Murray, 1968).

The visuo-spatial counterpart to the phonological rehearsal process is the inner scribe (Baddeley & Logie, 1999). Whilst there is evidence that attention towards locations can serve as a rehearsal mechanism for spatial information (Awh, Anllo-Vento & Hillyard, 2000; Awh, Jonides & Reuter-Lorenz, 1998; Awh, Smith & Jonides, 1995), there is little research addressing the rehearsal of visual information. However, one study found that the recall of objects was less accurate when a concurrent task required feature judgement than when it required them to locate which of an array of objects contained a gap (Matsukura & Vecera, 2009). Performing the feature judgement may have distracted attention from the object in memory, allowing its trace to decay. However, finding a shape with a specific feature requires only a location judgement and does not engage object based attention. Therefore, object based attention may help maintain visual stimuli in working memory, just as spatial attention aids in the maintenance of locations.

Another addition to the initial tripartite model was to link both the short-term stores to long-term memory (Baddeley, 2000). The link between the phonological loop and long-term memory is apparent in the observation that success in immediate recall predicts success in the acquisition of novel vocabulary (Service, 1992). This finding suggests that the phonological loop mediates access of new verbal information into long-term memory. An additional link between the visuospatial scratchpad and visual long-term memory is also evident. For example, participants maintain visual objects (e.g., faces and cars) that are familiar in working memory with a higher degree of accuracy than those that are unfamiliar (Buttle & Raymond, 2003; Curby, Glazek & Gauthier, 2009; Jackson & Raymond, 2008). Taken together, this evidence suggests that people can retrieve visual information from long-term memory to bolster the trace of an object in the visual cache.

Another amendment to the tripartite model has been the addition of a component known as the episodic buffer (see Figure 1.3 for an illustration of the tripartite model with previously described amendments). The primary function of this buffer is the integration of information from the phonological loop and visuospatial scratch pad across space and time

(Baddeley, 2000). Evidence for the episodic buffer comes in the form of cross-modal interactions. For example, when experimenters asked participants to recall the serial order and case (i.e., upper or lower) of briefly displayed sequences of letters, participants committed more errors when the lower case letters resembled the upper case letters in form (Logie, Del Sala, Wynn & Baddeley, 2000; Experiments 3 & 4). That is, the visuo-spatial aspects of the memory items interfered with verbal sequential information and that participants were therefore integrating verbal and visuo-spatial information in their mental operations. Additionally, when experimenters ask participants to remember sequences of digits in the order that they are highlighted, verbal recall is more accurate when the array resembles the familiar number pad of a keyboard than when the array is linear or consists of a serial presentation (Darling & Havelka, 2010). This demonstrates that people can combine spatial information from long-term memory with verbal sequential information in order to aid temporary memory, suggesting a link between the episodic buffer and long-term memory.

Figure 1.3: A contemporary version of Baddeley and Hitch's (1973) working memory model, adapted from Baddeley (2010).
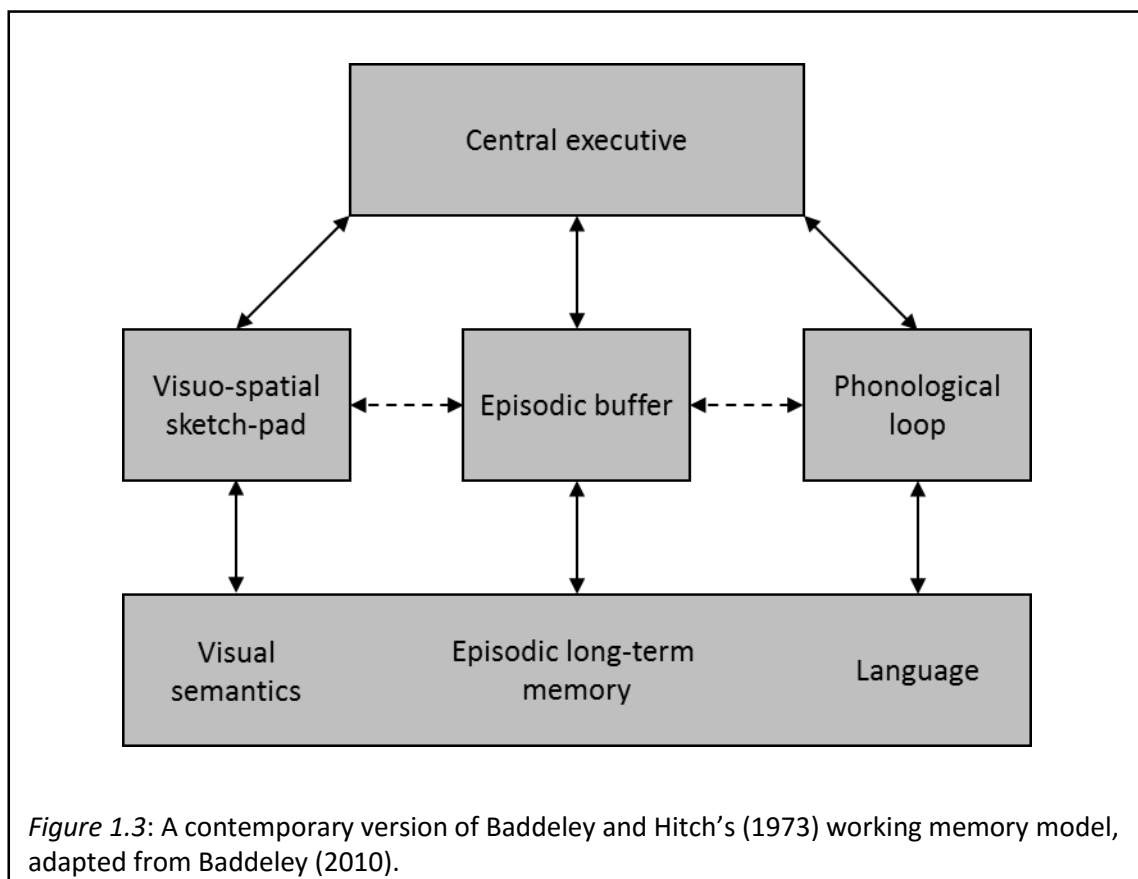
Just as researchers have segregated the phonological loop and visuospatial scratchpad by function, so too has the central executive been reconceptualised as a collection of functions. One such function is the ability to carry out more than one task at a time (Baddeley, 1996). In support of this, participants with a low working memory capacity are less efficient in alternating between one task rule (e.g., the target will follow a cue at the same location) and another (e.g., the target will appear opposite the previous location of the cue) than those with a high capacity (Butler, Arrington & Weywadt, 2011; Kane, Bleckley, Conway & Engle, 2001). Another proposed executive function is selective attention (Baddeley, 1996). In one study, increasing memory load also increased errors in categorising a name by occupation when superimposed on a face belonging to an individual with an incongruent occupation (de Fockert, Rees, Frith & Lavie, 2001). This demonstrates that participants were less able to inhibit attention to irrelevant information when working memory was strained, highlighting the role of working memory in controlling selective attention. Another function of the executive is the activation of information stored in long-term memory (Baddeley, 1996). In support of this, there is evidence that access to items belonging to a particular semantic category is greater in participants with a high memory span compared to participants with a low span (Rosen & Engle, 1997), showing that the ability to access long-term memory is dependent on the efficiency of working memory. Though the label remains useful, based on this evidence it is more fruitful to consider the central executive as a group of functions rather than a unitary construct.

There are other theoretical perspectives that place an emphasis on attention in the working memory process. In one such model, the short-term store is comprised of temporarily activated long-term memory (Cowan, 1988; see Figure 1.4). This is consistent with observation that priming using semantic associates is more effective in increasing word recognition than priming using visually similar words (Lesch & Pollatsek, 1993), as the information needed to sort the target stimuli is made more readily available. Individuals can focus attention on a subset of this short-term store depending on a number of factors, with a limit of about four items (Cowan, 2000). The central executive is one such factor (Cowan, 1988). When presented with two rows of numbers, participants' RTs are slowed to a greater extent by an increase in set size when both rows require updating than when one row requires updating and the other only requires memorisation (Oberauer, 2002). Thus, information that is not immediately relevant can be stored in a passive state with no

decrement to current operations. Another factor is the inhibition or disinhibition of information arriving from a brief sensory store. Specifically, novel stimuli are automatically dishabituated and enter the focus of attention (Cowan, 1988). Hence, there is greater attention capture by novel stimuli (Colombo & Bundy, 1983; Escera, Alho, Winkler & Näätänen, 1998; Johnston, Hawley, Plewe, Elliot & DeWitt, 1990). On the other hand, unchanged stimuli eventually become habituated, but can be dishabituated on a voluntary basis (Cowan, 1988).

Figure 1.4: A schematic representation of Cowan's working memory model, adapted from Cowan (1988).
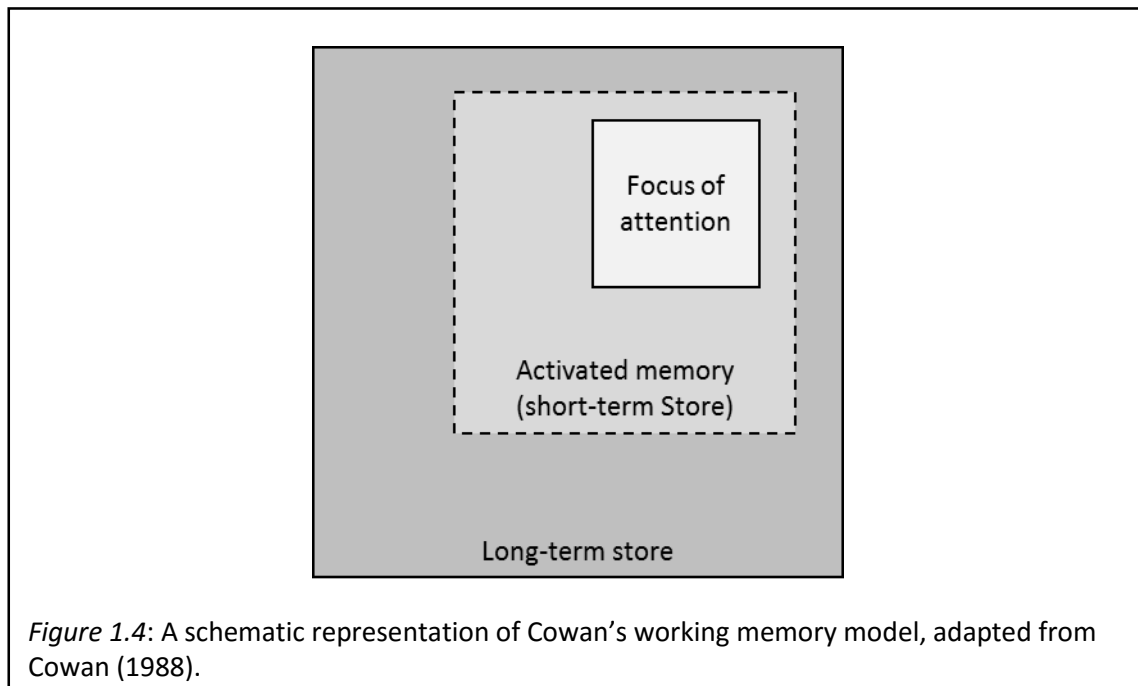
Although this view appears initially to be opposed to the tripartite model, this may not be the case. For example, the focus of attention is broadly analogous to the episodic buffer, as they both represent multimodal integrated information. Additionally, Cowan attributes everything outside of the attentional focus to active or inactive long-term memory, whilst acknowledging the importance of verbal rehearsal (Cowan, 2000). This model may constitute a proposal of an interface between the central executive and the episodic buffer rather than a complete model, as some have already suggested (Baddeley, 2010). Furthermore, this model suggests that both working memory and attention are functions that are vital in the operation of the other.

WM-Attention Interactions as a Mechanism of Resource Prioritisation

A common feature of the capacity model of attention and both the tripartite and activated long term-memory models of WM is that they each posit interactions between executive functions and the ongoing processing of stimuli. Accordingly, one suggestion as to how working memory influences attention is the idea that it biases competition for attention is towards objects that have relevance to current behaviour, thus prioritising current objectives (Desimone & Duncan, 1995). Specifically, objects in the environment that share features with stimuli held in WM may be more likely to receive attention and therefore be processed more efficiently (Desimone & Duncan, 1995). Thus, because the WM system often contains information relevant to current behavioural tasks, it may bias attention deployment toward similar (and likely task-relevant) environmental stimuli.

This idea has received considerable support in the literature, primarily from studies that utilise a "dual-task" paradigm in which participants simultaneously perform two tasks (see Figure 1.5 for a schematic representation; Ansorge, Kiss & Eimer, 2009; Hollingworth & Luck, 2009; Kang, Hong, Blake & Woodman, 2011; Soto, Heinke, Humphreys & Blanco, 2005; Soto & Humphreys, 2009; Soto, Humphreys & Heinke, 2006). For example, in one study, participants were required to maintain a shape in WM during the performance of a search task (Soto, Humphreys & Rotshtein, 2008) involving targets and distractors embedded in distinct shapes. Reaction times were faster when the target was embedded in a WM-matching shape and slower when this shape surrounded a distractor compared to when no memory match was present, suggesting that memory matching shapes captured attention. In a similar study using faces as the WM cue, participants holding a face in memory were faster to report the orientation of a shape when it was cued by a face matching the identity of the remembered face compared to when it was cued by a non-matching face (Downing, 2000). This suggests that WM guided attention-capture occurs with more naturalistic as well as more perceptually simple stimuli.

Figure 1.5: A schematic representation of the typical dual-task paradigm used to investigate WM-attention interactions. Note the congruence between the colour of the WM item and the target/distractor (left) and the expected effect on visual search (right).
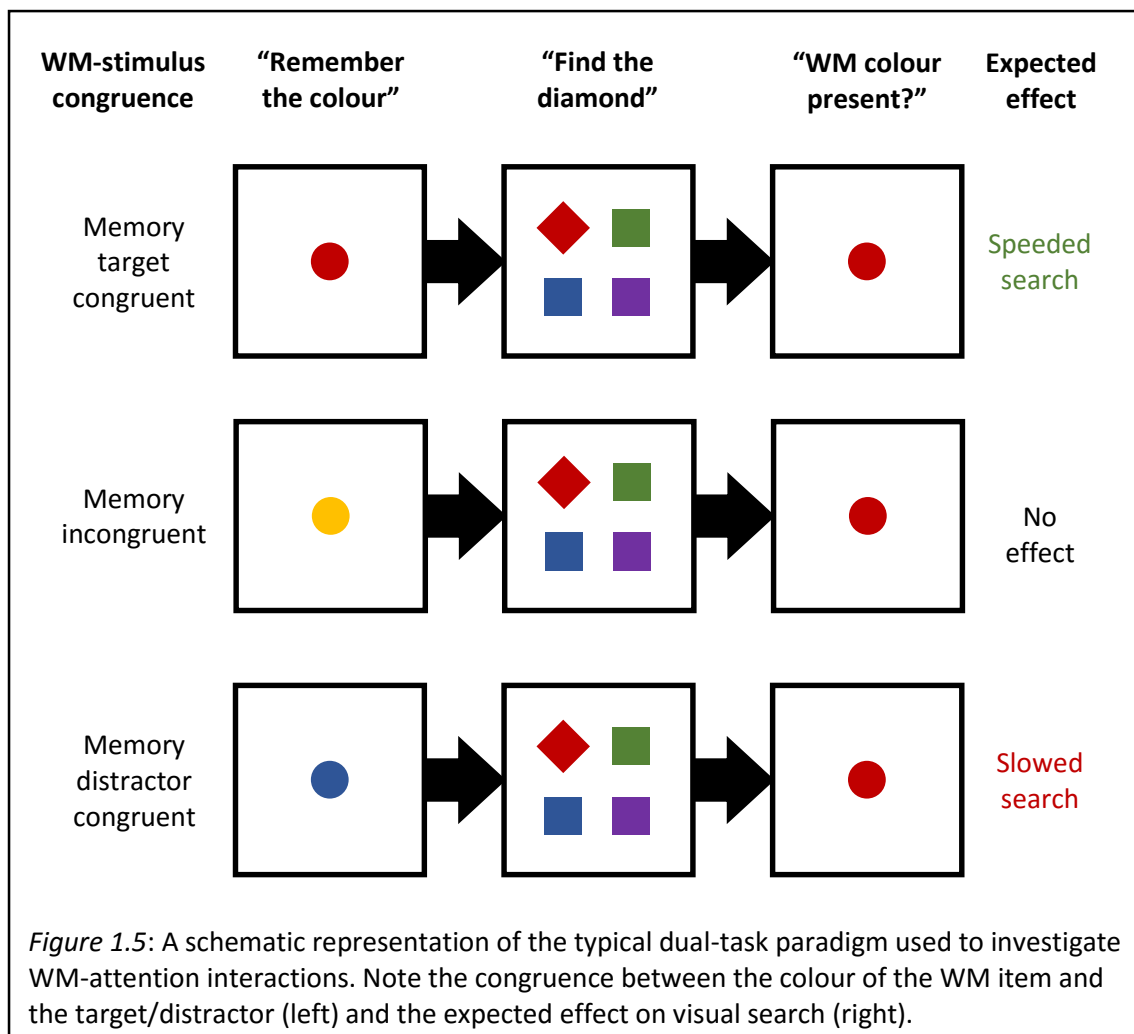
Interestingly, not all research strongly supports WM-attention interactions. In particular, the extent to which stimuli in WM actually guide attention may depend on the degree to which they are task-relevant. This prediction would be congruous with the capacity model of attention, which suggests that the extent to which resources are committed to the processing of a stimulus depends upon the current intentions of the perceiver (Kahneman, 1973). Pertaining specifically to WM as an executive function, one study found that a memory-matching stimulus distracted participants during a visual search only when it was identical to a WM item on a relevant feature, but not when it was identical to a WM item on a non-relevant feature (Olivers, Meijer & Theeuwes, 2006). This finding is consistent with the suggestion that selective attention is biased towards stimuli relevant to current behavior, and hints that memory-task irrelevant items may not guide attention.

The effect of task relevance in WM-attention interactions may be influential enough to eliminate reliable stimulus driven biases. In one study (Moriya, Koster & De Raedt, 2014),

participants held a colour in WM whilst attempting to locate an angry face among happy distractors or a happy face among angry distractors. When a distractor matched the WM colour (i.e., it was an invalid cue), participants were faster to locate angry compared to happy targets, reflecting an established bias to threatening faces (Eastwood, Smilek & Merikle, 2001; Lamy, Amunts & Bar-Haim, 2008; Feldmann-Wüstefeld, Schmidt-Daffy & Schubö, 2011; Hansen & Hansen, 1988). However, when the target matched the WM colour (i.e., it served as a valid cue), this benefit for angry faces disappeared. Interestingly, this was the case only when participants were aware that the memory colour could provide a cue to the target's location. This suggests that when people perform a search with the knowledge that WM contents relate to task objectives, the influence of WM contents can outcompete stimulus-related biases in the control of attention.

Despite this evidence, some research finds that WM contents, relevant or irrelevant, bias attention towards congruent stimuli. For example, several studies find either no slowing of search by WM-matching distractors (Downing & Dodds, 2004; Houtkamp & Roelfsema, 2006) or alternatively that WM-matching distractors are more efficiently rejected than non-matching distractors (Woodman & Luck, 2007; Sreenivasan & Jha, 2007). Findings showing that WM contents can enhance the rejection of distractor stimuli suggest that WM may play a role in the rejection of irrelevant stimuli, rather than attention capture by relevant ones. What factors account for this discrepancy?

One factor that may determine the presence of WM-attention interactions is task difficulty. As is demonstrated by research supporting the capacity models of attention, people allocate resources according to an assessment of the resources that are currently available to the perceiver (Cosman & Vecera, 2009; Kahneman, 1973). To elaborate, WM may only be able to influence attention when there are sufficient resources to allow it to exert control. For example, research has demonstrated that when visual search is perceptually difficult, stimuli matching WM contents do not distract participants from the search process but under easy search conditions, they do (Han & Kim, 2009). This suggests the possibility that WM-attention interactions depend upon the availability of cognitive resources, meaning that these interactions may not be present when task conditions are difficult.

Given that individuals can attenuate the processing of some stimuli in order to prioritise the processing of others (Flowers & Stoup, 1977; Treisman, 1960), another

possible explanation for the inconsistency in results is that after the initial allocation of attention memory-matching stimuli receive less processing. This may mean that response measures such as RTs do not index differences between WM-matching and non-matching stimuli. The phenomenon of "repetition suppression," which is a decrease in neural responses to repeated object presentations, supports this suggestion (Buckner et al., 1998; Rugg, Soardi & Doyle, 1995; Vuilleumier, Henson, Driver & Dolan, 2002). For example, one experiment asked participants to detect a particular face identity among 13 other faces presented in quick succession. The target identity occurred three times in the visual stream. Results showed reduced neural activity (as measured using functional magnetic resonance imaging) on each successive target presentation (Ishai, Pessoa, Bikle & Ungerleider, 2004). Ultimately, this research suggests that after the allocation of attention, the signal representing previously seen objects weakens.

Research using event-related potential (ERP) measures suggests the presence of a complementary process. Specifically, evidence shows that a memory-matching stimulus elicits neural signatures of attentional allocation followed by neural signatures of attentional suppression (Sawaki & Luck, 2013), or neural signatures of suppression alone (Sawaki & Luck, 2010; 2011). Together, this work suggests that an active suppression process prevents further processing of memory-matching stimuli. This process of suppression suggests a process that prevents WM from influencing responding after attention capture.

One possible function of this reduction of visual processing is to reduce interference between two concurrent tasks and therefore maximise performance. Research suggests that successful maintenance of WM contents, and therefore performance of an active task, is dependent on the effective suppression of irrelevant stimuli, and that failure to do so is associated with a higher WM load (Rutman, Clapp, Chadick & Gazzaley, 2010; Zanto & Gazzaley, 2009). Furthermore, people with high WM capacity are better at excluding irrelevant information from WM than those with low WM capacity (Vogel, McCollough & Machizawa, 2005), suggesting a cyclical relationship whereby an increased WM load resulting from encoding irrelevant information leads to further susceptibility to encoding such information erroneously. These studies suggest that the successful maintenance of information in WM relies on the prevention of irrelevant information from entering WM, which individuals may achieve by reducing processing of such objects. Failure to do so results in fewer resources being available for other cognitive tasks.

The studies detailed so far have dealt primarily with non-emotional stimuli chosen for perceptual equivalence, and may therefore not be generalizable to stimuli with significance extending beyond the lab. For example, a stimulus an individual fears (e.g., blood, snakes, spiders) captures their attention more than a stimulus they do not (Buodo, Sarlo & Munafò, 2009; Öhman, Flykt & Esteves, 2001; Pflugshaupt et al., 2005), demonstrating that attention is sensitive to evolutionary implications (e.g., whether an object represents a threat to survival). Beyond fear, emotional objects in general exert a stronger control over attention, as demonstrated by more rapid and accurate detection of emotional pictures compared to neutral pictures (Nummenmaa, Hyönä & Calvo, 2006; Schupp, Junghöfer, Weike & Hamm, 2004). Additionally, emotional objects also receive priority in WM, as they are more quickly and accurately recognised then non-emotional objects (D'Argembeau & Van der Linden, 2007; Lindström & Bohlin, 2011). Compared to non-emotion-related stimuli, people prioritize those containing emotion in both attention and memory.

Review of Emotion

Emotion is "any short-term evaluative, affective, intentional, psychological state" (Colman, 2006, p. 248) and is generally conceived to comprise of at least three components, behaviour, physiology and subjective feeling (Braisby & Gellatly, 2005). Behaviour refers to the patterns of physical activity associated with particular emotional states, for instance, the tendency to smile when happy or to become withdrawn or lethargic when sad. Physiology refers to the somatic activity associated with emotion, for example, the increased heart rate and production of sweat associated with anxiety. Feelings are the private component of emotion and refer to a person's awareness of the experience. Although these are relative uncontentious features of emotion, how they interact has been a matter of extensive debate. For example, there is much disagreement about whether cognitive appraisals are a prime factor in determining responses stimuli. Some accounts allege that they are (e.g., Leventhal & Scherer, 1987; Schachter & Singer, 1962; Scherer, 1987, 2001; Smith & Lazarus, 1993), whereas others suggest that cognition does not intervene (e.g., Kunst-–Wilson & Zajonc, 1980; Moreland & Zajonc, 1977). Additionally, there have been two methods of classifying emotion. On one hand, some have argued that there are discreet emotions (e.g., Ekman & Friesen, 1971; Power & Dalgleish, 1997). On the other hand, other theorists

conceptualise emotions as being continuous along two or more dimensions (e.g., Fontaine et al., 2007; Gunes, 2010; Posner, Russell & Peterson, 2005; Russell, 1980; Russell & Barrett, 1999). In this section, we consider the evidence for each position and attempt to reconcile each account where relevant.

Concerning emotion as a process, early biological accounts posited that emotional experiences follow the perception of physiological changes. Philosopher William James observed how "In rage, it is notorious how we 'work ourselves up' to a climax by repeated outbreaks of expression. Refuse to express a passion, and it dies" (James, 1884, p. 197). In other words, James was claiming that emotions are the observation of physiological reactions, and do not occur in the absence of such reactions. Carl Lange, on the other hand, was a physiologist and therefore interested in identifying specific indices of the phenomenon. Specifically, he claimed that emotional reactions were synonymous with cardiovascular reactions to events (Lang, 1994). Thus, Lange's claim was that emotion was synonymous with physiology and not merely the perception of physiology. Nonetheless, the ideas of James and Lange were similar in that they alleged that the experience of emotion does not precede associated physiological processes. Hence, later writers gave them the collective label of the James-Lange theory (Dalgleish, 2004).

The James-Lange theory was not consistent with subsequently available evidence, thus there was a need to develop an alternative account. For example, one prediction of the James-Lange theory would be that the presence of emotional experiences is dependent on the ability to monitor bodily change. However, when experimenters removed the cerebrums of animal subjects, they still observed the subjects to exhibit rage-like behaviour (Cannon, 1931). This suggests that the removal of sensory-motor areas, and thus the ability to observe bodily change, did not eliminate the experience of emotion. The experimenters did however eliminate this rage-like behaviour by excision of the subjects' thalami (Cannon, 1931). Thus whilst the cerebrum inhibits emotional experience, it is the thalamus that is responsible for its generation. This alternative account, called the Cannon-Bard theory (Dalgleish, 2004), challenged the notion that emotion results from the observation of physiological responses.

Later accounts introduced cognitive attribution as an important factor in the emotional experience. Early studies had found that inducing physiological arousal by means of adrenaline injections only produced self-reports of an emotional nature in a minority

(e.g., 29%) of participants (Cantril & Hunt, 1932; Landis & Hunt, 1932; Marañon, 1924). Additionally, those reports that did have an emotional nature emphasised the likeness of participants' experiences to genuine emotion rather than emphasising emotional aspects themselves (e.g. "I feel as if I were afraid"). This suggested that it was possible to have a physiological experience in the absence of an emotional experience, and thus that the two are dissociable. A later experiment demonstrated that the presence of a confederate displaying a specific emotional experience (e.g., euphoria & anger) could elicit reports of that specific emotion from participants (Schachter & Singer, 1962). In light of data such as these, Schachter and Singer (1962) suggested that a situational attribution concurrent with the physiological experience was the source of emotion, and not the physiological experience itself.

Later theorists challenged the suggestion that cognitive processes are necessary for emotions. Zajonc and colleagues (Kunst-Wilson & Zajonc, 1980; Moreland & Zajonc, 1977) demonstrated that participants' liking of old stimuli relative to new stimuli was apparent even when these stimuli appeared for very brief durations (e.g. ~ 1ms) and when recognition performance was at chance for both old and new stimuli. That is, even when participants could not recognise the stimuli beyond the level of guessing, they still performed affective evaluations. Based on this evidence Zajonc inferred that conscious recognition and affective judgements are separate, and thus that a cognitive appraisal may not necessary for rapid emotional responses (Zajonc, 1980). Others have cautioned that Zajonc only examined the valence quality of emotion, and furthermore only claimed that cognition was unnecessary for this minimal form of emotion, not the full experience of specific emotions (Moors, 2009). Nonetheless, these findings are relevant for the basic claim that appraisal causes emotion.

Later models of emotion affirmed the importance of cognitive attribution, but elaborated on the cognitive processes involved. For example, the appraisal model (Lazarus, 1982) suggests that a series of situational evaluations lead to specific physiological responses and emotions. Primary appraisals are assessments of the situation and include evaluations of motivational relevance and motivational congruence (Smith & Lazarus, 1993). For example, individuals who rated themselves as being highly fearful of snakes displayed greater electrophysiological activity associated with frowning than did individuals who rated themselves as having a low fear of snakes (Dimburg, Hansson & Thunberg, 1998). Note that

primary appraisals address the reservations of Zajonc (1980) by including automatic evaluations that are without awareness, such as the negative evaluation of snakes. Secondary appraisals are assessments of resources and include evaluations of accountability, problem-focused coping potential, emotion-focused coping potential and future expectancy (Smith & Lazarus, 1993). For example, when considering a hypothetical scenario where a friend discloses the romantic affair the participant is having, participants are more likely to report anger if the text places emphasis on the actions of the friend than their own actions (Smith & Lazarus, 1993).

The sequence theory of emotional differentiation (Leventhal & Scherer, 1987; Scherer, 1987, 2001) similarly posits a series of appraisals that commence with low-level stimulus checks and continue with complex conceptual checks (see Figure 1.6). These checks are organized under four consecutive appraisal objectives, which determine the perceiver's emotional response (Scherer, 2001). The first objective is to check whether the stimulus is relevant to the perceiver, such as whether it represents an environmental change, for example, the tendency to orient to novel stimuli (Knight, 1984). This response is then differentiated into an appropriate emotional response by the second objective, which is to check whether the stimulus furthers or endangers the perceiver's goals or needs. For example, events which are congruent with goals elicit facial expressions associated with happiness (Gentsch, Grandjean & Scherer, 2015). Another objective is for the perceiver to determine whether they can cope with an event. For example, low-status individuals teasing high-status individuals display more embarrassment than low-status individuals who teased other low-status individuals (Keltner, Young, Heerey, Oemig, & Monarch, 1998). Another of the perceiver's appraisal objectives is likely to be whether an action is in congruence with internal or group norms. For example, individuals with low self-esteem show a greater decrease in ratings of self-worth in response to perceived poor performance than do individuals with high self-esteem (Brown & Dutton, 1995).

Figure 1.6: The sequence model of emotion, adapted from Scherer (2001).
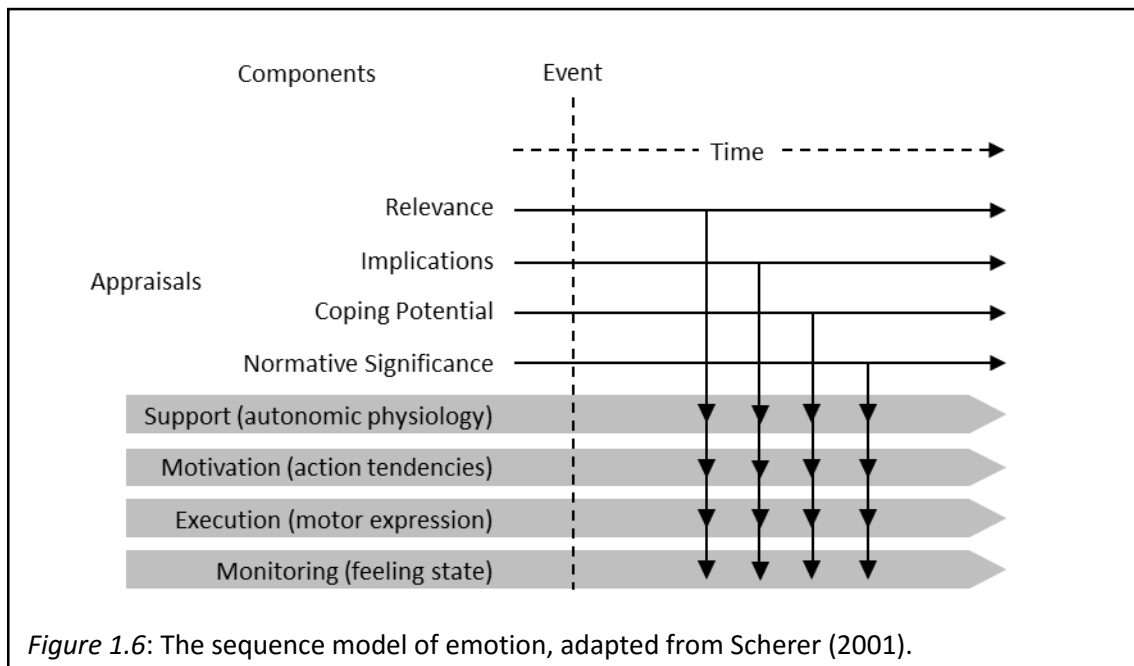
An examination of brain function suggests that the primacy of cognition in the emotion process may not be absolute, and that Zajonc and colleague's reservations (Kunst-– Wilson & Zajonc, 1980; Moreland & Zajonc, 1977) may still have validity. Viewing negative stimuli, such as angry or fearful faces, stimulates the amygdala more than the viewing of happy or neutral stimuli (Williams, Morris, McGlone, Abbott & Mattingley, 2004; Thomas et al., 2001). Importantly, when emotional pictures are presented in a way that prevents explicit acknowledgement this greater activation is still present (Whalen et al., 1998; Williams et al., 2004), suggesting that the amygdala processes this information in the absence of conscious appraisal. Nonetheless, cognitive evaluations can also modulate amygdala reactivity (George, Driver & Dolan, 2001; Hariri, Mattay, Tessitore, Fera & Weinberger, 2003; Schaefer et al., 2002). For example, when required to match threatening pictures (e.g., snakes or guns) perceptually, participants exhibit stronger bilateral activity in their amygdalae than they do when matching geometric shapes (Hariri et al., 2003). However, when participants were required to select the most appropriate emotional labels for the same pictures, they exhibited attenuated and unilateral amygdala activity and heightened prefrontal activity. Thus, in support of previous claims made based on animal models (LeDoux, 1989, 1996, 2000), information can directly access brain regions involved in emotional processing independent of appraisal, or alternatively cognitive evaluations can mediate this access.

Regarding the categorisation of emotion, there have historically been two general arguments, one of which is that there are discreet emotional categories. The alleged number of these basic emotions has varied from two to eleven (Power & Dalgleish, 1997). However, there is above chance recognition accuracy for at least seven categories (i.e., anger, contempt, disgust, fear, happiness, sadness & surprise) among both western-literate and non-western literate cultural groups, and more importantly among non-literate cultural groups, suggesting that the labelling of these emotions is universal (Ekman & Friesen, 1971; Ekman & Heider, 1988; Ekman, Sorensen & Friesen, 1969). Beyond verbal labels, there is also evidence for a degree of biological innateness of at least some emotions. For example, individuals who have been blind from birth, and thus cannot observe others demonstrating facial expressions, nonetheless exhibit spontaneous facial expressions of happiness and sadness (Galati, Ricci-Bitti & Scherer, 1997; Matsumoto & Willingham, 2006, 2009; Tracy & Matsumoto, 2008) as well as bodily expressions of pride and shame (Tracy & Matsumoto, 2008).

Affective circumplex models view emotions as being related and continuous on one or more dimensions, rather than discrete categories (see Figure 1.7 for an illustration of this principle). These models usually identify a minimum of two dimensions, such as valence and arousal, although theorists have posited other dimensions such as power and predictability that are not directly relevant here (Fontaine, Scherer, Roesch & Ellsworth, 2007; Gunes, 2010). Valence refers to how positive and negative, or pleasant and unpleasant, the experienced emotion is (Fontaine et al., 2007; Gunes, 2010; Posner, Russell & Peterson, 2005; Russell, 1980; Russell & Barrett, 1999). For example, basic emotions such as happiness would be located more towards the pleasant pole of the continuum, whilst anger would be located further towards the unpleasant pole. Arousal, on the other hand, refers to whether the emotional state is more relaxing or exciting (Fontaine et al., 2007; Gunes, 2010; Posner et al., 2005; Russell, 1980; Russell et al., 1999). Here, both happiness and anger are considered highly arousing emotions, whereas an emotion like sadness falls more towards the least arousing pole.
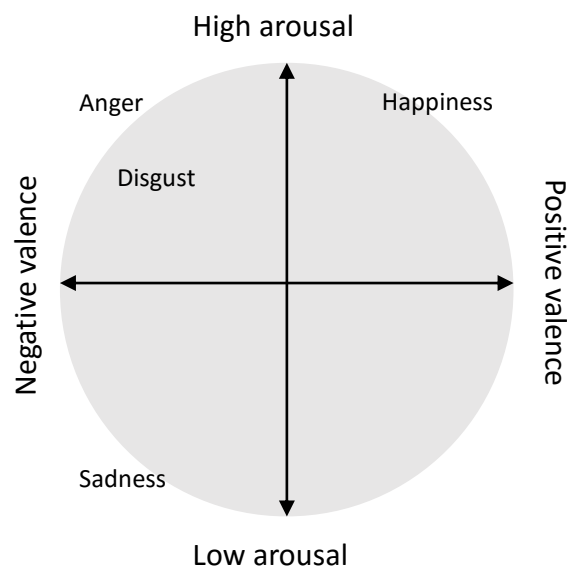
Figure 1.7: The typical affective circumplex model using the minimal number of dimensions of valence and arousal. This example illustrates where four of Ekman and colleague's (1969, 1971, 1988) six basic emotions might be found on each dimension.

Arguably, the discrete and circumplex models both have some degree of descriptive power in the categorisation of emotion. As illustrated in Figure 9, we can at least conceptually map discrete emotions onto at least two dimensions of the circumplex model. In support of this, sorting lexical stimuli into words or non-words results in larger ERP modulations (~ 100ms) when viewing words specifically rated as happy compared to those rated neutral, but also larger ERP modulations (~ 400ms) when viewing non-specifically positive compared to neutral stimuli (Briesemeister, Kuchinke & Jacobs, 2014). This suggests that participants were attributing the words both a discrete emotion and a general valence. Additionally, children (aged 2-5 years) are able to use a greater number of labels for emotional facial expressions as they mature, beginning with angry and happy and broadening out to the six basic emotions (Widen & Russell, 2008). This suggests that elaborate emotion recognition develops on top a foundation of basic valence recognition. Collectively, these studies suggest that the two models may not be mutually exclusive.

Facial Expressions of Emotion and their Effect on Attention and Memory

Recall that the sequential model of emotion and supporting research highlights normative significance as a factor determining the response an individual takes to perceived

stimuli (Brown & Dutton, 1995; Leventhal & Scherer, 1987; Scherer, 1987, 2001). Thus, we can predict that evaluations of valence will have implications for the allocation of attention and memory resources. For example, people fixate on positive stimuli more than they do on negative stimuli (Humphreys, Underwood & Chapman, 2010) and positive stimuli are also be more likely to survive the "attentional blink" when presented in rapid succession (Vuilleumier & Huang, 2009). Together, these studies suggest an attentional benefit for positive compared to negative stimuli. Moreover, recognition memory is better for positive than for negative photographs (Becker, 2012), even when displayed very briefly (Maljkovic & Martini, 2005), demonstrating that memory for positive emotional stimuli is more efficient than memory for negative emotional stimuli. These studies suggest that emotion valence may interact with attentional and memory systems.

One common source of positive and negative emotional stimuli are facial expressions. Research shows that people reliably recognise facial expressions of emotion, even when they are separated by geography (Ekman & Friesen, 1971; Ekman & Heider, 1988; Elfenbein & Ambady, 2002), highlighting their importance in this function. Even infants show a preference for looking at faces compared to other objects (Farroni et al., 2005; Gliga, Elsabbagh, Andravizou & Johnson, 2009; Johnson, Dziurawiec, Ellis & Morton, 1991), a difference that increases with age (Frank, Amso & Johnson, 2014). Adults continue to show a preference in looking faces compared to non-face objects (Devue, Belopolsky & Theeuwes, 2012; Langton, Law, Burton & Schweinberger, 2008). These studies suggest a benefit for faces compared to non-face stimuli in attention. Thus, when emotional facial expressions serve as stimuli, they may shape attention-WM interactions in interesting ways.

Indeed, not only do faces receive priority in attention over non-faces, people attend to the expressions they display very rapidly and with greater sensitivity than they do with non-faces. EEG research indicates that facial expression detection occurs as early as around 100ms after the onset of the face (Eimer & Holmes, 2002; Utama, Takemoto, Koike & Nakamura, 2009), suggesting that attention to emotion in faces is very rapid. In one task, where participants judged emotional expression, they were faster in their decisions when the face expressed one of six emotions (anger, disgust, fear, happiness, sadness & surprise) compared to when it was neutral (Eimer, Holmes, McGlone, 2003). Furthermore, neural responses associated with emotional processing are stronger to emotion displayed on faces than emotion contained in scenes (Hariri, Tessitore, Mattay, Fera & Weinberger, 2002).

These studies indicate rapid detection of emotion in faces, as well as greater sensitivity to emotion displayed in faces compared to non-face stimuli, suggesting that faces are particularly powerful conveyers of emotion.

Interestingly, research on the efficiency of attention and memory for positive and negative emotional facial expressions shows contradictory results. Some research indicates that faces associated with threat (e.g., angry expressions) capture attention more rapidly than do other expressions. For example, participants detect angry faces more rapidly in search tasks compared to happy faces (Eastwood, Smilek & Merikle, 2001; Lamy, Amunts & Bar-Haim, 2008; Feldmann-Wüstefeld, Schmidt-Daffy & Schubö, 2011; Hansen & Hansen, 1988) or other negative expressions (Öhman, Lundqvist & Esteves, 2001). This research suggests an attention benefit for threatening expressions. Moreover, the number of face identities that can be held in short-term memory is increased when they are angry compared to when they are happy or neutral, suggesting a memory benefit for angry faces (Jackson, Wu, Linden & Raymond, 2009).

However, other research indicates that the angry benefit may result from perceptual confounds. Specifically, a review (Becker, Anderson, Mortensen, Neufeld & Neel, 2011) found that studies reporting faster search times for angry faces used predominantly schematic face stimuli, which allowed participants to discern features with greater ease than would be possible with photographic stimuli. The authors of this review found that using comparatively more life-like stimuli resulted in faster search for happy faces on balance. Faster detection of happy compared to angry photographic and dynamic face stimuli (Becker et al., 2012; Juth, Lundqvist, Karlsson & Öhman, 2005), further supports this argument. Additionally, when looking at memory performance, happy expressions improve identity recognition for faces (D'Argembeau & Van der Linden, 2007). These studies imply that when participants are not able to rely on high contrast visual features, and instead experimenters present them with more ecologically valid stimuli, happy face stimuli dominate attention.

Evidence for Emotion-Attention Interactions

Considering positive stimuli have a greater influence on attention, it is unsurprising that this influence extends to controlling the allocation of attention to other stimuli. In particular, research using emotion induction demonstrates that positive emotions broaden

attention relative to negative emotion, and therefore that positive and negative emotional states have opposing influences on the executive control of attention. For example, there is greater interference from incompatible flankers (Rowe, Hirsh & Anderson, 2007), greater holistic relative to feature-based processing (Fredrickson & Branigan, 2005; Gable & Harmon-Jones, 2011; Huntsinger, 2013; Johnson, Waugh & Fredrickson, 2010), and greater fixation on positive stimuli in the periphery (Wadlinger & Isaacowitz, 2006). Conversely, induced negative emotion leads to the narrowing of attention, as demonstrated by slower eye movements towards targets after fixation on negative compared to neutral pictures (van Steenbergen, Band & Hommel, 2011). Furthermore, inducing negative mood leads to less holistic processing of faces than inducing positive mood (Curby, Johnson & Tyson, 2012). This literature suggests the broadening of attentional focus during positive emotion and the narrowing of attention during negative emotion.

Additionally, the modulation of attentional breadth is not dependent on participants' mood, as negative faces decrease flanker effects when displayed as targets compared to both positive and neutral targets (Fenske & Eastwood, 2003; Horstmann, Borgstedt & Heumann, 2006). Furthermore, the influence of the gaze of a stimulus face on a participants' attention is stronger when the task involves locating a positive target (Bayliss, Schuch & Tipper, 2010). This research demonstrates that facially expressed emotions also modulate the focus of attention depending on their valence, with positive emotions leading to a more diffuse distribution of attention than negative emotions.

As well as influencing the breadth of attention focus, there is evidence that positive emotions promote more efficient attentional deployment than do negative emotions. For example, self-reported positive affect correlates positively with the detection of a target in an attentional blink paradigm whereas negative affect reduces the likelihood of target detection (Vermeulen, 2010). This work therefore suggests faster recovery of attentional resources after their deployment for individuals in positive mood states and impaired recovery in negative mood states. It is therefore possible that positive emotions lead to more efficient redeployment of attention than negative emotions. In addition to encouraging efficient use of attentional resources, there is also evidence that positive emotion boosts memory performance relative to negative emotion or neutral information. For example, induced positive affect increases recognition memory performance (Yang, Yang & Isen, 2013). This suggests that positive emotion facilitates efficient cognition.

Alternatively, rather than positive emotion leading to a broader and more efficient deployment of attention, as we argue, emotion in WM and emotion in the visual environment may interact in a similar manner as non-emotion-related objects do. That is, attention may be biased toward objects in the visual environment that contain emotionally expressive features congruent to those associated with memory contents (Ansorge, Kiss & Eimer, 2009; Hollingworth & Luck, 2009; Kang, Hong, Blake & Woodman, 2011). For example, one study (Grecucci, Soto, Rumiati, Humphreys & Rotshtein, 2009) required participants to search for a photo of a person, expressing an emotion (e.g., fear, happiness), whilst maintaining a word describing an emotion in memory. They found that RTs were faster when the target's expression matched the emotion word, suggesting that holding an emotionally expressive stimulus in WM biases attention to displays of that emotion. Additionally, expression recognition is better when an expressive face appears in an emotion-congruent context, rather than an incongruent context (Righart & de Gelder, 2008). This research suggests that emotional information in WM will influence attention equivalently, regardless of valence and against what the evidence we have presented suggests.

Another affect-related factor that may control attention capture is the subjective desirability of the emotion. For example, adolescents' experience of positive emotion positively correlates with measures of reward reactivity (Forbes et al., 2010), and positive verbal feedback is more effective at increasing intrinsic motivation than monetary feedback (Deci, 1971). This research suggests that positive emotions, and likely their displays, carry intrinsic value. Research using monetary reward finds that distractors associated with high monetary reward slow responses to targets compared with distractors associated with low monetary reward (Anderson, Laurent & Yantis, 2011; Mine & Saiki, 2015). These results suggest that learned reward value can affect the allocation of attention. Furthermore, this influence appears to be long lasting, as the influence of a learned reward value on attention persisted for several days after the initial learning period (Yantis, Anderson, Wampler & Laurent, 2012). Similarly, visual search targets associated with high monetary rewards elicit ERP signatures of attention capture more strongly than targets associated with low reward (Kiss, Driver & Eimer, 2009). Additionally, participants attend to faces associated with high reward more efficiently than faces associated with low reward value (Raymond & O'Brien, 2009; Rutherford, O'Brien & Raymond, 2010). These studies demonstrate that learned

reward value can influence the allocation of attention, and can do so long after the association is relevant. Thus, the value of an emotional display may also determine attention capture.

Interestingly, smiles may also have intrinsic value that can be measured in monetary terms (Shore & Heerey, 2011; Averbeck & Duchaine, 2009). Genuine smiles involve the orbicularis oculi muscle (see Figure 1.8 for an example) and are associated with the experience of genuine pleasure, whereas polite smiles do not involve orbicularis oculi and are typically used when smiling is the socially desirable response (Ekman, Davidson, & Friesen, 1990; Ekman, Sorenson, & Friesen, 1969). Research demonstrates that participants cooperate with (Mussel, Göritz & Hewig, 2013; Scharlemann, Eckel, Kacelnik & Wilson, 2001), and expect cooperation from genuinely smiling partners more than they do from partners displaying other expressions (Knutson et al., 1996; Van Doorn, Heerdink & Van Kleef, 2012). In addition, happy faces induce positive emotions in the perceiver (Surakka & Hietanen, 1998; Wild, Erb & Bartels, 2001) and their reciprocation is associated with subsequent satisfaction with an interaction (Heerey & Kring, 2007). Recall also that the implications of a stimulus for a perceiver can influence their reaction toward it (Leventhal & Scherer, 1987; Scherer, 1987, 2001), for example, whether the stimulus is congruent with or in opposition to the perceiver's goals or needs (Gentsch, Grandjean & Scherer, 2015). Given that genuine smiles possess a desirability, similar to the relationship between high and low monetary rewards, it is reasonable to suggest that the extent to which they capture attention may also be in proportion to their subjective value.

Figure 1.8: Typical displays of a genuine (left) and a polite (right) smile.

Thesis Overview

Whereas non-emotional stimuli bias attention to WM-congruent stimuli, research suggests that positive emotional stimuli may exert more control over attention than negative emotional stimuli. Specifically, positive emotion results in a broader focus of attention as well as more efficient processing generally than negative emotion. Based on this research, we expected that facial displays of positive emotion would make attention allocation more efficient relative to negative facial expressions of emotion. Given that studies using non-emotional stimuli indicate that WM-attention interactions only occur when stimuli are task-relevant, we expected that only task-relevant positive emotion would make attention more efficient. When task-irrelevant we suggested that WM-congruent expressions receive less processing than incongruent expressions. Additionally, based on observations that value drives attention capture, we expected that genuine smiles, which are valuable social cues, would capture attention in proportion to their subjective value.

Chapter 2 explored the idea that emotion in WM biases attention to emotion-congruent environmental stimuli. Here we use a dual-task paradigm (similar to that in Figure 1.1) in which emotion is a key WM variable and ask how it influences attention depending on task relevance. Participants memorized a face displaying an emotional expression and then performed a decision task on a subsequent display in which emotion was present. We also varied whether emotion was task-relevant. We examined the influence of these variables on RT and recognition accuracy. Results generally showed that happy faces in WM make attention allocation more efficient when emotion is relevant to task objectives and when the task is relatively easy.

Chapter 3 used an ERP paradigm to explore processes that occur after the deployment of attention in order to elucidate the inconsistencies in research examining WM-attention interactions. Previous research has either depended on RT and accuracy measures (Ansorge, Kiss & Eimer, 2009; Hollingworth & Luck, 2009; Kang, Hong, Blake & Woodman, 2011), or only examined direct ERP measures of attention (Sawaki & Luck, 2010, 2011, 2013) providing little insight into the processes that follow attention capture but may nonetheless influence attention. To address this shortcoming, we modified the basic paradigm used in Chapter 2 in order to cue participants to the location of a target. This cueing paradigm allowed us to focus on processes that follow attention capture (as attention is already oriented to the location of the stimulus). Specifically, we asked whether

memory-matching facial expressions receive more superficial processing following initial attention capture, and whether such stimuli interfere with visual processing. In order to investigate this we measured ERP indices of visual processing and interference. As expected, we found WM-matching expressions appeared to be processed superficially, compared to WM non-matching stimuli, but that WM-matching stimuli still interfere with processing of faces under perception.

Finally, in chapter 4, we shift our focus slightly and ask how differences in the subjective values of two facial expressions (genuine and polite smiles) influence attention capture. Previous research has investigated this by associating monetary reward value with stimuli and asking how this shapes attention capture effects (Anderson, Laurent & Yantis, 2011; Mine & Saiki, 2015; Shore & Heerey, 2013; Yantis, Anderson, Wampler & Laurent, 2012). However, if facial expressions have their own intrinsic subjective values as other findings suggest (Mussel, Göritz & Hewig, 2013; Scharlemann, Eckel, Kacelnik & Wilson, 2001; Shore & Heerey, 2011), this value should serve to guide attention capture effects. To answer this question, we first ascertained the degree to which participants subjectively valued genuine and polite smiles in an economic game. We then used these stimuli in a "flanker" style task to assess differences in participants' responses to these expressions when they were trial targets. Interestingly, the speed with which participants responded to these targets correlated with their subjective values. Results therefore hint that the subjective value of an expression drives the attention capture effect.

Chapter 2

WM Emotion-Attention Interactions: The Role of Valence and Task-Relevance

In daily life, people encounter many objects, each of which may or may not be relevant to current concerns. This presents a substantial problem because the extent of available cognitive resources is limited. Researchers have suggested that in order to solve this problem, the attentional system is sensitive to similarity between perceived objects and the contents of WM. In theory, this allows the biasing of attention toward goal-salient objects and the rapid release of attention from irrelevant objects (Desimone & Duncan, 1995). However, emotion is an important aspect of daily life, and therefore likely to affect this process. Specifically, valence and type of emotion may have different consequences for behavior and therefore for how cognitive systems treat different emotional stimuli (Kringelbach & Rolls, 2003). The goal of the current research is to investigate how positive and negative emotional stimuli, maintained in WM, influence attention when emotion is embedded in, but not central to a subsequent target, and depending on whether emotion is task-relevant.

According to biased competition theory (Desimone & Duncan, 1995), attention is a process whereby objects in the visual field compete for limited processing capacity until one object becomes selected. Bias can be the result of both bottom-up processes that help the visual system separate an object from its background, and top-down mechanisms that activate object representations. Desimone and Duncan (1995) suggest that one top-down mechanism for resolving this competition is input from WM systems, based on templates for objects and locations. According to this idea, when individuals compare objects in the visual field, those that are more similar to a template in memory will attract more attention than less similar objects.

Evidence in support of biased competition theory comes predominantly from studies that employ dual-task procedures, in which participants complete a task while holding an object in WM. This research has generally found that WM contents enhance RTs to stimuli that share one or more features. For example, Soto, Humphreys and Heinke (2006; Experiment 1) showed that similarity between WM content and a subsequent cue lead to faster RTs to a test target, and that the more features the cue and WM representation shared the faster the response. This supports a key prediction, of biased competition theory: that memory-congruent stimuli should bias the allocation of attention. Other studies, including one using faces, have also demonstrated support for biased competition theory (Ansorge, Kiss & Eimer, 2009; Downing, 2000; Downing & Dodds, 2004; Hollingworth

& Luck, 2009; Kang, Hong, Blake & Woodman, 2011; Soto, Heinke, Humphreys & Blanco, 2005; Soto & Humphreys, 2009; Soto, Humphreys & Heinke, 2006).

Stimuli that are associated with emotional value may further bias the competition for attentional resources. Emotions, and their associated stimuli, have intrinsic adaptive properties and are associated with distinct sets of thoughts, actions, and physiological responses (Kringelbach & Rolls, 2003). For example, in the cognitive domain, research shows that positive emotions may broaden the focus of attention relative to negative emotions, which constrict it (Fredrickson, 2001). More importantly, there is evidence that positive emotions promote a more efficient recruitment of attentional resources. For example, people are more likely to detect positive stimuli than other stimuli when presented shortly after an initial target, that is, when attention is preoccupied (Vermeulen, 2010; Vulleumier & Huang, 2009). Additionally, faces displaying positive emotions than can elicit stronger gaze cuing effects than faces displaying other expressions (Bayliss, Schuch & Tipper, 2010). Together, these results suggest that when participants hold emotionally positive stimuli in WM their recruitment of attention should be more efficient relative to when they maintain negative stimuli.

However, independent of WM, emotional content in a visual display may also bias attention in interesting ways. For example, research has shown that people respond more quickly to indicators of threat (e.g., angry or fearful faces) than to positive cues such as happy faces across a variety of tasks (Barratt & Bundesen, 2012; Eastwood, Smilek & Merikle, 2001; Eastwood, Smilek & Merikle, 2003; Horstmann, Scharlau & Ansorge, 2006; Huang, Chen & Chang, 2011; Maratos, 2011; Moriya, Koster & De Raedt, 2014; Schubö, Meinecke, Abele & Gendolla, 2006; Öhman, Lundqvist & Esteves, 2001; O'Toole, DeCicco, Hong & Dennis, 2011). On the other hand, a growing literature fails to replicate these results, suggesting instead that positive emotion facilitates responding (e.g., Becker et al., 2012; Becker, Anderson, Mortensen, Neufeld & Neel, 2011; Juth, Lundqvist, Karlsson & Öhman, 2005).

Regardless of emotional valence, the interaction between WM and selective attention may depend on whether the WM contents are task-relevant. For example, research suggests that only when features held in WM are necessary to the completion of a subsequent task, do they bias attention (Olivers, Meijer & Theeuwes, 2006). This may also be true when stimuli are emotional, although previous research has not tested this idea

clearly, as emotional stimuli in WM have not been specifically examined and therefore, may not have been adequately maintained (Moriya, Koster & De Raedt, 2014).

Here, we use a dual-task design to probe the role of positive and negative emotion in WM-attention interactions, depending on whether emotion is task-relevant. In our paradigm, participants first encoded a photograph of a face displaying happiness or anger for a later recognition task. Between the encoding and recall stages, they viewed two schematic faces (each expressing a different emotion) on either side of a fixation cross. Participants determined which of these schematics was their "target" based on a coloured frame and then decided whether it's "nose" was oriented horizontally or vertically. In order to investigate task relevance, participants in one version of the task maintained the initial face's emotional expression whereas in another, participants remembered the identity of the initial face, rather than its expression. When participants must maintain expression type, emotion is essential for the memory task goal, whereas when participants maintain identity emotion is unrelated to the task and therefore not essential to task performance.

Based on the previous research, we propose two hypotheses. First, we expect attention to be more efficient when positive emotion is held in WM compared to when negative emotion is held in WM. Therefore, when focused on a central fixation, happy WM contents should make people faster to determine which of two lateral locations contains a target than angry WM contents. The result should be faster RTs to both schematic expressions with happy relative to angry faces in WM. Second, we expect that the relevance of emotion to the task-at-hand will determine whether WM contents influence attention to the visual scene. If task-relevance is an important factor, participants will show no effect of WM emotion when emotion is not relevant to a task. In this case, we expect that angry schematic stimuli should provoke faster RTs than happy schematic stimuli.

Experiment 1

We first ask whether happy faces held in WM elicit more efficient attention recruitment (leading to faster target responses) relative to angry faces when emotion is relevant to the recognition task.

<center>**Methods**</center>

Participants

      Fifty-one university undergraduates (34 female, 17 male; mean age = 19.61, SD = 1.43) reporting either normal or corrected-to-normal vision participated in exchange for partial course credit. The University's ethics committee approved all study procedures. Participants gave written informed consent before participating (likewise for Experiments 2 – 4 below).

Stimuli

      Cropped grey-scale photographs ($0.03° \times 0.05°$) of three adult male faces from the Pictures of Facial Affect set (Ekman & Friesen, 1976) served as stimuli in the memory task (see Figure 2.1a: example stimuli). There were six unique images as each face appeared in happy and angry poses. Eight schematic faces ($0.03° \times 0.05°$) framed by an orange (N = 4) or blue (N = 4) oval ($0.001°$ in thickness), expressing either anger or happiness, served as stimuli in the line-orientation ("nose") task (see Figure 2.1b). Each schematic face contained a horizontal (N = 4) or vertical (N = 4) "nose" ($0.004° \times 0.006°$). The eight schematic faces displayed each combination of frame colour, expression and nose orientation.

Figure 2.1: Example stimuli used throughout this study. A single identity face (a) expressing anger (L) and happiness (R); 1b) schematic faces (b) depicting anger (L) and happiness (R).
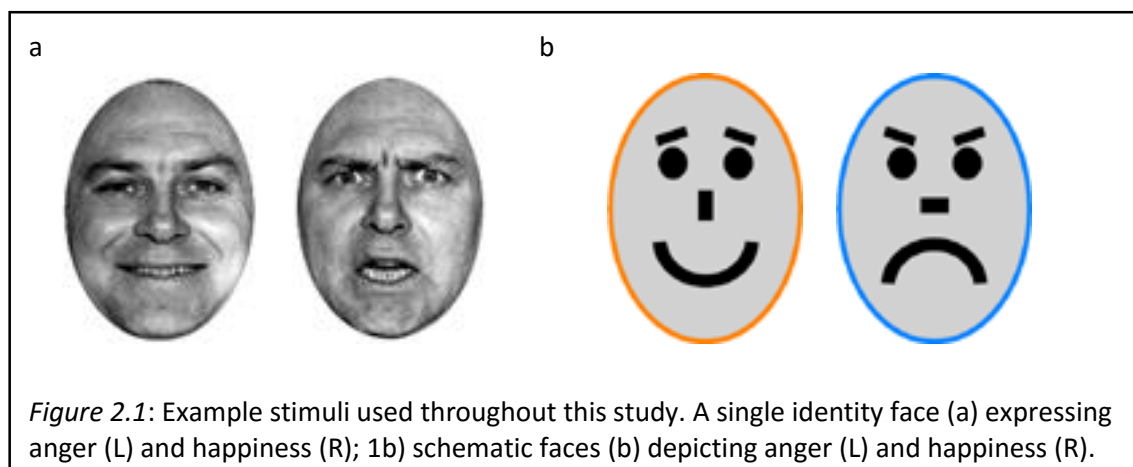
Procedure

      Experimental trials began with a 2000ms central fixation cross, which was subsequently replaced at the same location by an angry or happy face that participants were instructed to remember (500ms; Figure 2.2). After a second central fixation (1200ms)

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two schematic faces briefly appeared (200ms), flanking the fixation cross, which remained visible for an additional 1300ms. The schematic faces always depicted different emotions; one was framed in orange and the other in blue. The frame colour designated the schematic as a target or distractor (50% of participants responded to the blue frames as target stimuli). Participants identified the orientation of the central line (the "nose") using a key press. The RT cut-off for this response was 1500ms from stimulus onset. Participants responded using a keyboard with the index finger of their right hand. Half of participants pressed the "1" key when the nose was horizontal, and the "2" key when the nose was vertical, for the other half of participants we reversed this mapping. To test participants' ability to maintain the initial emotion in WM, the computer then prompted participants to recall the expression displayed by the initial face ("happy" or "angry") using a key press. Participants pressed the "1" key on their keyboard when the face was happy and the "2" key when it was angry. A practice phase of 64 trials (providing accuracy and speed feedback for both decisions) was followed by four experimental blocks of 64 trials each (without feedback), for 256 experimental trials.

Figure 2.2. Experiment 1 trial timeline. Participants memorize the expression of a face, report the orientation of a schematic target face's nose (vertical or horizontal), and finally report the expression of the initial face.
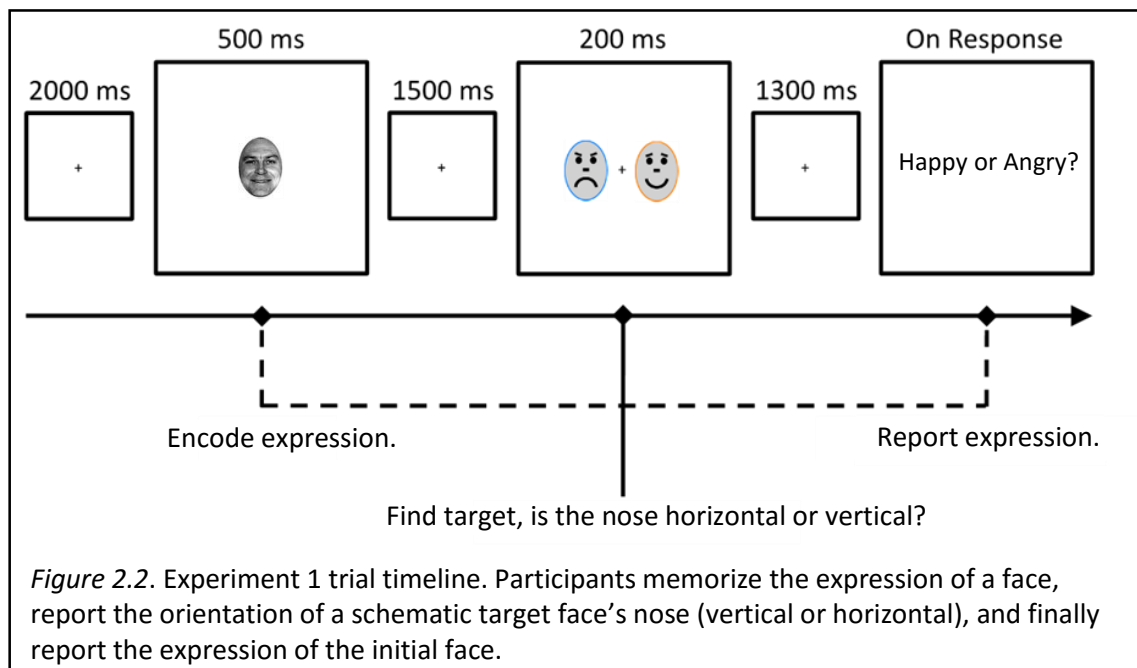
We counterbalanced target colour (orange or blue frames) and key press response mappings across participants. We balanced encoding emotion and schematic congruence within participant. The schematic target had an equal likelihood of appearing on the left and right sides of the fixation cross. Line-orientation congruence between two schematic faces

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was such that on 25% of trials they matched (e.g., vertical-vertical) whereas on the remaining trials they did not (e.g., vertical-horizontal). This allowed us to ensure that participants did not base their line-orientation judgments on the non-target schematic (we note here that data analysis suggested this was not an issue).

Stimuli were displayed on a 20-inch colour monitor (85 Hz, 32-bit, resolution 1280 × 1024), at a viewing distance of 80 cm. E-Prime software (Version 1.1) operating on a computer with a 3.4 GHz Pentium 4 processor displayed stimuli and recorded responses made via keyboard.

Data Analysis

We examined average RTs and error rates for both schematic and memory test responses with repeated measures analyses of variance (RM-ANOVA). WM emotion (happy, angry) and schematic emotion (happy, angry) served as within-subjects factors. We used paired samples t-tests to conduct pairwise comparisons. We excluded RTs on incorrect trials from these averages, as well as trials with RTs faster than 150ms.

Results and Discussion

The final sample consisted of 38 participants (mean age = 19.55, SD = 1.13), 27 female and 11 males. We excluded thirteen participants for chance or sub-chance performance on either the line-orientation or the recognition tasks (≤ 50% correct for both).

As Figure 2.3 shows, there was a significant effect of WM emotion on RTs, $F_{(1, 37)}$ = 4.599, p = .039, η^2 = .11, such that participants were faster in the line-orientation task when holding a happy photo in memory compared to an angry photo, regardless of schematic emotion. There was no main effect of schematic emotion, $F_{(1, 37)}$ = .428, p = .517, η^2 = .01, nor was there an interaction between WM and schematic emotion, $F_{(1, 37)}$ = 2.307, p = .137, η^2 = .06. Happy faces in WM elicited faster RTs to the orientation task, suggesting modulation of attention by WM contents, consistent with findings that positive emotions cause a more efficient recruitment of attention (Bayliss, Schuch & Tipper, 2010; Vermeulen, 2010; Vulleumier & Huang, 2009).

Figure 2.3: Experiment 1 mean RTs on the line orientation task, within-subjects error bars represent +/- 1 SEM.

WM emotion had no effect on recognition accuracy, $F(1, 37) = .158$, $p = .693$, $\eta^2 < .01$, neither did schematic emotion, $F(1, 37) = .030$, $p = .863$, $\eta^2 < .01$. There was also no significant interaction between the two variables, $F(1, 37) = .698$, $p = .409$, $\eta^2 = .02$. See Table 1 below for a summary of mean recognition accuracy.

Table 1

Experiment 1 Mean recognition accuracy (%) by WM and schematic face emotion

	Happy WM Face		Angry WM Face	
Schematic Emotion	M	SE	M	SE
Happy	91.97	1.09	92.74	.96
Angry	92.34	1.30	92	.89

Experiment 2

One alternate explanation for the Experiment 1 findings is that they are simply due to a visual priming effect (i.e., mere exposure to an emotional stimulus drives response speed). If this were true, then participants should respond faster schematic faces preceded

by happy photos even when they do not need to maintain emotional information in WM. In order to test this idea, we replicated Experiment 1 but removed the WM component.

Methods

Participants

Forty undergraduates students (30 female, 10 male; mean age = 20.05, SD = 2.47) reporting either normal or corrected-to-normal vision participated in exchange for partial course credit.

Procedures

The Experiment 2 stimuli and procedures were identical to those used in Experiment 1. However, rather than encoding the expression on the initial face, participants simply named the expression it possessed aloud ("happy" or "angry"). Thus, there was no WM component to this experiment, even though the task was visually identical to that in Experiment 1.

Results and Discussion

The final sample consisted of 38 participants (mean age = 19.97, SE = 2.44), 28 female and 10 males. We excluded two participants for chance or sub-chance performance on the line-orientation task (≤ 50% correct).

As Figure 2.4 shows, there was no effect of emotion in the initial photo on RT, $F_{(1, 37)} = .402$, $p = .530$, $\eta^2 = .01$, or schematic emotion, $F_{(1, 37)} = .650$, $p = .425$, $\eta^2 = .02$, nor was there an interaction between these variables, $F_{(1, 37)} = 1.657$, $p = .206$, $\eta^2 = .04$. The absence of a priming effect in these data suggests that we cannot attribute results of Experiment 1 to mere exposure to emotion in photographs. Rather, those results depend instead upon the maintenance of emotion in WM.

Figure 2.4: Experiment 2 mean RTs on the line orientation task, within-subjects error bars represent +/- 1 SEM.

Experiment 3

Here we address the question of whether emotional contents in WM guide selective attention when emotion is not task-relevant. That is, we ask whether happy versus angry emotional expressions guide subsequent responses to schematic expressions when emotion is not relevant to either experimental task.

Methods

Participants.

Fifty-eight university undergraduates (40 female, 18 male; mean age = 21.76, SD = 5.52) reporting either normal or corrected-to-normal vision participated in exchange for partial course credits.

Procedures.

The stimuli and design of this experiment were identical to that of Experiment 1, with a slight difference in procedure. Rather than encoding the expression of the photograph in the first display, we asked participants to maintain the personal identity of

the face. Participants reported this using a key-press at a memory prompt after the line-orientation task (see Figure 2.5). We randomised memory test-target position, as well as the positions of the memory test non-targets.

Figure 2.5. Experiment 3 trial timeline. Participants memorize the identity of a face, report the orientation of a schematic target face's nose (vertical or horizontal), and finally report the expression of the initial face.

Results and Discussion

The final sample consisted of 48 participants (mean age = 21.50, SD = 4.96), 34 female and 14 males. We excluded ten participants for performance at or below chance on either the line-orientation or the recognition tasks (≤ 50% and ≤ 33% respectively). Contrary to the results of Experiment 1, where positive emotion lead to a broader focus of attention, there was no main effect of WM emotion (see Figure 2.6), $F (1, 47) = 1.461$, $p = .233$, $\eta^2 = .03$, nor was there an interaction between WM and schematic emotion, $F (1, 47) = 2.113$, $p = .153$, $\eta^2 = .04$. Instead, angry schematics elicited faster RTs than happy schematics, $F (1, 47) = 5.144$, $p = .028$, $\eta^2 = .10$, suggesting that when emotion is not task-relevant, the valence of the remembered face's expression did not affect schematic performance. These results, together with those of Experiment 1 suggest that in order for WM maintained emotion to influence attention, it must be a feature that is relevant for later retrieval, as previous research suggests (Olivers, Meijer & Theeuwes, 2006). The results of this experiment are also consistent with research suggesting that expressions of anger capture attention more readily than other expressions in visual search tasks (e.g., Barratt & Bundesen, 2012; Eastwood, Smilek & Merikle, 2001; Eastwood, Smilek & Merikle, 2003).
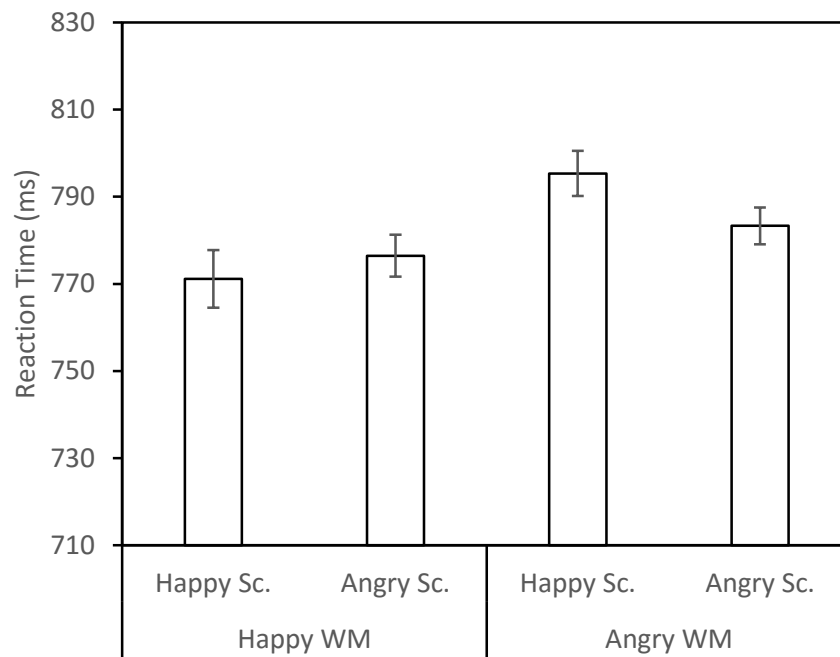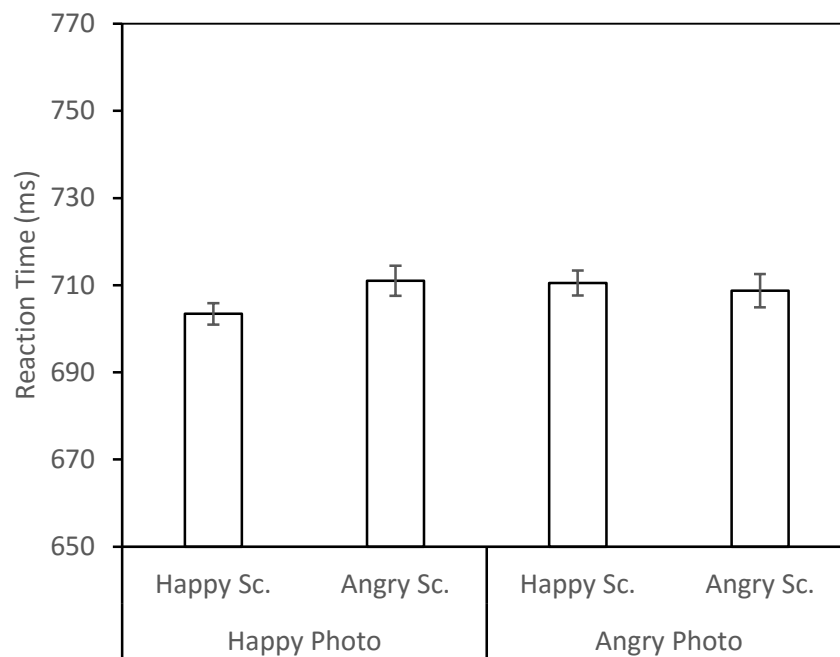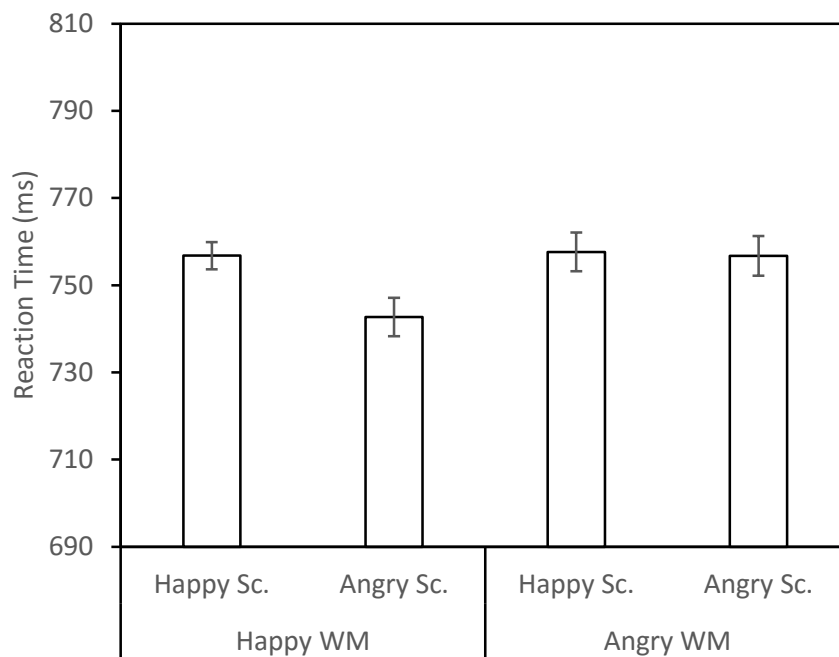
Figure 2.6: Experiment 3 mean RT on the line orientation task, within-subjects error bars represent +/- 1 SEM.

WM emotion had no effect on recognition accuracy, $F (1, 47) = .028$, $p = .868$, $\eta^2 < .01$, neither did schematic emotion, $F (1, 47) = .485$, $p = .490$, $\eta^2 = .01$. There was a trend level interaction between the two variables, $F (1, 47) = 3.809$, $p = .057$, $\eta^2 = .08$, but paired-samples t-tests revealed no significant difference between conditions (all p-values > .611). See Table 2 below for a summary of mean recognition accuracy.

Table 2

Experiment 3 Mean recognition accuracy (%) by WM and schematic face emotion

Schematic Emotion	Happy WM Face		Angry WM Face	
	M	SE	M	SE
Happy	81.58	2.23	82.96	2.20
Angry	82.42	2.02	81.31	2.24

Experiment 4a

In Experiment 4, we attempted to replicate and extend our results. In Experiment 1, positive emotions led to more a more efficient allocation of attention relative to negative

expressions. Here, we ask how positively and negatively valenced expressions affect RTs, relative to a "neutral" baseline condition – a non-emotive face. If, as we have argued, positive expressions broaden attentional focus, then participants should show faster RTs when holding happy faces in WM, relative to neutral or angry faces. Thus, the neutral control condition is necessary to examine relative differences in the attentional effects of such expressions. In Experiment 4a, we add the neutral condition to the experimental design from Experiment 1, in which emotion is task-relevant.
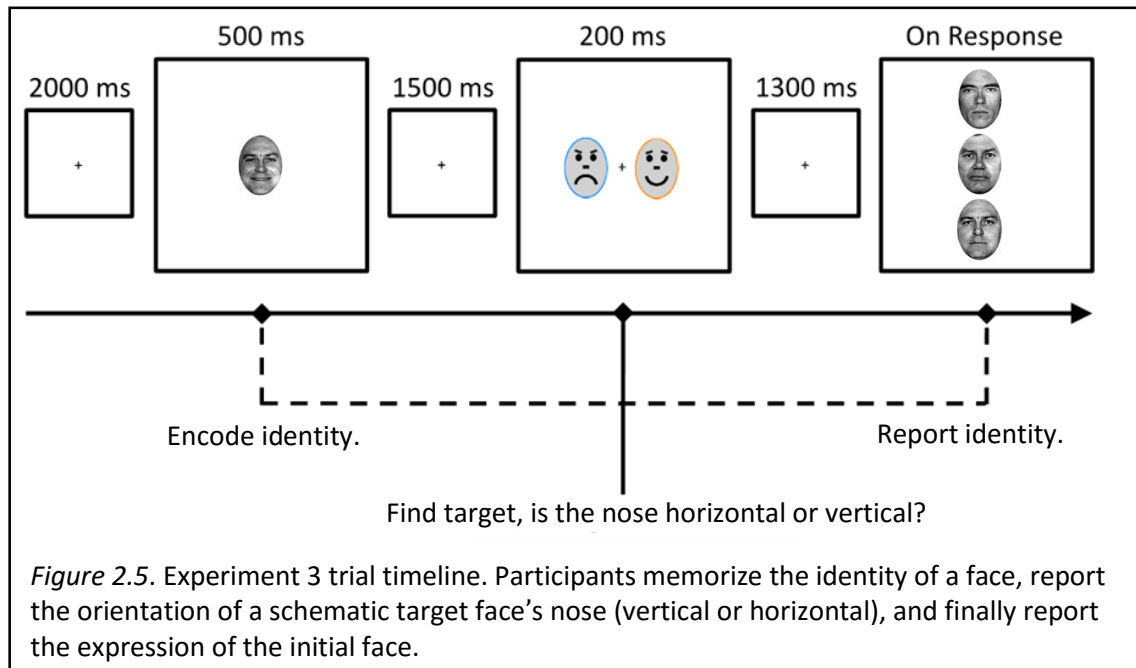
Methods

Participants

Forty-eight university undergraduates (27 female, 21 male; mean age = 20.06, SD = 1.98) reporting either normal or corrected-to-normal vision participated in exchange for partial course credit.

Procedures

The procedure of Experiment 4a was identical to the procedure of Experiment 1 save for the addition of a neutral stimulus to each stimulus set (see Figure 2.7). At the recognition screen, participants pressed the "3" key when the WM face was neutral. Accordingly, we rebalanced trial numbers so that each permutation of expression combinations was equiprobable.
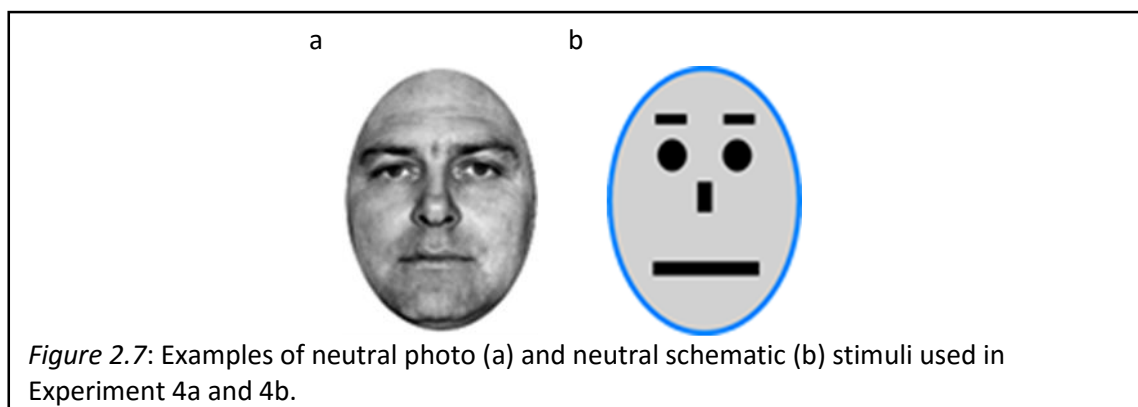
Figure 2.7: Examples of neutral photo (a) and neutral schematic (b) stimuli used in Experiment 4a and 4b.

Results and Discussion

The final sample consisted of 44 participants (mean age = 20.09, SD = 2.07), 25 female and 19 males. We excluded four participants for performance at or below chance on either the line-orientation or the recognition tasks (≤ 50% and ≤ 33% respectively).

As Figure 2.8 shows, when examining the RT data, we found no significant main effect of WM emotion, $F (2, 86) = .486$, $p = .616$, $\eta^2 = .01$, or of schematic emotion, $F (2, 86) = .711$, $p = .494$, $\eta^2 = .02$. There was no interaction between the two variables, $F (4, 172) = 1.374$, $p = .245$, $\eta^2 = .03$, meaning that the inclusion of the neutral display reduced the ability of the WM expression to influence RTs on the subsequent task.

Figure 2.8: Experiment 4a mean RT on the line orientation task, within-subjects error bars represent +/- 1 SEM.
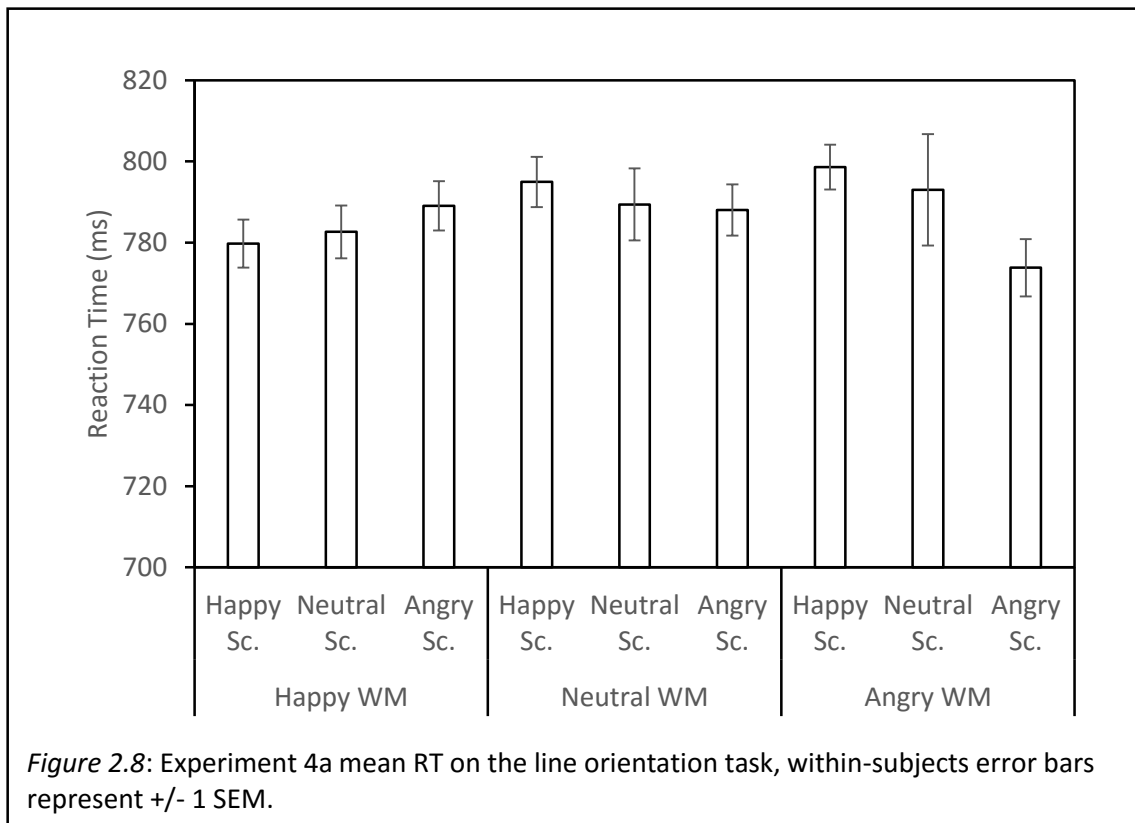
However, participants exhibited a valence dependent recall accuracy pattern depending on WM expression (see Figure 2.9), $F (2, 86) = 12.931$, $p < .001$, $\eta^2 = .23$. Specifically, responses were more accurate when the initial photo expressed happiness compared to a neutral display ($p = .012$) or an angry display ($p < .001$). The recall accuracy difference was not statistically significant between neutral and angry WM faces ($p = .117$). There was no effect of schematic emotion on recall accuracy, $F (2, 86) = .740$, $p = .480$, $\eta^2 = .02$, nor was there an interaction between WM and schematic emotion, $F (4, 172) = .327$, $p =$

.859, η^2 = .01. This result suggests that participants were better able to remember happy faces, relative to both neutral and angry faces, even though they did not show RT differences to the schematic faces.

Figure 2.9: Experiment 4a mean accuracy on the line orientation task, within-subjects error bars represent +/- 1 SEM.
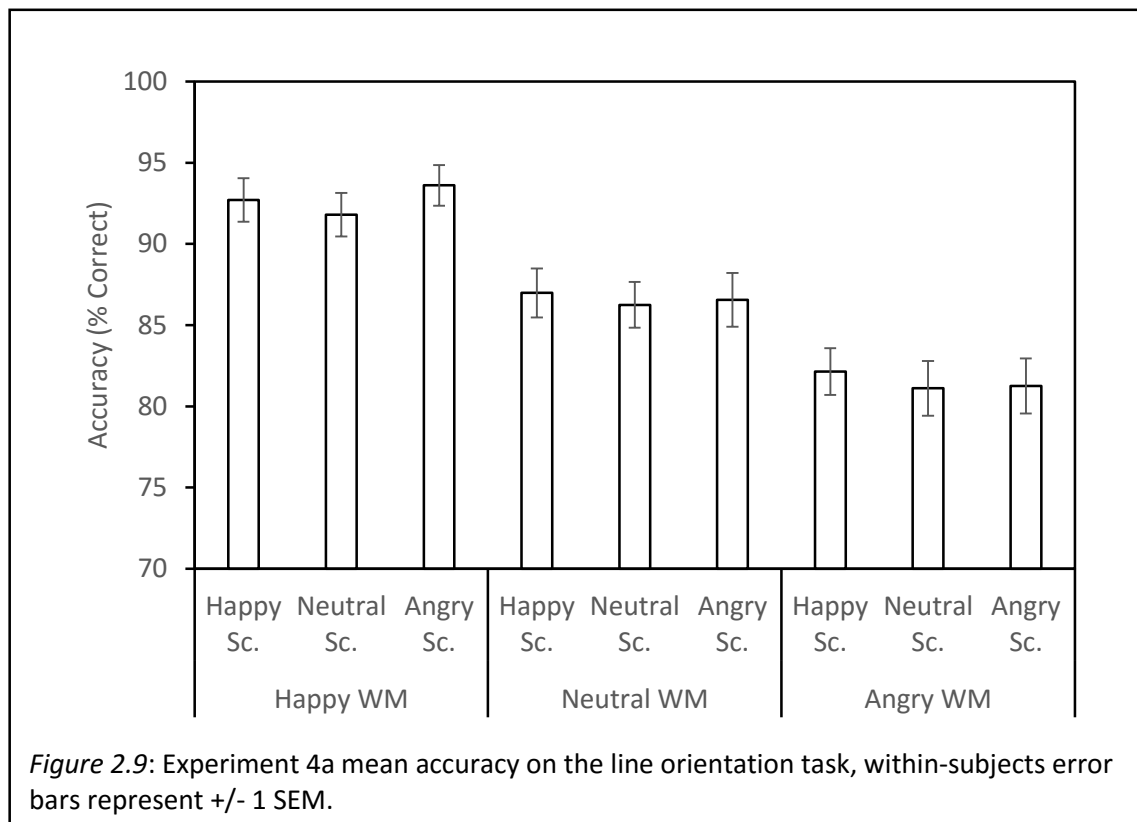
Experiment 4b

We now ask whether the neutral display condition affects results when emotion is not task-relevant, as in Experiment 3.

Methods

Participants

Forty-three university undergraduates (27 female, 16 male; mean age = 19.71, SD = 2.13) reporting either normal or corrected-to-normal vision participated in exchange for partial course credit.

Procedures

The procedure was identical to the procedure of Experiment 3 save for the addition of a neutral stimulus to each stimulus set. Again, we rebalanced trial numbers so that each permutation of expression combinations was equiprobable.

Results and Discussion

The final sample consisted of 39 participants (mean age = 19.61, SD = 1.98), 25 female and 14 males. We excluded four participants for performance at or below chance on either the line-orientation or the recognition tasks (≤ 50% and ≤ 33% respectively).

As Figure 2.10 shows, participants were faster to respond when the line orientation task was embedded in a neutral face than a face expressing happiness or anger. This was supported by a main effect of schematic emotion, $F(2, 76) = 8.345$, $p = .001$, $\eta^2 = .18$. Pairwise comparisons revealed that responses were faster when the schematic face was neutral compared to when it was happy ($p = .034$) or angry ($p < .001$). However, there was no difference in RT between responses to happy and angry schematics ($p = .966$). As in Experiment 3, the effect of WM emotion did not reach statistical significance, $F(2, 76) = 2.359$, $p = .101$, $\eta^2 = .06$, nor was there an interaction between WM and schematic emotion, $F(4, 152) = 1.439$, $p = .224$, $\eta^2 = .04$. Thus, when emotion is not task-relevant, it does not appear to influence response speed to the schematic faces. However, the addition of the neutral display condition suggests that regardless of valence, emotion slows responses on this task.

Figure 2.10: Experiment 4b mean RT on the line orientation task, within-subjects error bars represent +/- 1 SEM.
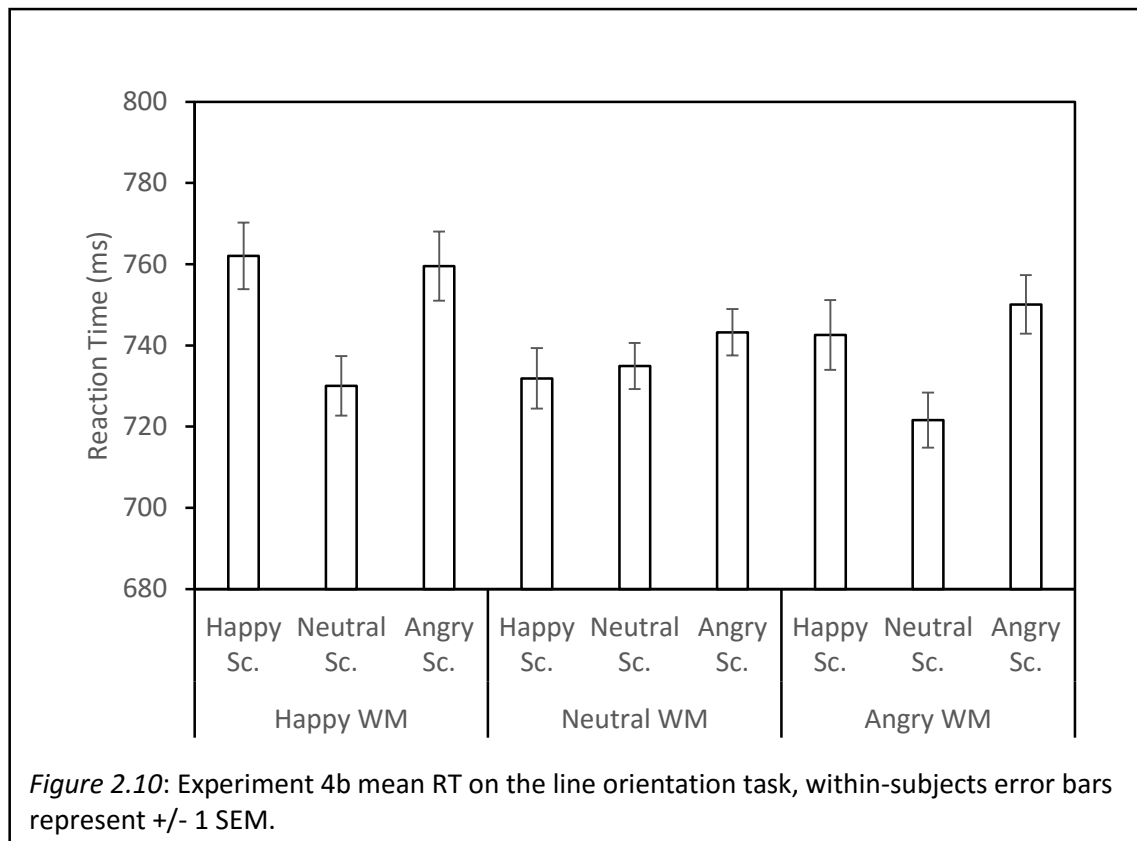
We found a significant main effect of WM emotion on the recall accuracy task (see Figure 9), $F_{(2, 76)} = 3.282$, $p = .043$, $\eta^2 = .08$. However, pairwise comparisons revealed no significant difference in recognition for the expressions (all p-values > .095). There was no main effect of schematic expression, $F_{(2, 76)} = .765$, $p = .469$, $\eta^2 = .02$, and no interaction between the variables, $F_{(4, 152)} = 1.375$, $p = .245$, $\eta^2 = .04$. Thus, unlike in Experiment 4a, there was no difference in recognition between happy and neutral or angry faces (see Table 3 below).

Table 3

Experiment 4b Mean recognition accuracy (%) by WM and schematic face emotion

Schematic Emotion	Happy WM Face		Neutral WM Face		Angry WM Face	
	M	SE	M	SE	M	SE
Happy	74.41	3.25	77.13	3.27	77.46	2.96
Neutral	75.03	3.22	78.38	2.93	76.46	3.04
Angry	74.59	3.36	77.95	3.26	73.85	3.22

Recall Accuracy between Experiments

One reason for our differential results may be changes in task difficulty when we added the neutral expressions. For example, when emotion was task-relevant participant decided whether the initial photo matched the expression "happy" or the expression "angry," meaning that participants decided which of two options was present. However, in Experiment 4a, they decided amongst three options. This may have made the task more difficult, as WM stimulus set-size can increase recognition difficulty (e.g., Jackson, Wolf, Johnston, Raymond & Linden, 2008; Morgan, Klein, Boehm, Shapiro, & Linden, 2008; Van Dillen & Derks, 2012). Previous results show that WM-attention interactions can be eliminated by increases in task difficulty (Han & Kim, 2009). We therefore compared participants' overall recall accuracy across the experiments.

An ANOVA with expression number (happy, neutral, angry) and identity judgment type (emotion, identity) as between subjects variables and WM accuracy as the dependent variable showed main effects for both expression number, $F(1, 165) = 7.549$, $p = .007$, $\eta^2 = .04$, and judgment type, $F(1, 165) = 26.971$, $p < .001$, $\eta^2 = .14$. There was no interaction between the variables, $F(1, 165) = .021$, $p = .884$, $\eta^2 < .01$. Results appear in Figure 2.11. These data show that participants who were required to maintain WM faces that expressed only two expressions were more accurate in recall than participants who maintained a range of three expressions, regardless of whether emotion was task-relevant. In addition, the maintenance of emotion in WM was more efficient than the maintenance of identity, likely due to task difficulty.

Figure 2.11: Comparison of recall accuracy rates between experiments by number of expressions present and recall criteria, error bars represent +/- 1 SD.
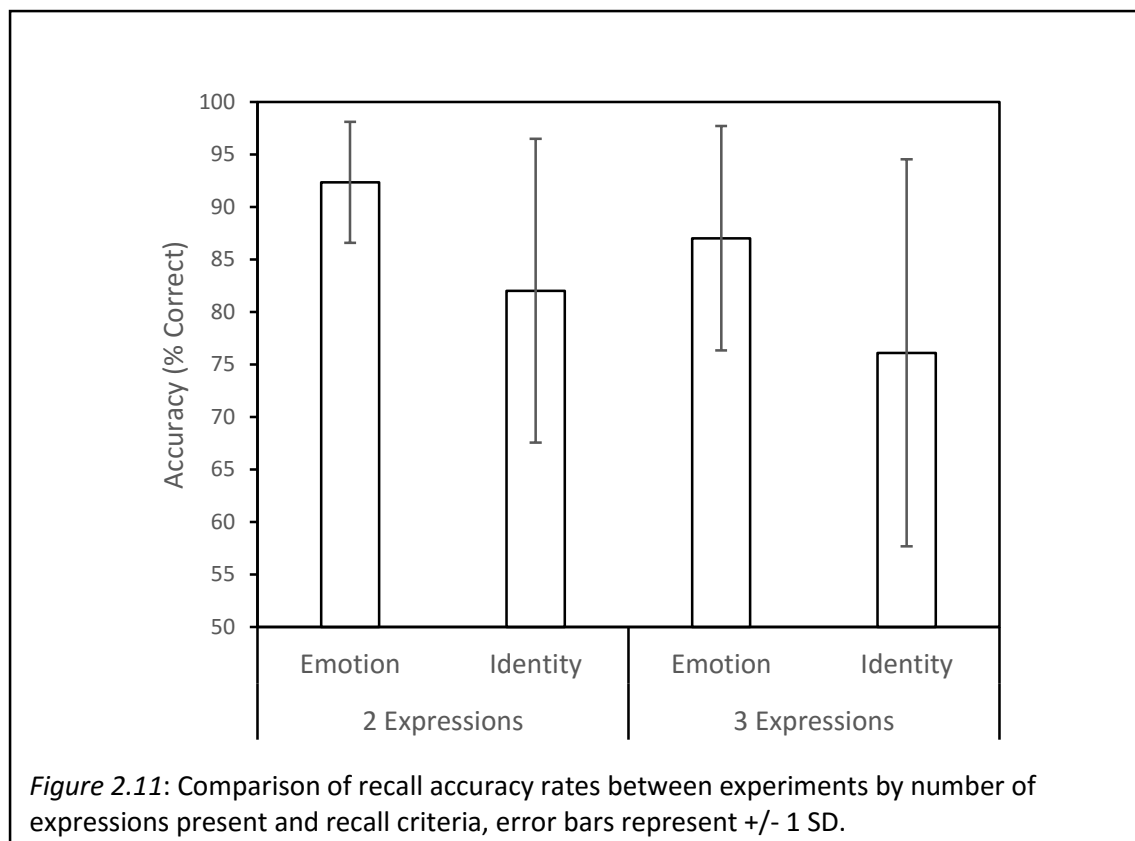
General Discussion

Taken together, our results show some support for both of our hypotheses: that positive emotions cause a more efficient use of attention than negative emotion and that this only occurs when emotion is task-relevant. This was particularly apparent in Experiments 1 and 3. Specifically, we found that when participants remembered the emotional expression displayed in a photo, expression valence differentially affected their RTs on a subsequent task. That is, when they held a happy face in WM, RTs were faster to a schematic display, regardless of the expression it contained. However, when emotion was not task-relevant (i.e., participants recalled face identity) the expression in the schematic display influenced performance such that participants responded more quickly to angry than to happy faces and WM emotion did not influence this process.

Interestingly, when we added a "neutral" comparison display to the task design, these results did not hold. Specifically, we found no RT differences in Experiment 4a, when emotion was task-relevant. In Experiment 4b, when emotion was not task-relevant, we did find a main effect of schematic emotion, however, it showed that participants responded faster to neutral schematics, and there were no differences between happy and angry

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schematics. In both Experiment 4a we did observe an effect of emotion on recall accuracy such that participants were better able to recall happy faces than either neutral or angry ones.

One reason why we may have failed to replicate our initial findings is that task difficulty interfered with the WM–attention interactions. The results of our cross-experiment comparison showed that participant simply found the WM task to be more difficult when the neutral face was present in the stimulus set. For example, research has shown that WM driven biases on attention processes can be eliminated under difficult conditions (Han & Kim, 2009). This idea is consistent with our results and suggests that the additional expression increased the demands of the recall task.

Our results broadly support the idea that positive emotions influence attention more than negative emotion (Bayliss, Schuch & Tipper, 2010; Vermeulen, 2010; Vulleumier & Huang, 2009). We found direct evidence of this idea in Experiment 1. Specifically when emotion was task-relevant, participants were faster to locate and respond to a subsequent target when holding positive stimuli in mind. Although we did not replicate this effect on the RT data in our subsequent Experiment (4a), we did find differences in the ease with which participants recalled happy relative to angry and neutral faces. This result suggests that the wider attentional focus under positive condition may actually relate to recruitment of cognitive resources being greater when people process happy stimuli. Such a result would be broadly consistent with research showing that under positive conditions, people may have increased access to attentional resources (Vermeulen, 2010), greater approach motivation (Stins et al., 2011) and better memory recall (D'Argembeau & Van der Linden, 2007).

Our results also hint that the degree to which stimuli in WM are task-relevant may shape WM – attention interactions, as the Experiment 3 and 4b results show. Indeed, when emotion was not task-relevant the WM stimulus did not appear to influence RTs in the subsequent task. Although the absence of a WM effect in Experiment 4a (when emotion was task-relevant) somewhat tempers this conclusion, these results are generally consistent with research showing that only goal-salient features in WM elicit attention capture (Moriya, Koster & De Raedt, 2014; Olivers, Meijer & Theeuwes, 2006).

Interestingly, we also found only mixed support for the idea that angry faces capture attention (e.g., Barratt & Bundesen, 2012; Eastwood, Smilek & Merikle, 2001; Eastwood,

Smilek & Merikle, 2003; Moriya, Koster & De Raedt, 2014). Indeed, when we included the neutral expression, the angry face capture we observed in Experiment 3 disappeared. Instead, we found that participants made faster responses to neutral faces, arguing for the importance of including neutral stimuli in such research. Unfortunately, previous studies have failed to do so (e.g., Moriya, Koster & De Raedt, 2014).

We collected the data used in the current research from participants recruited from a general population. However, the results also have implications for cognitive function in individuals with abnormal social functioning. For example, attention bias modification (ABM) is an emerging therapy for anxiety disorders, aimed at measuring and manipulating the extent to which anxious individuals are biased towards threat-related stimuli (Bar-Haim, 2010). ABM therapy relies on altering the frequency of valid and invalid cues paired with different expressive displays, which ultimately lead to stimulus-response re-mappings and to symptom improvements (Amir, Weber, Beard, Bomyea & Taylor, 2008). Our experimental paradigm might be useful in demonstrating the strength of such effects and in quantifying the mechanisms that underlie such change.

The present results are limited for several reasons. First, although we have suggested that task difficulty lead to our Experiment 4 failure to replicate our earlier results, we do not have a systematic variation of this variable, which is necessary to make such a conclusion. Another reason why our results may have been inconsistent with predictions is that our hypotheses about the effects of emotional valence were generally based on literature that does not typically utilize a neutral condition. The presence of absence of affective stimuli may actually shape responding more than the valence of faces (Lamy, Amunts, & Bar-Haim, 2008), which, in the present paradigm, may not have been tremendously powerful in eliciting emotion. Finally, we note that findings using affective faces in general do show a degree of inconsistency, depending on stimulus set, laboratory and other factors (Becker, Anderson, Mortensen, Neufeld, & Neel, 2011).

Conclusions

Our results generally support two main ideas. First, they broadly demonstrate that the valence of emotion in WM may influence the recruitment or allocation of attentional resources. Specifically, it is likely that the presence of positive emotion in WM enhances the recruitment of attentional resources. This indicates that we need a more nuanced model to

describe WM-attention interactions than those tested using non-affective stimuli. Second, we also found some support for the idea that task-relevant is important in how WM contents interact with attentional processes, although we qualify this conclusion by suggesting that task difficulty may reduce the influence of WM of attentional allocation as previous research shows (Han & Kim, 2009). Taken together, this research suggests that the control of attention by WM when emotion is involved depends on both the particular emotion and its relevance to the attainment of current goals.

Chapter 3

Working memory and attention interactions: An event related potential study

In the complex visual environment, many objects compete for attention. However, because attentional resources are limited, people cannot process all of them. Instead, they must employ a mechanism that filters irrelevant objects, preserving available resources for important ones. How do people prioritise information for further processing, especially given flexibility in their goals and environments? One suggestion for how this competition is resolved is that attention is biased towards stimuli that are similar to objects held in WM, and therefore might be immediately relevant to a task such as a visual search (Desimone & Duncan, 1995). According to this account, objects that are relevant to current goals (e.g., a recognition target) should be processed more efficiently and thereby outcompete irrelevant objects within the visual scene.

However, research has found that irrelevant stimuli can also guide attention. For example, one study examined this assumption using face identity as the key feature (Downing, 2000). Participants encoded the identity of a face and then performed a shape orientation judgment. Results showed that participants were faster to decide the orientation of the shape when its location was pre-cued by a memory-matching face than when it appeared in the location of a non-matching face, even though face identity was not relevant to the task. Other research has found similar results, supporting the idea that objects in WM can bias selective attention, even when a feature is not relevant to the explicit task (Ansorge, Kiss & Eimer, 2009; Soto & Humphreys, 2009; Soto, Heinke, Humphreys & Blanco, 2005; Soto, Humphreys and Heinke, 2006).

Evidence that non-task-relevant content in WM captures attention suggests that related but irrelevant objects can act as distractors, leading to less efficient attentional processing. Here, we suggest that perhaps such objects are processed more superficially, even though they may initially capture attention. For example, one study measuring ERPs found that viewing circles matching the colour of a rectangle held in memory elicited an ERP marker indexing attentional suppression (the Pd) after initial attention capture (Sawaki & Luck, 2011). Other studies have shown similar results (Olivers, Meijer & Theeuwes, 2006; Sawaki & Luck, 2010, 2013). Together, these findings suggest the existence of neural processes that may help to manage cognitive resources by decreasing the processing of non-task-relevant objects. These studies indicate that the degree to which WM contents influence attentional processing or are dismissed as non-relevant depends on the degree to which WM contents are salient to a task goal.

Here, we focus on stimuli that are highly salient to most people: faces. We chose these stimuli because they capture attention, relative to non-face objects. For example, the presence of facial stimuli during a saccade decision task increases the speed with which people make saccades (Crouzet, Kirchner & Thorpe, 2010) and enhances attention capture effects (Langton, Law, Burton & Schweinberger, 2008). Moreover, because faces often display different expressions, the same face can appear in multiple configurations, thereby creating multiple task conditions (e.g., happy and angry). Emotional content is also highly salient to perceivers, as when faces have emotional content, research shows enhanced gaze cueing effects (Bayliss, Schuch & Tipper, 2010), altered inhibition of return (Fox, Russo & Dutton, 2002) and emotional content also influences the flanker compatibility effect (Fenske & Eastwood, 2003). Because the presence of emotional cues appears to enhance the salience of faces, we chose face stimuli with and without emotional expressions for our task. We previously found that only task-relevant WM expressions modulate responding (Chapter 2), what processes intervene between the allocation of attention and responding that result in non-task-relevant WM expressions failing to influence attention?

We investigated whether memory matching but non-task-relevant faces are indeed processed more superficially than non-matching faces after attention capture. Our task had three components. First, we loaded WM by asking participants to view and remember a photo of a face posed neutrally, or expressing happiness or anger. Participants' task was to remember the identity of the face, rather than its expression, meaning that expression was not task-relevant. Second, participants were cued to attend to the left or right side of the screen (while maintaining fixation) and viewed a display with two schematic faces (located to the left and right of fixation). If the cued location contained a target (determined by the colour of its frame), participants judged whether its "nose" was horizontally or vertically oriented. This cue was necessary to create a condition where participants had to withhold their response, in order to elicit a no-go N2, the purpose of which we will elaborate on in the following paragraphs. We used schematic faces here to strengthen the claim that any interaction between WM and perceived stimuli was due to expression rather than overall perceptual similarity between the stimuli. Finally, participants identified the original face in a memory recall task. In order to investigate the processing of, and competition for resources from memory congruent and incongruent schematics we measured three ERP components, time-locked to the onset of the schematic face display.

To examine the idea that memory-matching targets would be processed more superficially, we measured the anterior N1, a negative deflection peaking around 100ms following stimulus onset at fronto-central electrode sites. The anterior N1 differentiates target from distractor objects presented at cued locations (e.g., Awh, Anllo-Vento & Hillyard, 2006; He, Fan, Zhou & Chen, 2004; Luck, 1995; Luck, Fan & Hillyard, 1993; Luck & Hillyard, 1995; Vogel & Luck, 2000). In addition, the anterior N1 is sensitive to repetition such that it decreases with subsequent presentations of the same stimulus (Hsu, Hämäläinen & Waszak, 2014). This decline in response magnitude may relate to neural fatigue (Grill-Spector, Henson & Martin, 2006), or, more likely, the prediction of subsequent stimuli (Friston, 2005). Thus suggests that memory-matching stimuli receive more cursory processing. Here, we take a conceptual approach to this issue and ask whether WM contents that are merely related to perceived visual stimuli (e.g., a happy photograph in memory and a "smiling" schematic display) are sensitive to this effect. We expect that when the emotional contents of a remembered stimulus are congruent with those of a target the "repetition" of such content should lead to more cursory or superficial processing at early stages and therefore a smaller N1, relative to when those contents are not congruent.

One possible criticism of focusing on the N1 here is that it might represent the gating of attention to the spatial location of the schematic face rather than the expression it displays. This is a reasonable suspicion based on the observation that the N1 is larger to stimuli appearing at attended locations than it is to stimuli to appearing at unattended locations (Clark & Hillyard, 1996). However, the anterior N1, which we intend to measure, has also been specifically implicated in the processing of facial expression. For example, researchers have observed larger N1 amplitudes to fearful faces than to happy or neutral faces (Luo, Feng, He, Wang & Luo, 2010). This increases the utility of the N1 for the purpose of measuring attention in the current chapter.

We also examined the P2 ERP component, a positive deflection in the waveform occurring ~200ms following stimulus onset over fronto-central electrode sites (Potts & Tucker, 2001). Previous research suggests that the P2 is sensitive to the task relevance of stimuli, such that the P2 is larger when memory matching features are present in a visual display (e.g., Kim, Kim, Yoon & Jung, 2008; Luck & Hillyard, 1994; Potts, 2004; Potts & Tucker, 2001). Evidence shows that task-relevant stimuli capture attention (Lamy, Leber & Egeth, 2004), thus, participants must expend effort in preventing interference from such

stimuli. Based on this reasoning, we anticipate that if there is strong similarity between the affective components of WM and the visual display, sensitivity to matching affective features should be greater, leading to emotionally matched stimuli being mistaken for task-relevant objects when they are not. This should be reflected in larger amplitude P2s to WM-matching schematic faces than WM-mismatching schematics.

In addition to its modulation by task-relevance, the P2 is also associated with other phenomena, which may present some ambiguity in interpreting our data. Specifically researchers have observed the P2 to be sensitive to stimulus probabilities. For example, P2 amplitude is larger to infrequent than to frequent targets (Luck & Hillyard, 1994). Nonetheless, if we did elicit a P2 associated with the violation of expectations, this would be reflected in larger P2 amplitudes when schematic faces are incongruent with WM contents than when they are congruent with WM contents. Such a result would be in the opposite direction to what we predict. Therefore, despite alternative accounts of the P2, both possibilities should be easy to disambiguate.

A final measure of the extent to which the affective contents of WM might interfere with the processing of perceived stimuli is the ease with which people can inhibit a pre-potent response. One index of such effort is the "no-go" N2, the difference between the N2 ERP component (a negative deflection, ~200-300ms after stimulus onset) on "no-go" trials, in which participants withhold a response, and "go" trials in which the response occurs (e.g., Azizian, Freitas, Parvas & Squires, 2004; Donkers & Van Boxtel, 2004; Folstein & Van Petten, 2008). For example, in one study (Nieuwenhuis, Yeung, Wildenberg & Ridderinkhof, 2003) participants viewed a series of letters ("M" or "W") underneath a fixation cross. Depending on their assigned condition, participants responded when one letter appeared but withheld their response to the other. The probability of go trials differed depending on task block. The amplitude of the no-go N2 related to the frequency of go trials, such that the more go trials present within a block, the greater the no-go N2 amplitude. The no-go N2 is also larger when participants must withhold overt versus covert responses (Bruin & Wijers, 2002). These results suggest that the more pre-potent a response, the larger the no-go N2 amplitude. In the current study, participant responded only to schematics framed in a target colour (orange or blue) and withheld their responses to non-targets. This allowed us to compute the N2 difference between no-go and go trials. We anticipate that if congruency

between the emotional components of WM and visual display increase the pre-potency of a response, we should find a larger no-go N2 on congruent relative to incongruent trials.

As with the other ERP components examined in this chapter, the no-go N2 has other plausible interpretations that could complicate the interpretation of our results. Specifically, there is considerable support for the idea that the no-go N2 reflects conflict processing rather than response inhibition. For example, Donkers & Van Boxtel (2004) found that the no-go N2 was larger when their task required a forceful response than when it required a normal response, demonstrating that the no-go N2 is present even when no inhibition is necessary. However, a schematic that is incongruent with WM contents would constitute a stimulus that conflicts with the correct memory response, and accordingly result in a larger no-go N2 than a congruent schematic. Because of this, as with the P2, the alternative explanation for what cognitive process the no-go N2 reflects would predict a pattern of results that is incompatible with that which our preferred interpretation predicts. The no-go N2 should therefore be a relatively unambiguous component to analyse in the context of the present chapter.

Methods

Participants

Thirty-two university students (19 female, 13 male) with a mean age of 19.43 years (SD = 2.18 years) volunteered as study participants. All provided written informed consent and reported normal or corrected-to-normal vision. The Bangor University School of Psychology Ethics Committee approved all study procedures.

Stimuli

Cropped grey-scale photographs (0.03° × 0.05°) of three adult male faces (Ekman & Friesen, 1976) served as stimuli in the memory task (see Figure 3.1a for examples). There were nine unique images as each face appeared in happy, neutral and angry poses. We used a black-coloured circle (0.03° × 0.05°) to cue the location of the target schematic. Eight schematic faces (0.03° × 0.05°) framed by an orange (N = 4) or blue (N = 4) oval (0.001° in thickness), with happy, neutral or angry displays, were used as stimuli in the line-orientation task (see Figure 3.1b for examples). Each schematic face contained a horizontal (N = 4) or vertical (N = 4) "nose" (0.004° × 0.006°). The eight schematic faces displayed each combination of frame color, expression and nose orientation. Stimuli were displayed on a 20-inch color monitor (85 Hz, 32-bit, resolution 1280 × 1024), at a viewing distance of 80 cm. The task was programmed and presented using E-Prime software (Version 1.1) on a computer with a 3.4 GHz Pentium 4 processor.

Figure 3.1: Example stimuli used in the experiment. A single identity face (a) expressing happiness (L), neutrality (M) and anger (R); schematic faces (b) depicting happiness (L), neutrality (M) and anger (R).
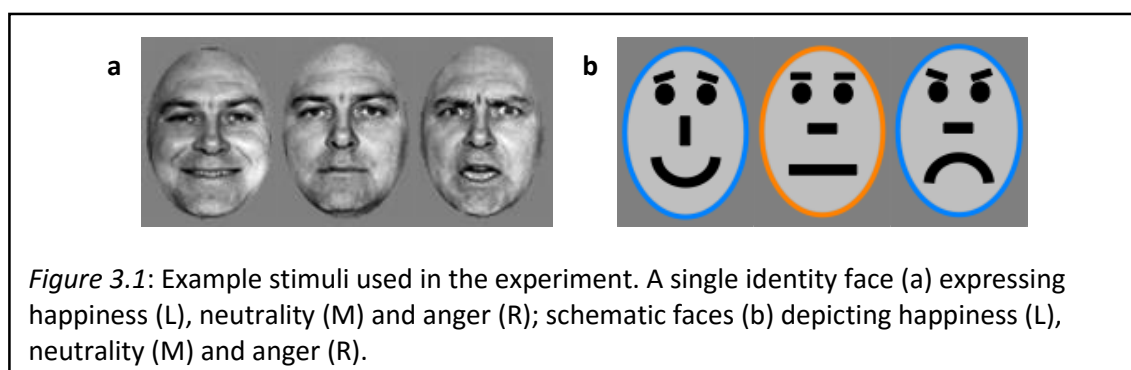
Procedure

After being informed of the study procedures and providing consent, participants were fitted with a 64-channel electrode cap. Experimental trials (see Figure 3.2 for an

example) began with a 500ms central fixation cross, followed at the same location by an angry, happy or neutral face that participants were instructed to remember (500ms). After a second central fixation (1000ms), a black circular cue appeared to direct participants' attention the left or the right side of the screen (200ms). After a variable delay (500, 700 or 900ms) two schematic faces appeared, flanking the fixation cross (200ms). The schematic faces always depicted different expressions, and it was possible that neither schematic face matched the expression of the WM face; one was framed in orange and the other in blue. Participants identified the orientation of the central line (the "nose") of the cued schematic using a key press only if the schematic was framed with the participant's designated "go" colour, otherwise they made no response. Participants responded using a keyboard with the index finger of their right hand. Half of participants pressed the "1" key when the nose was horizontal, and the "2" key when the nose was vertical, for the other half of participants we reversed this mapping. The central fixation persisted for an additional 1000ms, after which responses could not be made. To test recall of the original face identity, three photographs matching the WM face in emotion then appeared in a central-vertical arrangement and remained visible until response. Participants pressed the "1" key on their keyboard when the face was happy, the "2" key when it was angry, and the "3" when it was neutral in expression. Each trial was followed by a blank screen for 2000ms. An initial practice phase of 72 trials, in which participants received feedback about accuracy and speed, was followed by 9 experimental blocks of 72 trials each, for a total of 648 trials and an approximate duration of 84 minutes.

Figure 3.2: In a typical trial (here photo and schematic expression are congruent), participants (A) encode the identity of a photo, (B) attend to a cue, (C) identify whether the schematic at the cued location requires a response and if so whether its "nose" is horizontal or vertical, and (D) which of three photos matches the first in identity.
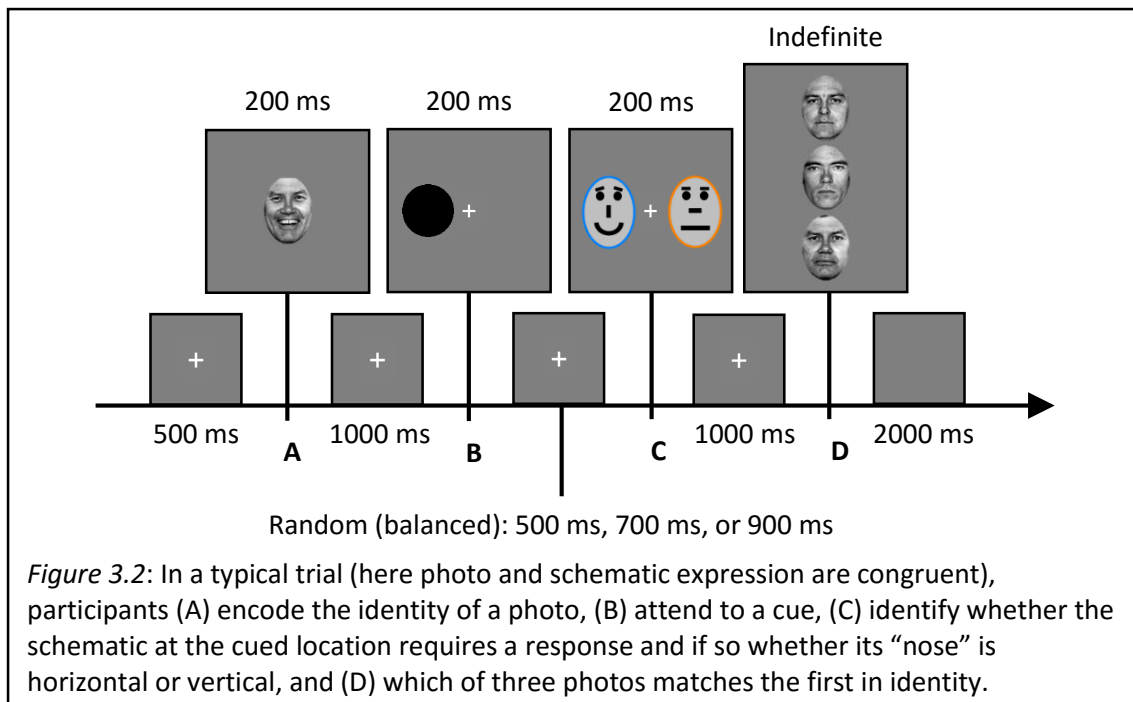
"Go" color (orange or blue frames) and key press response mappings were counterbalanced across participants. We balanced encoding emotion and schematic congruence within participant. The schematic target had an equal likelihood of appearing in both horizontal hemi-fields, and we randomised memory test target and non-target positions. The orientation of lines between two schematic faces was always mismatched (e.g., horizontal-vertical).

Recording and Analysis

We recorded the electroencephalogram (EEG) using 64 active Ag-AgCl electrodes affixed to an electrode cap arranged over frontal, central, parietal, temporal and occipital positions according to the International 10-20 system (see Figure 3.3 for electrode locations). We referenced online to common mode sense (active) and driven right leg (passive) electrodes located over a parietal-occipital position and re-referenced offline to the average of two mastoid electrodes to reduce hemispheric bias (Luck, 2014). We recorded horizontal electrooculogram (EOG) from two electrodes located on the external canthi to measure horizontal eye movements, and vertical EOG from two electrodes located above and below the right eye to measure blinks. We created a bipolar channel (VEOG) by subtracting upper eye voltages from lower eye voltages in order to aid in detection of blinks.

We identified blink artefacts (i.e., voltages exceeding 80μV) using VEOG and non-blink artefacts (i.e., voltages exceeding 100μV) in the 64 scalp channels. An average of 22.28% (SD = 18.87%) trials were identified as being contaminated by artefacts and excluded from subsequent analysis. We amplified and digitised the EEG and EOG using an ActiveTwo AD-box, filtered offline with bandpass criteria of .1-30 Hz, and averaged offline. A higher proportion of rejections were no-go trials (M = 73.34% of rejected trials, SE = 3.51%) compared to go trials (M = 26.69% of rejected trials, SE = 3.50%).

Accuracy on the orientation and recognition tasks, excluding anticipation errors (responses < 150ms), were analysed separately using paired samples t-tests. RTs to correct go trials were also a dependent behavioural measure and again analysed using a using a paired samples t-test. Based on previous research (e.g., Luck, Fan & Hillyard, 1993), anterior N1 mean amplitude was measured between 100 and 140ms at frontal-polar (i.e., Fp1, Fpz & Fp2), anterior-frontal (i.e., AF3, AFz & AF4), and frontal sites (i.e., F3, F1, Fz, F2 & F4). Based on previous research (e.g., Luck & Hillyard, 1994), P2 mean amplitude was measured between 150 and 210ms at anterior-frontal (i.e., AF7, AF3, AFz, AF4 & AF8) and frontal (i.e., F7, F5, F3, F1, Fz, F2, F4, F6 & F8) sites. The no-go N2 was quantified as the mean amplitude of go trials subtracted from the mean amplitude of no-go trials at frontal-polar (i.e., Fp1, Fpz & Fp2); anterior-frontal (i.e., AF3, AF7, AFz, AF4 & AF8); frontal (i.e., F1, F3, F5, F7, Fz, F2, F4, F6 & F8); frontal-central (i.e., FC1, FC3, FC5, FCz, FC2, FC4 & FC6); central (i.e., C1, C3, C5, Cz, C2, C4 & C6); and central-parietal (i.e., CP1, CP3, CP5, CPz, CP2, CP4 & CP6) sites. Sites included in the analysis are illustrated in Figure 3.3.

Figure 3.3: Electrode sites that were included in the analysis of the N1 (left), P2 (middle) and No-Go N2 (right) ERP components. Included sites are shaded black
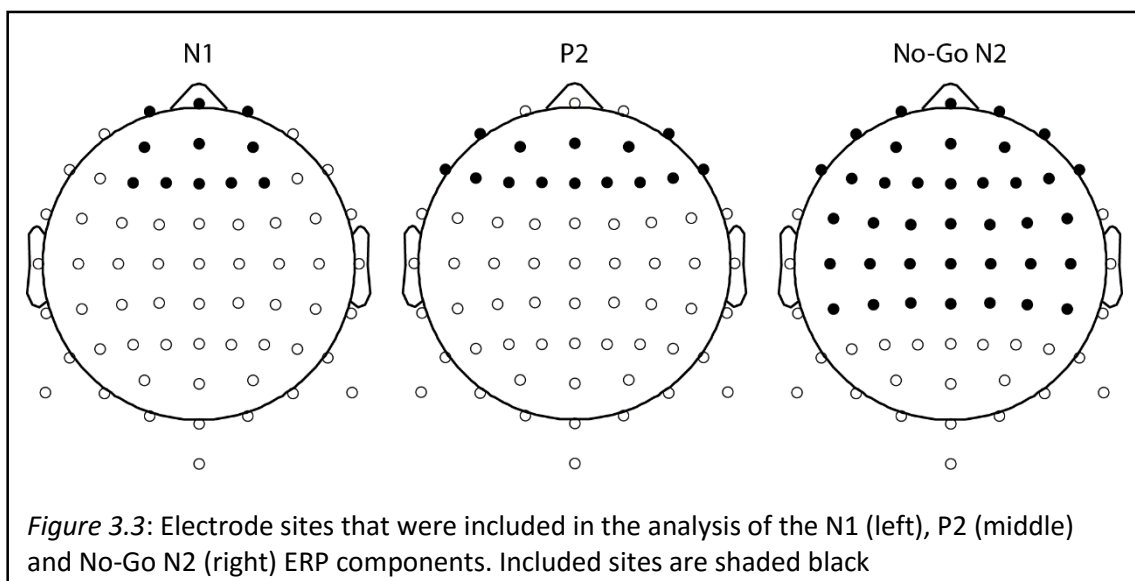
Based on previous research (e.g., Nieuwenhuis, Yeung, Wildenberg & Ridderinkhof, 2003), a window of between 200 and 400ms was used. All time windows were locked to the onset of the schematic display, with a pre-stimulus baseline of 200ms. All components were then averaged by WM-schematic congruence, the levels of which were congruent (e.g., happy WM, happy schematic) and incongruent (e.g., happy WM, neutral schematic). Only correct trials (on go/no-go, orientation and recognition responses), and trials that did not include anticipation errors (i.e., responses < 150ms) were included in these analyses.

Results

The final sample used in the analysis consisted of 29 individuals (17 female, 12 male) with a mean age of 19.43 years (SD = 2.18 years). Two participants were excluded for below chance go/no-go and orientation task performance (accuracy ≤ 50%). We excluded an additional participant because artefacts affected more than 80% of trials.

Behaviour

As expected, there was no effect of the experimental manipulations on participant's RTs to schematic faces (Congruent: 543ms, SE = 17ms; Incongruent: 542ms, SE = 16ms), t (28) = 0.146, p = .885. There was also no difference in the accuracy of their responses (Congruent: .90, SE = .02; Incongruent: .90, SE = .02), t (28) = -0.634, p = .531. Interestingly, participants were slightly better at the WM recall task when the stimuli were incongruent with the schematic faces (M = .87, SE = .02) versus when they were congruent (M = .86, SE=.02). This result was significant at the trend level, t (28) = -1.964, p= .059. This result suggests that the competition for attentional resources is reduced when the WM and schematic items are incongruent because the non-task-relevant emotion is easier to ignore.

Electrophysiology

We conducted an initial repeated measures ANOVA with congruence between the WM and schematic expressions (congruent, incongruent) as a factor and electrode site as a second factor (Fp1, Fpz, Fp2, AF3, AFz, AF4, F3, F1, Fz, F2 & F4), and N1 mean amplitude as the dependent variable. There was no interaction between electrode site and congruence F (10, 280) = 1.303, p = .228, η^2 = 04. We therefore collapsed across the electrode sites to create an overall grand average. As shown in Figure 3.4, and consistent with predictions, N1

mean amplitudes were smaller to schematics that were congruent with the expression held in WM than to schematics that were congruent with WM contents. A paired-samples t-test revealed that this was a significant difference, t (28) = 3.625, p = .001, suggesting that WM-congruent schematic expressions are more superficially processed than WM-incongruent schematics.

Figure 3.4: Grand average waveforms, with a bar-chart (error bars represent +/- 1 SEM) and topographic maps displaying mean N1 amplitudes to WM-congruent and WM-incongruent schematic faces (100-140 ms post stimulus onset). Electrode sites shaded black were the focus of analysis.
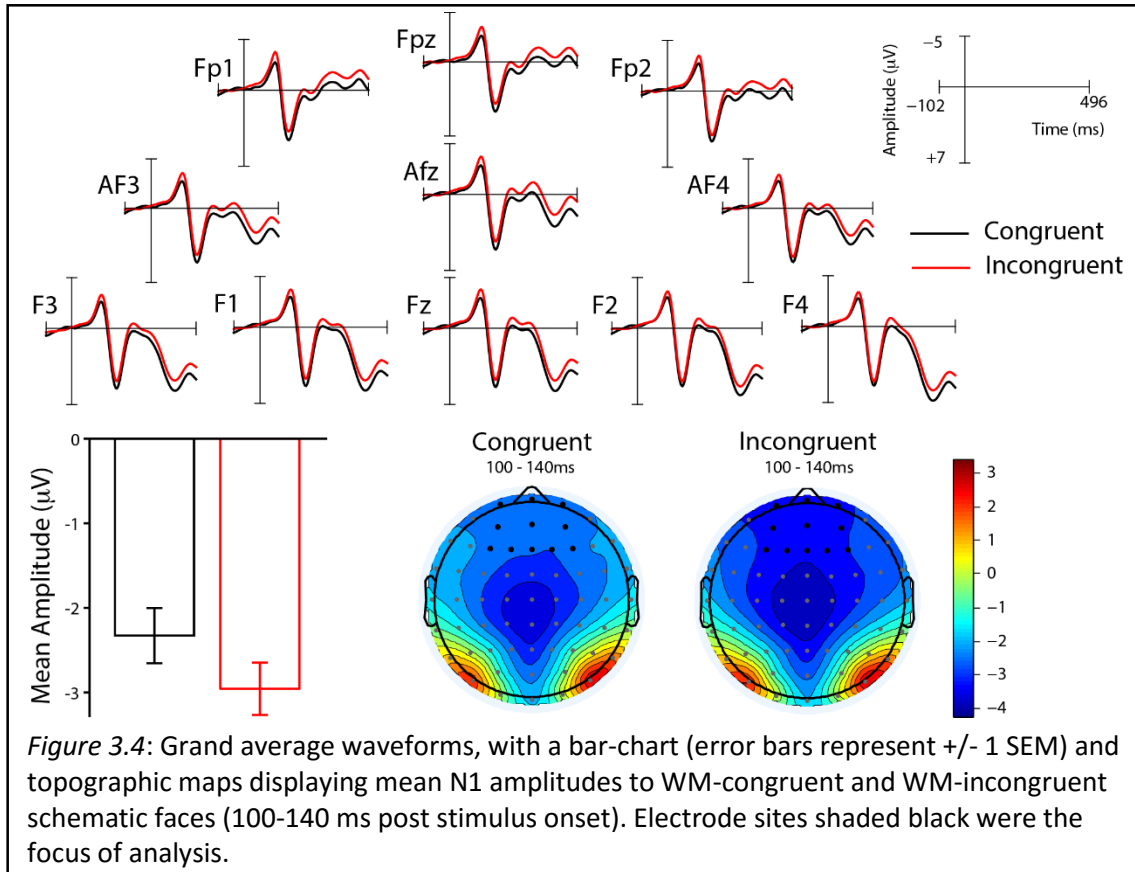
At anterior-frontal and frontal sites, P2 mean amplitudes were larger when schematic expression was congruent with the face held in WM than when schematic expression was incongruent (see Figure 3.5). As above, we conducted a repeated-measures ANOVA with congruence between the WM and schematic expressions (congruent, incongruent) as a factor and electrode site as a second factor (AF7, AF3, AFz, AF4, AF8, F7, F5, F3, F1, Fz, F2, F4, F6 & F8), and P2 mean amplitude as the dependent variable. There was no interaction between electrode site and congruence F (13, 364) = 1.500, p = .115, η^2 = .05. We therefore computed an overall grand average across the electrode sites. A paired-samples t-test revealed that this difference was statistically significant, t (28) = 3.402, p = .002. This suggests that participants more readily identified WM-congruent schematic

expressions as targets relative to WM-incongruent schematics, and suggests greater sensitivity to features congruent with WM contents.

Figure 3.5: Grand average waveforms, with a bar-chart (error bars represent +/- 1 SEM) and topographic maps displaying mean P2 amplitudes to WM-congruent and WM-incongruent schematic faces (150-210 ms post stimulus onset). Electrode sites shaded black were the focus of analysis.
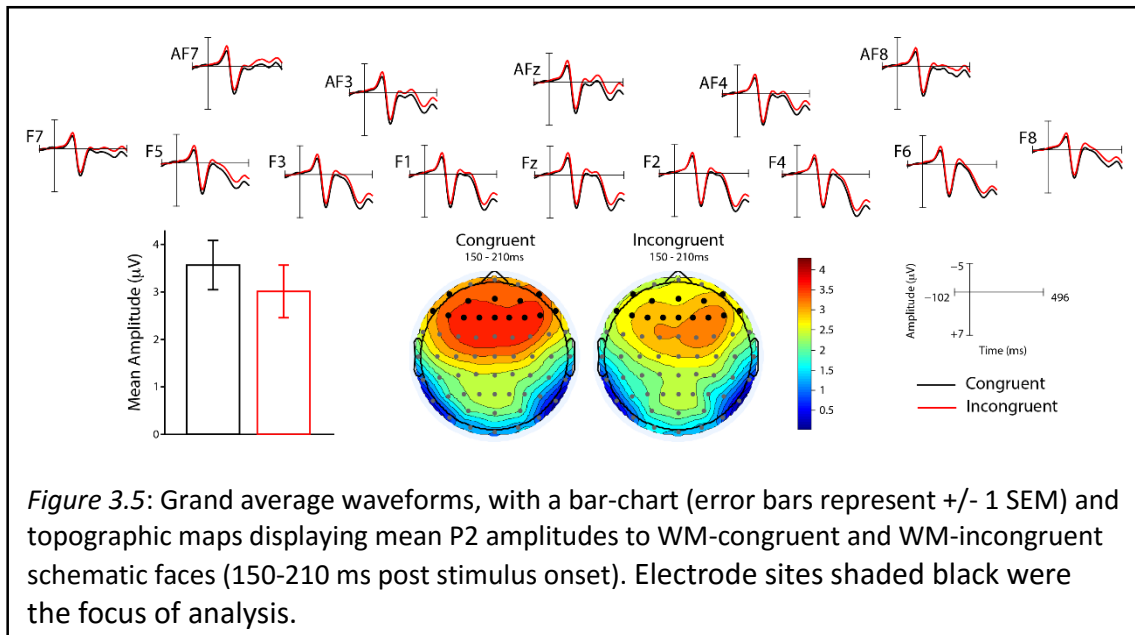
As above, we conducted a repeated-measures ANOVA with congruence between the WM and schematic expressions (congruent, incongruent) as a factor and electrode site as a second factor, and no-go N2 mean amplitude difference as the dependent variable. However, in this case the congruence by electrode site interaction reached statistical significance, $F_{(28)} = 4.914$, $p = .035$, $\eta^2 = .15$. An inspection of the topographical distributions of the no-go N2 showed clear evidence of a laterality effect, consistent with previous reports of the lateralisation of the no-go N2 (e.g., Kaiser et al., 2006). We therefore derived separate averages for left and right hemisphere electrodes.

Repeated measures ANOVA showed a congruence by hemisphere interaction $F_{(28)} = 4.914$, $p = .035$, $\eta^2 = .15$, such that the mean N2 amplitude was larger to congruent than to incongruent trials at right hemisphere, $t_{(28)} = -2.858$, $p = .016$ (bonferroni corrected), but not at left hemisphere locations, $t_{(28)} = -1.230$, $p = .458$ (bonferroni corrected). In addition, there was an effect of congruence, such that the magnitude of the no-go N2 minus go N2 difference wave was larger when schematic expression was congruent with the expression of the WM face than when WM and schematic expression was incongruent (see Figure 3.6), $F_{(28)} = 4.241$, $p = .049$, $\eta^2 = .13$. This suggests that participants required more effort to inhibit a response to WM congruent schematic faces than WM incongruent schematics,

providing further evidence to suggest that WM congruent schematics compete more strongly for resources than WM incongruent schematics. There was also a main effect of hemisphere, with larger difference mean amplitudes at right hemisphere sites, $F_{(28)} = 7.897$, $p = .009$, $\eta^2 = .22$.
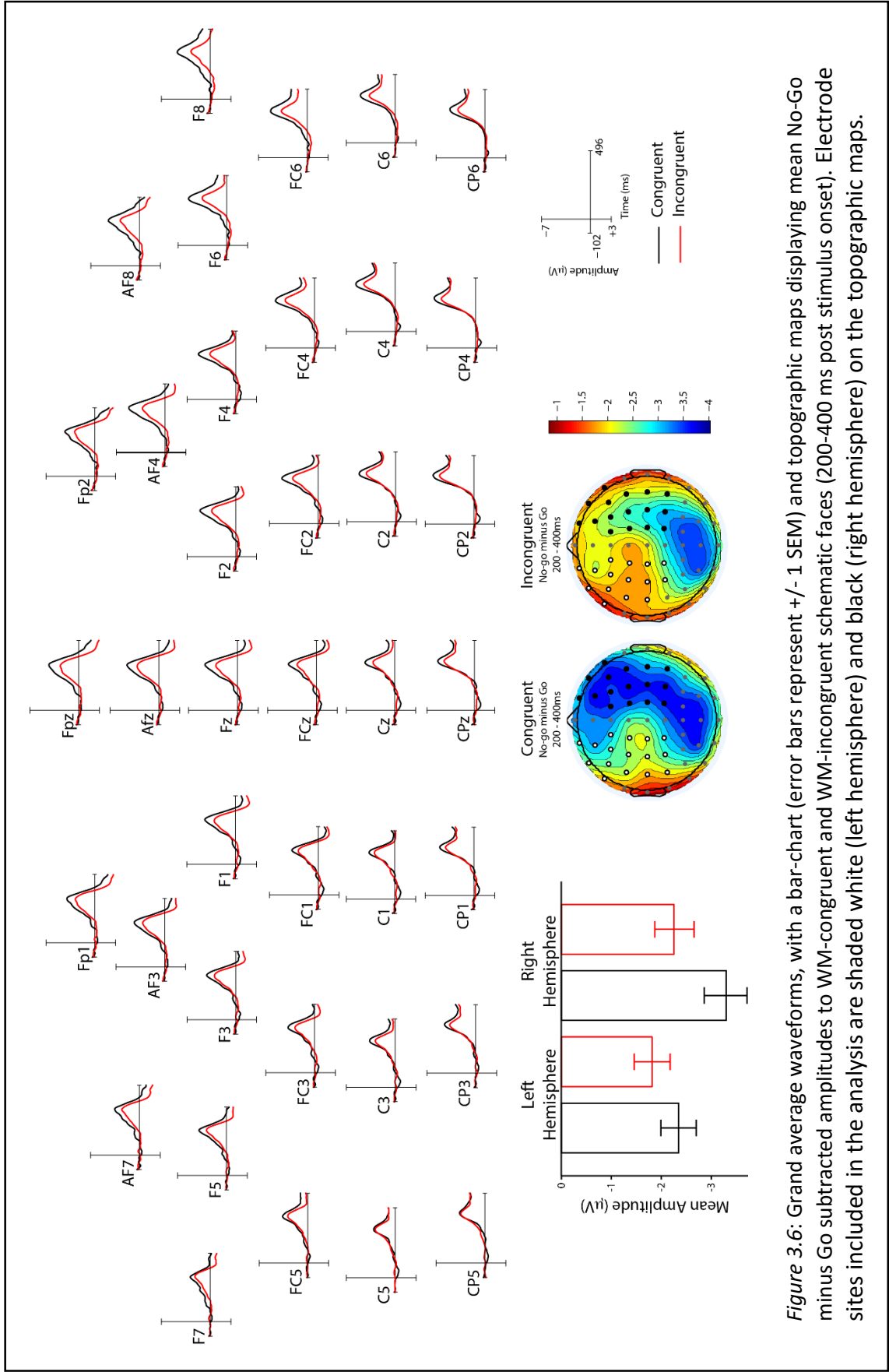
Figure 3.6: Grand average waveforms, with a bar-chart (error bars represent +/- 1 SEM) and topographic maps displaying mean No-Go minus Go subtracted amplitudes to WM-congruent and WM-incongruent schematic faces (200-400 ms post stimulus onset). Electrode sites included in the analysis are shaded white (left hemisphere) and black (right hemisphere) on the topographic maps.

Discussion

The first objective of the current research was to examine the idea that congruence between WM contents and incidental aspects of a visual display lead to superficial processing of a display target. Indeed, we found lower N1 amplitudes to schematic faces that displayed expressions congruent with those displayed on a remembered face than schematic faces with incongruent expression displays. Two mechanisms may explain this finding. First, this result shows that conceptual congruency in the affective domain between the content of WM and task-irrelevant aspects of the display (e.g., a smiling photograph and a smiling cartoon) leads to more superficial processing at early stages. This is interesting because it is consistent with the idea that affective information may influence attentional processing at very early stages (e.g., Eimer & Holmes, 2002; Ishai, Pessoa, Bikle & Ungerleider, 2004; Utama, Takemoto, Koike & Nakamura, 2009), and even when this information is abstract. Second, previous research shows that the N1 amplitude is larger when further processing of an object is required than when the same object can be ignored (e.g., Awh, Anllo-Vento & Hillyard, 2006; He, Fan, Zhou & Chen, 2004; Luck, Fan & Hillyard, 1993). Our finding of lower N1 amplitudes to congruent displays suggests more superficial processing of the display when the schematic and WM expressions matched. Notably, most other research in this domain uses identical WM and visual stimuli to prime this supressed processing (Buckner et al., 1998; Vuilleumier, Henson, Driver & Dolan, 2002). Here, our results show this effect despite the fact that the affective content of the WM and visual display was conceptually congruent although the stimuli differed significantly on visual features.

Our second objective was to explore the assumption that this superficial processing of WM congruent expressions relates to how they compete for attentional resources. One measure of resource competition is the extent to which participants identify non-task-relevant expressions as salient because they are congruent with an expression held in WM. We indexed this with the P2 amplitude. Findings showed that P2 amplitudes were larger to schematic faces when they displayed congruent expression to those held in WM than when they displayed incongruent expressions. Evidence shows that the P2 amplitude is larger when a stimulus possesses target features than when those features are absent (e.g., Kim, Kim, Yoon & Jung, 2008; Luck & Hillyard, 1994; Potts, 2004). We therefore suggest that features of WM content sensitise perceivers to similar content in the visual environment,

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meaning that participants misidentified affective content as task-relevant even though it was not. Behavioural results tended to confirm this notion, suggesting interference by the emotion-congruent stimuli, despite more superficial processing.

Another measure of competition for resources was the extent to which WM congruent schematic expressions activated "go" responses and the effort participants expended to withhold them. We expected that the no-go N2 would be larger to WM congruent faces than to WM incongruent faces, indexing this effort. As expected, schematic faces on no-go trials had larger N2 amplitudes when they were congruent in expression with the face held in WM than when they were incongruent. Based on observations that the no-go N2 is positively associated with the pre-potency of a response (e.g., Azizian, Freitas, Parvas & Squires, 2004; Bruin & Wijers, 2002; Donkers & Van Boxtel, 2004), our data show that these responses required more effort to withhold. Interestingly, this result was greater over the right than the left hemisphere, suggesting that the conceptual priming of affect may be lateralized. This idea is consistent with previous emotion research showing right hemisphere lateralisation of processing of emotive stimuli (e.g., Borod, Andelman, Obler, Tweedy & Welkowitz, 1992; Bourne, 2010; Schwartz, Davidson & Maer, 1975).

Taken together, the effects on the P2 and no-go N2 suggest that WM congruent facial expressions command attentional resources to a greater degree than do WM incongruent expressions. Thus, despite more superficial processing of WM congruent schematics as indexed by lower N1 amplitudes, target salient features can still influence processing at subsequent stages, even when they are not relevant to task goals. This finding may help to reconcile previous contradictory findings showing differences depending on whether WM stimuli must be congruent with task goals (e.g., Olivers, Meijer & Theeuwes, 2006).

Notably, we used two different formats for our faces (i.e., photographs and schematic cartoons) in the present study. This allows us to attribute our effects to conceptual differences in the type of expressive display rather than irrelevant perceptual features. However, some research suggests that people process schematic faces less holistically than facial photographs, even though they recognize schematic expressions to the same degree (Prazak & Burgund, 2014). In our experiment, it may have been easier to parse the nose from the rest of the schematic face than if we had used photographs for the main task. However, we note that our cueing paradigm allowed us to eliminate the reaction-

time differences that such a manipulation might have generated. Our N1 results similarly suggest that people view schematic faces as representations of emotional expressions and process them accordingly.

Although the current study explored WM-attention interactions in the general population, our results may offer insight into the formation of affect related attention biases in individuals who process social cues atypically. For example, individuals with high levels of anxiety are hypersensitive to cues relating to threat (Bar-Haim, Lamy & Glickman, 2005; Bishop, Duncan & Lawrence, 2004). More specifically, individuals with social anxiety disorder appear to be particularly attuned to cues indicative of threat in social situations (Guyer et al., 2008), even misinterpreting neutral displays as indicators of threat (Cooney, Atlas, Joormann, Eugène & Gotlib, 2006). The underlying neural mechanisms that lead to these biases might be explored with a similar experimental paradigm.

Conclusions

The results of the present study begin to answer questions about WM-attention interactions, particularly when these involve the presence of affective cues. Specifically, we show that people process WM congruent affective stimuli more superficially than WM incongruent ones. This result is consistent with previous research using non-affective stimuli (Sawaki & Luck, 2010; 2011; 2013), but extend our understanding of WM-attention interactions subsequent to the allocation of attention. The N1 response to schematic faces was reduced when they were congruent in expression with a face maintained in WM than when expression was incongruent with the remembered face. Our results also show that WM congruent schematic faces appear to compete for cognitive resources, as indexed by the P2 and no-go N2. We therefore conclude that stimuli sharing features with those in WM are processed more superficially at early stages, even though they may continue to influence processing at later stages. This may represent the first step in a stream of neural processes that help to dismiss irrelevant stimuli and allow the attentional system to prioritise resources for current goals.

Chapter 4

The value of a smile predicts the strength of the attention capture response

Social environments present a particular challenge to selective attention systems. Even in the simplest dyadic interaction, people must process the large volumes of information they receive simultaneously in multiple modalities (e.g., speech and nonverbal signals). Given limits to processing capacity, people must somehow determine what to attend and what to ignore. One mechanism by which they do this may relate to the degree to which they value the stimuli they encounter. Research suggests that monetary value drives the degree to which stimuli capture attention (Anderson, Laurent & Yantis, 2011; Della Libera & Chelazzi, 2006). Here we investigate whether this relationship is present for stimuli that naturally vary social value, such as different social cues.

Research shows that different social cues possess different subjective values depending on their implications for the perceiver. For example, genuine smiles (involving the orbicularis oculi muscle) are associated with the experience of positive emotion, whereas polite smiles are not (Ekman, Davidson, & Friesen, 1990). Rather, polite smiles may be important social token, exchanged when social conventions necessitate a smile (Goffmann, 1955; Ekman et al., 1990; Ekman, Sorenson, & Friesen, 1969). Genuine smiles may also be valuable social stimuli because they predict positive social outcomes such as cooperation and positive regard, etc. (Bernstein, Sacco, Brown, Young & Claypool, 2010; Knutson et al., 1996; Van Doorn, Heerdink & Van Kleef, 2012). People also use smiles to explicitly communicate positive social intentions (Fridlund, 1991) and as social rewards (Blair, 1995). It is unsurprising then, that participants judge individuals who display genuine smiles as more likeable, attractive and trustworthy than individuals who display polite smiles (Johnston, Miles & Macrae, 2010; Krumhuber et al., 2007; Scharlemann, Eckel, Kacelnik & Wilson, 2001).

One outcome of the positive judgements elicited by genuine smiles is that individuals show a greater preference for engagement with genuinely smiling individuals than with politely smiling individuals (Johnston, Miles & Macrae, 2010; Krumhuber et al., 2007). For example, people prefer to work with genuinely smiling partners (Scharlemann, Eckel, Kacelnik & Wilson, 2001), and invest more with smiling partners in investment games (Mussel, Göritz & Hewig, 2013). Thus, these smiles appear to carry social "utility," such that genuine smiles are subjectively more desirable than polite.

Research also demonstrates that genuine smiles are financially valuable stimuli, relative to polite smiles. In one experiment (Shore & Heerey, 2011; Experiment 3),

participants played a gambling game with a series of computerized opponents. In the first part of the task, participants learned to associate each opponent with the probability of receiving a monetary reward. Importantly, the opponent provided genuine or polite smile feedback along with the financial reward. In a later test phase, participants chose the opponent they wanted to play on each trial from amongst an opponent pair. The data showed that participants were willing to give up the chance to win money in order to see genuinely smiling opponents, relative to politely smiling ones. Data from an explicit rating task suggested that participants believed that genuinely smiling opponents provided larger financial rewards, suggesting that participants integrated the social and monetary rewards.

Here, we ask how the subjective value of a smile shapes attentional processes. We adapted the matching-pennies task described in Shore and Heerey (2011) to obtain an estimate of smile value. We also employed a flanker task using faces that were either neutral or smiled genuinely or politely in order to obtain a measure of attention capture by all three social cues. We expect that because they are more subjectively valuable, genuine smiles will capture attention faster and more accurately than polite smiles in the flanker task. To determine how difference in the speed of the attention capture response relates to differences in subjective genuine smile value, we will correlate the speed with which participants respond to genuine smile targets in the flanker task with the degree to which they subjectively value genuine smiles. To determine whether this relates to reward sensitivity generally or is domain specific (i.e., relates to social stimuli specifically), we will also examine the relationship between how participants value monetary rewards (also determined from the matching-pennies task) and their responses to the social cues.

Methods

Participants

Fifty-three undergraduates (29 females, 24 males, mean age = 19.60 years, SD = 2.09 years) participated in exchange for partial course credit and a small performance based monetary bonus. The University's ethics committee approved all study procedures and participants gave written informed consent before participating.

Stimuli

Stimuli in the matching pennies task consisted of photos of 12 actors (6 female, 6 male) each exhibiting a genuine smile (involving zygomaticus major and orbicularis oculi muscles), polite smile (involving only zygomaticus major), frown and a neutral pose. For details about stimulus properties and validation, see Heerey (2014). We also used images of the "heads" and "tails" faces of a British one-pound sterling coin as stimuli in the task.

Flanker task stimuli included a white fixation cross, located at the centre of a black display (0.04° x 0.04°). Eighteen photos from 6 actors (3 female) served as both targets and distracters in the flanker task. The actors each posed a genuine smile (involving zygomaticus major and orbicularis oculi muscles), polite smile (involving only zygomaticus major) and a neutral expression as above (see Heerey, 2014; Shore & Heerey 2011). The photos were colour images of each actor's face presented in an oval frame that closely cropped the face (2.12° x 2.43°). During the response window, the target face appeared at the centre surrounded on the left and the right by two other face images at a distance of 2.12° from the centre of each stimulus.

Procedure and Design

Participants completed two tasks that allowed us to measure 1) the subjective value of genuine and polite smiles (relative to neutral faces) in and 2) the extent to which they captured attention.

Matching Pennies Task. In matching pennies tasks, participants play a competitive game in which their goal is to choose the same stimulus as an opponent, who attempts to avoid a match. In our version, participants played computerized opponents, each represented by a photo of a face, and attempt to choose the same side of a coin as the opponent. The task had learning and test phases. On each trial in the learning phase, participants played one of six opponents. They viewed a neutrally posed photo of the opponent, and below it, images of the heads and tails side of a coin. Participants made the heads/tails choice with a key press, and then viewed feedback about the outcome of the choice. Matches were worth 2 pence and non-match trials were worth 0 pence.

Unbeknownst to participants, their feedback was independent of the choice they had made. The feedback was probabilistically determined such that half of the opponents provided match feedback on 60% of trials and the other half provided match feedback on

80% of trials. Two of the opponents indicated matches with a genuine smile (one 60% and one 80% opponent), two indicated matches with a polite smile (one 60% and one 80% opponent), and the remaining opponents indicated matches by remaining neutral and text appeared, superimposed on the image indicating a match ("+ 2 pence!"). On non-match trials, the faces either frowned or provided text feedback ("+ 0 pence."). The same feedback contingencies also applied during the test phase of this task.

Participants played each opponent 10 times in random order for a total of 160 trials, divided into blocks. They knew that they would receive their earnings at the end of the task and were therefore motivated to learn the task contingencies to earn as much money as possible.

The purpose of the subsequent test phase (120 trials) was to examine the degree to which participants had learned the monetary contingencies and examine how feedback display influenced these choices. The extent to which this feedback influenced participants' choices constituted our measure of the subjective value of money, polite smiles and genuine smiles. To do this, participants began each trial by choosing the opponent they wished to play on that trial from a pair of opponents (neutrally posed and presented side by side), after which, the trial carried on as in the learning phase (see Figure 4.1 for an example trial). Participants viewed each possible opponent pairing eight times, with each face occurring as often on the left of the screen as on the right. The frequency with which participants chose genuinely or politely smiling opponents over neutral opponents indicated the extent to which they valued that smile. Within participants, opponent photos were randomized to value (60% or 80%) and expression type to prevent specific face-value pairings from influencing the results. Half the participants (counterbalanced by participant sex) viewed female opponents and half viewed male opponents (likewise for the flanker task below).

Figure 4.1: Matching pennies task test phase trial, displaying genuine smile match feedback and mismatch feedback in the form of a frown.
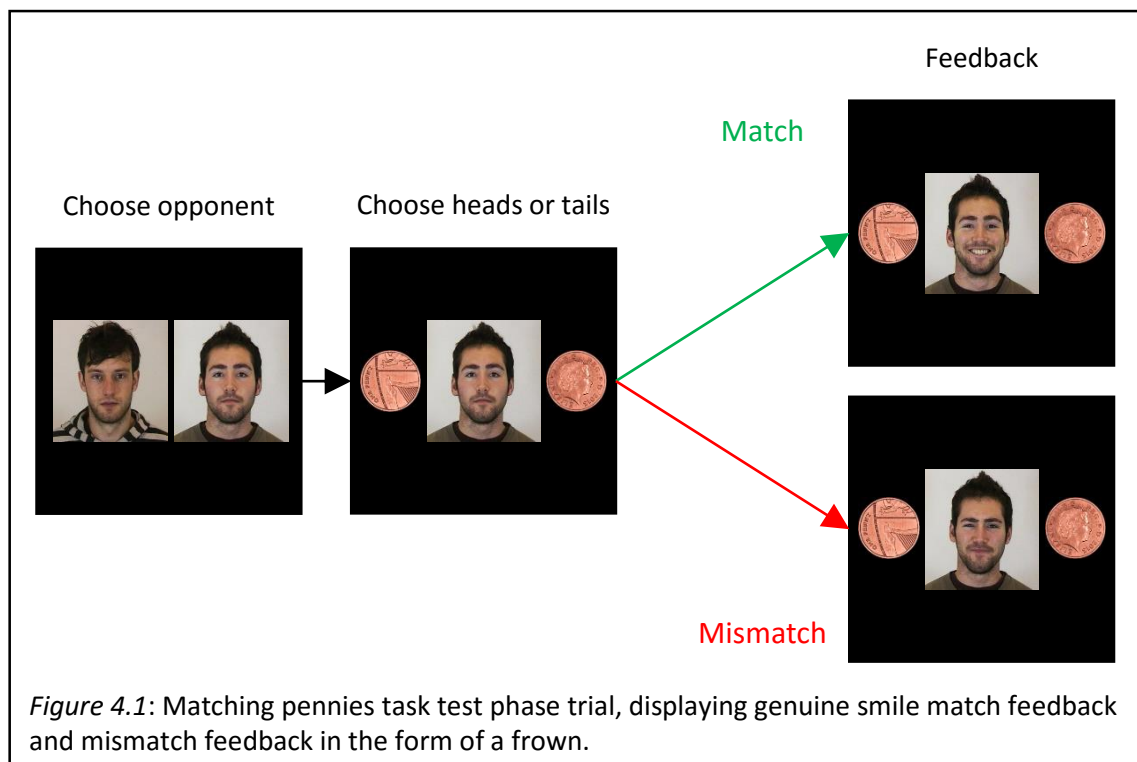
Flanker Task. This task consisted of an Eriksen-style flanker task using faces as stimuli. During the instruction phase of the task, we familiarized participants with the three expressions (genuine smile, polite smile and neural) they would encounter. On each trial of the task, participants viewed a central fixation cross (1000ms), followed by a display consisting of a central target, flanked by two identical, laterally positioned faces. The target displayed one of three expressions (genuine smile, polite smile and neural), as did the flankers. The display remained visible for 800ms (see Figure 4.2), after which the trial ended. Each trial was followed and preceded by a 1000ms blank display. To help control low-level stimulus characteristics, the three stimuli in each display were always photos from the same actor. All possible target/flanker expression combinations appeared with equal frequency and photos from three different actors served as stimuli.

Figure 4.2: Flanker task procedure, displayed here is an example of a genuine smile target accompanied by incompatible polite smile flankers, followed by a neutral target accompanied by compatible neutral flankers.
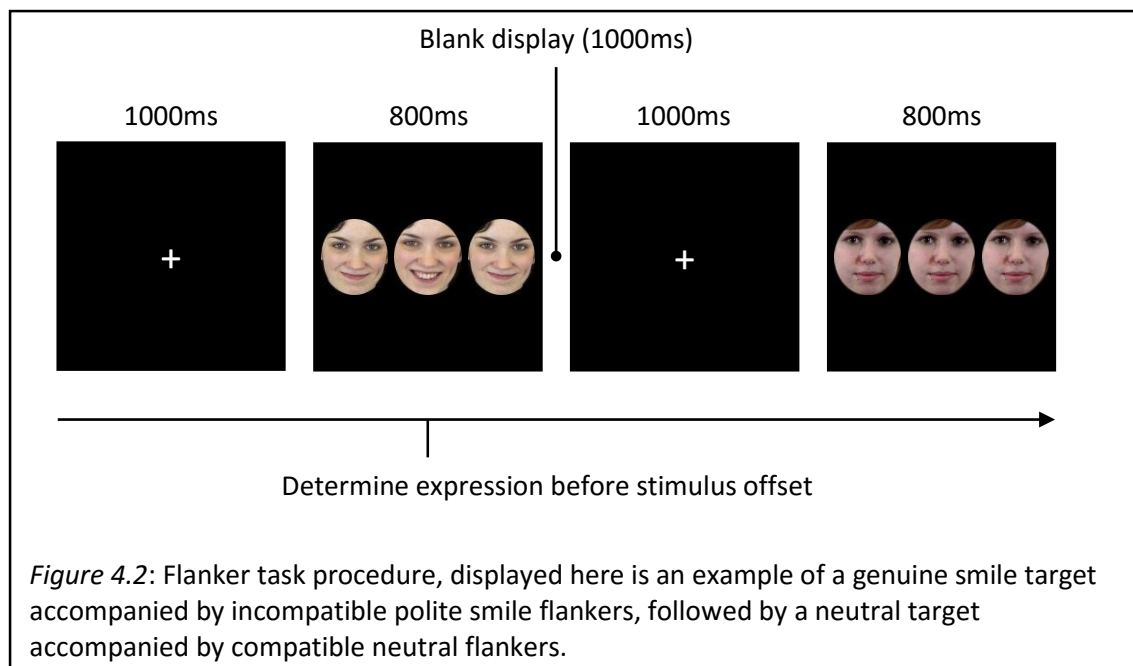
Participants began with a practice block of 27 trials (representing one of each possible target/flanker/identity combination) with feedback about speed and accuracy following each. During the subsequent blocks, participants identified the target face's expression using a key press. Participants responded "as quickly and accurately as possible" to the target's expression. Using the index finger of their right hand, participants pressed the "1" key when the target displayed a genuine smile, the "2" key when they displayed a polite smile and the "3" key when the target was neutral. The task did not wait for participants' responses before presenting the next trial. Therefore, the response time cut-off was 800ms from target onset, requiring participants to make rapid decisions. There were 12 experimental blocks with a total of 324 trials. Both tasks were programmed and presented in E-prime (version 1.2) on a computer running Windows XP.

Analysis

To examine the degree to which money, genuine smiles and polite smiles influenced participants' decisions, we apply von Neumann-Morgenstern Utility Theory (von Neumann & Morgenstern, 1953) to the choice data from the matching pennies task. We subjected these data to a logistic regression to estimate the extent to which money and smiles influenced participants' likelihood of choosing the left face ($P_{OpponentA}$) in the pair. Each participant's data were individually fit using the logistic response function:

$$P_{OpponentA} = \frac{\exp(\theta)}{1 + \exp(\theta)}$$

The parameter θ was estimated as:

$$\theta = \beta_{Money}X_{Money} + \beta_{Genuine}X_{Genuine} + \beta_{Polite}X_{Polite}$$

where β_{Money} is the regression weight for monetary value and X_{Money} codes the difference in expected value between the left and right faces in an opponent pair. Expected value is calculated as the amount of a win multiplied by the probability of winning (e.g., 2 pence x .8; Sutton & Barto, 1988). Therefore, if the face on the left was a high-value face (80%) and the face on the right was low in value (60%) we coded this as .4. If the values were reversed, we coded this as -.4 and if there was no difference in the value of the faces, we coded this as 0. $\beta_{Genuine}$ is the regression weight for genuine smiles, relative to neutral faces. $X_{Genuine}$ was coded as 1 if the face on the left smiled genuinely and the face on the right was neutral, -1 if the expressions were reversed, and 0 if both faces or neither face smiled genuinely. β_{Polite} is the regression weight for polite smiles, relative to neutral faces. X_{Polite} used similar coding as above, but for polite smiles. We used an iteratively re-weighted least squares algorithm to obtain the maximum likelihood estimate for each of the terms in the model (Daubechies, DeVore, Fornasier, & Guentuerk, 2009).

RT averages on the flanker task included all trials with correct flanker responses and RT latencies > 150ms (to eliminate anticipation errors from the means). Although we conducted a standard flanker analysis (i.e., examining target/flanker compatibility effects), the analysis of interest was the correlation between the unstandardized regression weights from the matching pennies task and participants' responses to the smile targets. To determine whether the subjective value of genuine smiles predicted the speed with which participants responded to genuine smile targets, we computed the correlations between the regression weights and the target effects in the flanker task. The target effects were participants' mean-centred RTs to genuine smile targets and polite smile targets.

Results

Fifty-two participants (28 females, 24 males, mean age = 19.58 years, SD = 2.10 years) comprised the final sample used in the analysis. We excluded one participant for below chance accuracy (≤ 33%) on the flanker task.

Flanker Task

As demonstrated by Figure 4.3, participants were faster to designate the expression of a target when it displayed a genuine smile than when it was neutral or smiled politely. Indeed, the results of an RM ANOVA with target type (genuine, polite neutral) and flanker type (genuine, polite or neutral) as within-subjects variable and RTs and the dependent variable showed a large main effect of target expression, $F (2, 102) = 38.842$, $p < .001$, $\eta^2 = .43$. Pairwise comparisons confirmed that RTs were significantly faster to genuine smile targets compared to neutral targets ($p < .001$) and polite smile targets ($p < .001$). There were no RT differences between neutral and polite smile targets ($p = 1$). We found no effect of flanker expression, $F (2, 102) = .501$, $p = .607$, $\eta^2 = .01$, nor was there an interaction between target and flanker expression, $F (4, 204) = .934$, $p = .445$, $\eta^2 = .02$. These results suggest that participants identified genuine smiles more rapidly than polite smiles or neutral expressions and that this difference was large enough to overcome small differences in the typical flanker effect.

Figure 4.3: RTs in the flanker task for each target and flanker type. Error bars represent +/- 1 SEM.
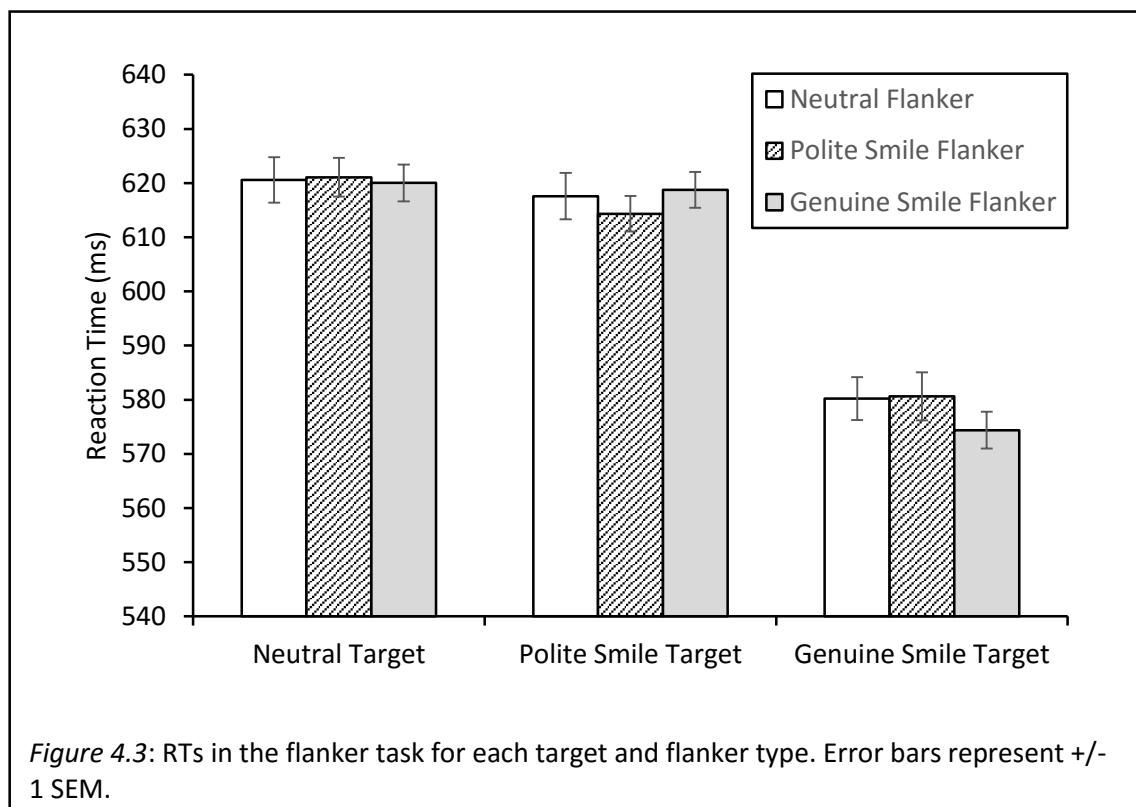
In addition, accuracy rates were higher for genuine smile targets than for neutral or polite smile targets, supported by a main RM ANOVA effect of target expression, $F (2, 102) =$

31.027, p < .001, η^2 = .38 (Figure 4.4), such that accuracy rates were higher to genuine smile targets than to neutral (p < .001) or polite smile (p < .001) targets. As above, there was no difference in accuracy rates between neutral or polite smile targets (p = .449). Neutral flankers elicited higher accuracy rates than polite smile or genuine smile flankers, $F_{(2, 102)}$ = 6.941, p = .001, η^2 = .12. Pairwise comparisons confirmed that accuracy rates were higher when flankers were neutral faces versus polite (p = .001) or genuine smiles (p = .032). There were no differences in accuracy between polite and genuine smile flankers (p = 1). These results suggest, unsurprisingly, that polite and genuine smile flankers interfered with target identification more than did neutral flankers.

Figure 4.4: Accuracy (percent correct) in the flanker task for each target and flanker type. Error bars represent +/- 1 SEM.
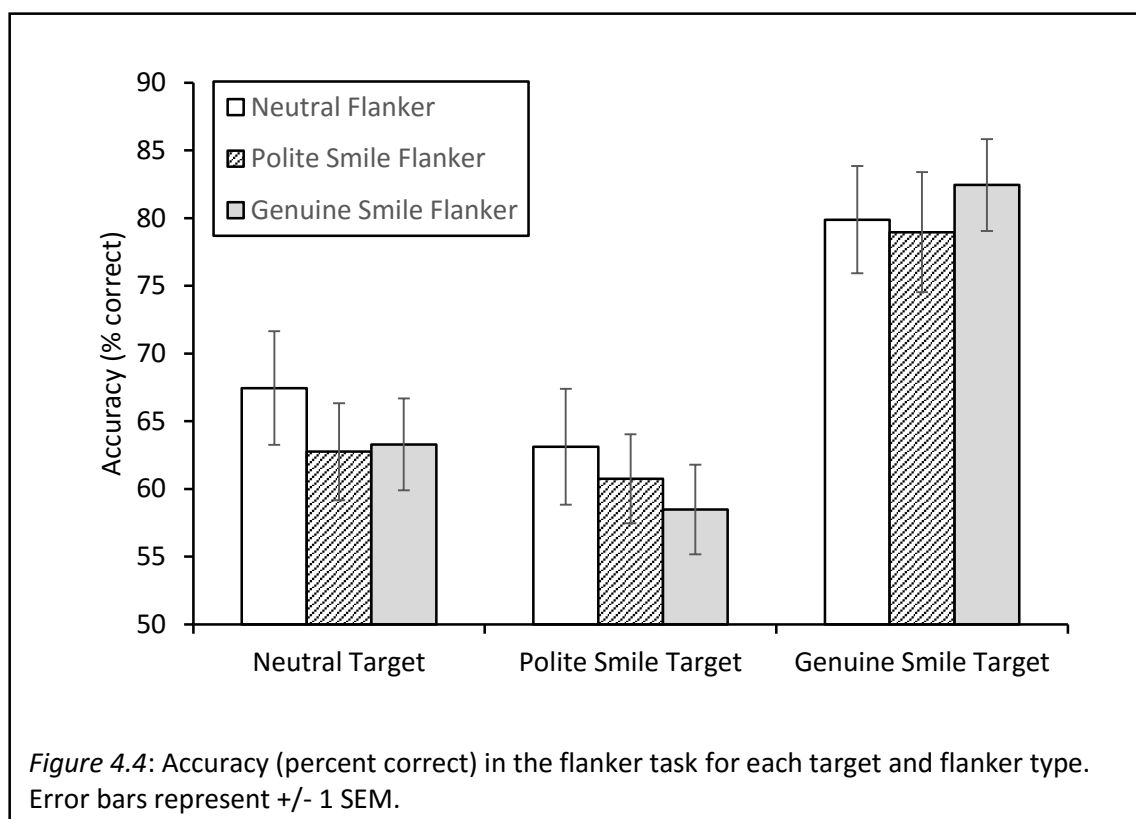
We also found a flanker-target compatibility interaction, $F_{(4, 204)}$ = 4.556, p = .002, η^2 = .08, suggesting a benefit for neutral targets. Specifically, responses were more accurate to neutral targets accompanied by neutral flankers than neutral targets accompanied by polite smile flankers, $t_{(51)}$ = 3.939, p < .001, or genuine smile flankers, $t_{(51)}$ = 2.510, p = .015, consistent with the interpretation of a benefit for compatible compared to incompatible flankers. There were trend level findings when comparing polite smile targets accompanied by polite smile flankers with polite smile targets accompanied by neutral

flankers, t (51) = -1.929, p = .059, and polite smile targets accompanied by genuine smile flankers, t (51) = 1.712, p = .093. Genuine smile targets accompanied by genuine smile flankers elicited more accurate responses than genuine smile targets accompanied by polite flankers, t (51) = 2.954, p = .005. Genuine smile targets accompanied by genuine smile flankers tended to elicit more accurate responses than genuine smile targets accompanied by neutral flankers, t (51) = 1.885, p = .065. Overall, these results suggest the presence of a target-flanker compatibility effect for the accuracy data, even though this was not apparent for the RT data.

Correlations

To determine whether participants treated genuine smiles as significantly more valuable than polite, we conducted a paired sample t-test on the unstandardized regression weights for genuine smiles (M = 0.84, SD = 2.31) compared to polite smiles (M = 0.29, SD = 2.13). Results showed that participants treated genuine smiles as significantly more valuable stimuli, t (51) = 4.093, p < .001. These data are consistent with previous research showing difference in the values of genuine and polite smiles.

We isolated the "target effects," the average RTs to each target, by centring participants' mean response to each target type (collapsed across flanker type) on zero, meaning that we subtracted out each participant's overall average RT. This allowed us a direct measure of the differences in people relative responses to the three target types (Figure 4.5). These data show that on average, participants were approximately 40ms faster to respond to genuine smile targets than to polite and neutral targets.

Figure 4.5: Mean-centred RTs to neutral, polite smile and genuine smile targets collapsed across flanker conditions. Error bars represent +/- 1 SEM.
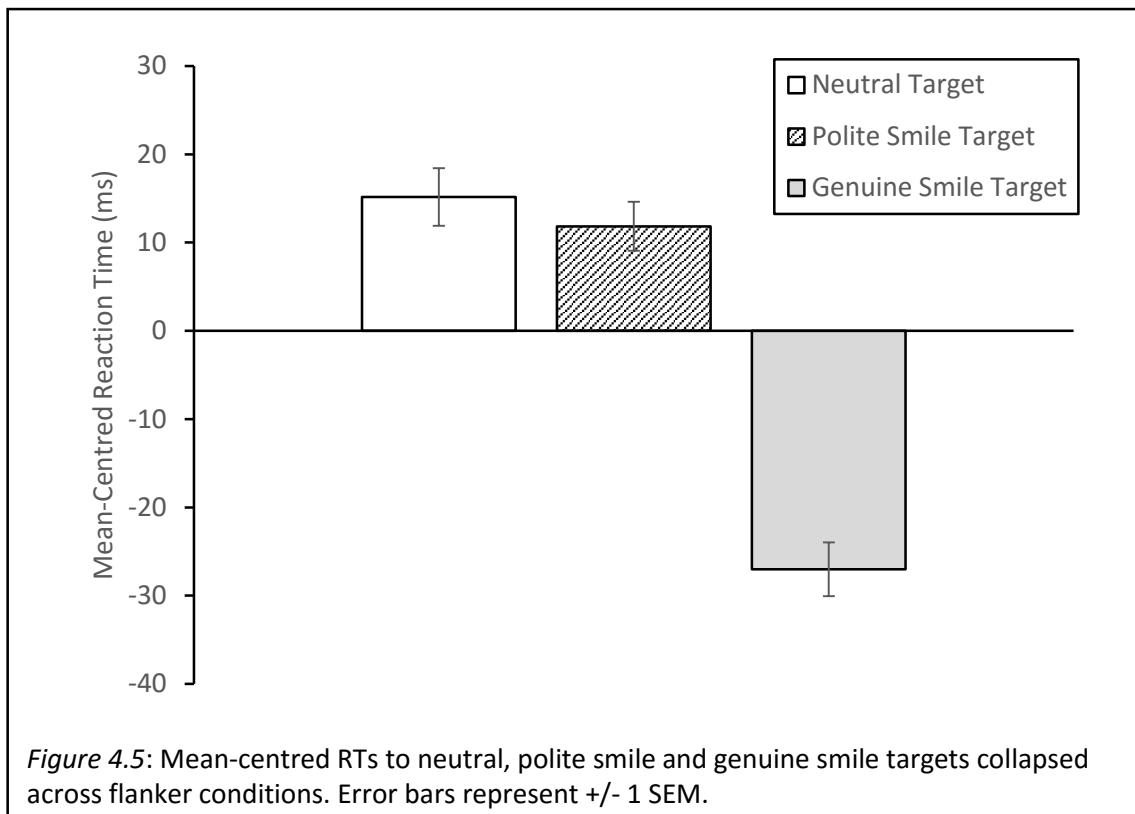
As demonstrated in Figure 4.6, there was a negative correlation between regression weights for genuine smiles and mean-centered RTs to genuine smile targets, *r* (52) = -.40, p = .004. Specifically, the more genuine smiles biased participants' decisions, the faster they were to respond to genuine smile targets. There was no relationship between the regression weight for genuine smiles and the speed with which participants responded to polite smile targets r (52) = .04, p = .766, meaning that this relationship is specific to genuine smiles. Interestingly, there was no correlation between the regression weight for money and the mean-centered RT for genuine smiles, r (52) = .03, p = .835, suggesting that it was the influence of genuine smiles specifically, and not reward more generally, that predicted attention capture by genuine smiles. Regression weights for polite smiles did not correlate with RTs to polite smile targets, *r* (52) = -.13, p = .376, suggesting that the extent to which polite smiles influenced opponent choice in the matching pennies task did not predict attention to polite smiles.

Figure 4.6: Relationships between regressions weights for genuine smile (left) and monetary feedback (right) and mean-centred RT to genuine and polite smile targets.

The relationship between regression weights and accuracy data showed a similar pattern. There was a positive correlation between the regression weight for genuine smiles and accuracy for genuine smile targets, r (52) = .38, p = .006. This showed that the extent to which genuine smiles influenced participants' choices in the matching pennies task also predicted accuracy in identifying genuine smiles. There was no correlation between the regression weights for money and accuracy to genuine smile targets, r (52) = -.10, p = .475, again suggesting a specific relationship between genuine smile value and attention, and not a general effect of reward. There was no correlation between regression weight for polite smiles and accuracy to polite smile targets, r (52) = .06, p = .692, again suggesting that the extent to which polite smiles influenced a participant's opponent choice did not predict accuracy in identifying polite smile targets.

Discussion

The objective of the current research was to determine whether the extent to which social cues capture attention is proportionate to their relative subjective value. Research using non-social stimuli suggests that associating an object with monetary value increases its ability to attract attention (Anderson, Laurent & Yantis, 2011). Given the greater intrinsic value of genuine smiles relative to polite smiles (e.g., Krumhuber et al., 2007; Shore & Heerey, 2011), we expected that genuine smiles would capture attention more quickly than

polite smiles in a flanker task in which participants identified the expression of a target face. Consistent with this hypothesis, we found that participants were faster and more accurate in their identification of genuine smile targets compared to polite smile and neutral face targets and this effect directly related to the degree to which they subjectively valued genuine smiles. This suggests that cues possessing greater social value, represented here by genuine smiles, capture attention to a greater degree than do social cues possessing lower subjective value.

This finding is consistent with research showing how people use these smiles in genuine face-to-face interaction. Specifically, people return genuine and polite smiles with high degrees of accuracy. That is, they return their partners' genuine smiles with genuine smile of their own and polite smiles with polite. Moreover, genuine smiles are reciprocated more quickly than polite smiles in both real social interactions, as well as in the laboratory tasks measuring facial muscle activity (Heerey & Crossley, 2013). This is likely to be related to the subjective value of these significant social cues.

Importantly, this result appears to be specific to social cue value, as the value of a financial reward did not correlate with RTs in the flanker task. This finding hints that attention capture by a particular cue may be specific to the domain in which the cue is valued. For example, previous research using neutral faces that had been conditioned to a monetary reward showed that difference in the monetary value drove difference in how people attended to those cues (Raymond & O'Brien, 2009). Other research has shown that participants are better at detecting pictures of high-value versus low value coins presented subliminally (Bijleveld, Custers & Aarts, 2011) and, when they are hungry or thirsty, more palatable food/beverage images (Piech, Pastorino & Zald, 2010). Furthermore, there was no correlation between regression weights for polite smiles and RTs or accuracy to polite smile targets. This suggests that the relationship between value and attention may be exclusive to genuine smiles, which appear to carry intrinsic value (Mussel, Göritz & Hewig, 2013; Scharlemann, Eckel, Kacelnik & Wilson, 2001; Shore & Heerey, 2011), perhaps because these stimuli cause feelings of positive emotion (Surakka & Hietanen, 1998) and likely predict positive social outcomes (Jakobs, Manstead & Fischer, 1999).

One limitation of our results relates to the way in which certain visual features may alter the overall discriminability of stimuli. Specifically, the models who provided our stimuli commonly displayed their teeth when presenting a genuine smile, thus introducing a bright

feature contrasting in luminance with the darker aspects of their faces. The genuine smiles we used may have been discriminated with greater ease compared to the expressions possessing a more homogenous luminance because of this unique feature. This possible confound may explain why genuine smiles were discriminated with greater ease than both polite smiles and neutral expressions. One possible resolution to this confound could be to use only genuine smiles where the models' mouths are closed or conversely polite smiles where the models present their teeth.

Another limitation of the current study is that we did not attempt a direct manipulation of the value of genuine and polite smiles. Therefore, we cannot be certain that smile value drives our effect. Rather, some other feature that is associated with smile value, such as facial attractiveness, may be responsible for the present results. One method of demonstrating a causal link between value and attention would be to use a manipulation that directly affected genuine smile value and then determine whether that influenced the results. For example, a genuine smile from an attractive face might be a significantly more valuable stimulus than a genuine smile from a person one finds unattractive (Aharon, 2001). If that turned out to be the case and people were faster to identify attractive genuine smiles targets than unattractive ones, then we might be able to make a stronger statement of this relationship.

One important implication of this result is that in complex social environments (e.g., an interaction amongst a larger group), in which people must determine both which cues they process and ignore and whom to attend, they may miss important information simply because it does not capture attention. For example, people might be more likely to focus on cues generated by a group leader rather than another member. They may therefore miss important information that has implications for their own relationship with the group leader or their social status within the group. Thus, errors in how people attend to social cues may lead to errors in social behavior and judgments, ultimately reducing the quality of a social outcome.

Conclusions

In this study, we found that genuine smile targets elicited faster and more accurate responses than polite smile and neutral targets in the context of a flanker task. The speed with which people responded to genuine smile targets correlated with the degree to which

they were willing to give up money to see genuine smiles in another task. Together, these findings highlight a possible mechanism for understanding how people navigate their social environments. Specifically, the value of a social cue may influence whether it is attended or ignored. As social cues are transient, this may determine the outcome of an interaction by biasing the information people ultimately receive, meaning that important information from less valuable cues is lost.

Chapter 5

General Discussion

Summary of Results

This thesis examined how emotional stimuli influence the interaction between WM and attention. Our results show three primary findings. First, we examine how emotional facial expressions stored in WM influence attentional deployment. Our findings suggest that positive emotional expressions broaden the focus of attention relative to negative expressions. Second, we demonstrate that WM-attention interactions as they pertain to emotion only occur when emotion is task-relevant. Finally, we move away from the effects of specific emotion on WM-attention interactions to examine positivity more broadly. Here, we rely on participants' own subjective judgments of facial expressions to show that the value of a positive emotional expression has a positive relationship with the extent to which such expressions capture attention. These results, taken together, suggest that the long-term semantic associations of social cues determines the extent to which they capture attention.

The results of our research suggested that happy faces in WM broadened the focus of attention relative to angry faces. This meant that when participants held happy faces in WM, they were faster to locate the target schematic face and judge the orientation of its "nose" (Chapter 2). Thus, attention was more efficiently oriented to the schematic target with a happy face in WM compared to an angry face. Interestingly, this WM-attention interaction was only present when the emotional stimuli were both task-relevant and the recognition task was relatively easy, which suggests that task difficulty may influence the degree to which stimuli in WM can control attention.

Interestingly, our electrophysiological results suggested that when emotion is not task-relevant, participants process faces with memory-matching expressions more superficially than faces with non-matching expressions (Chapter 3). Moreover, these results also suggested that an expression in WM might interfere attention to a subsequent schematic expression, because WM-matching schematic expressions elicited target-associated potentials and were more difficult to withhold a response when presented as a no-go stimulus.

Finally, we show that the degree to which an expression (e.g., a genuine smile) carries subjective value for an individual predicts the extent to which this expression captured that person's attention in a flanker task (Chapter 4). Interestingly, there was no relationship between a subjective estimate of financial value and the degree to which

genuine smiles captured attention in the task, suggesting that this finding is domain specific. Thus in order for an estimate of subjective value to drive attentional deployment, it must be specific to the test domain (here, facial expressions).

WM-Attention and Emotion-Attention Interactions

Our data suggest that WM contents can bias attention capture. They specifically concur with previous research suggesting that the speed of visual search can be modulated by the contents of WM (e.g., Ansorge, Kiss & Eimer, 2009; Hollingworth & Luck, 2009; Kang, Hong, Blake & Woodman, 2011). Indeed, in our task the expression participants held in WM affected RTs on the subsequent search task. However, this effect was not straightforward. That is, contrary to the findings of previous research (Grecucci, Soto, Rumiati, Humphreys & Rotshtein, 2009), as well as the predictions of Desimone and Duncan (1995), WM contents did not bias attention towards congruent stimuli. Instead, participants were generally faster when they held happy faces in WM than when they held angry faces in WM – regardless of any match between emotional and schematic expressions. Thus, these results appear to be consistent with research suggesting that positive emotion leads to more efficient cognition than negative emotion. Specifically, the fact that happy faces held in WM elicited faster responses in our task compared to angry faces is in concordance with research finding that the deployment of attention is more efficient in a positive emotional context than a negative context (Vermeulen, 2010). Furthermore, the finding of greater recognition memory for happy faces compared to neutral faces in WM is also consistent with the observation that positive emotion renders WM operations more efficient (Yang, Yang & Isen, 2013). Our data suggest that positive emotion increases both attention and memory performance compared to negative emotion.

It is possible that these results instead reflect the effect of emotion in WM on the breadth of attentional focus, rather than attentional efficiency. With attention at fixation, one would expect a broad focus of attention to translate into faster location and discernment of the schematic nose compared to a narrow focus. Given that we observed faster responses with happy faces compared to angry faces in WM, our results may alternatively indicate that positive emotion broadens the focus of attention relative to negative emotion. This interpretation would indeed be consistent with previous research (e.g., Bayliss, Schuch & Tipper, 2010; Fenske & Eastwood, 2003; Fredrickson, 2001, 2004;

Fredrickson & Branigan, 2002; Horstmann, Borgstedt & Heumann, 2006; Rowe, Hirsh & Anderson, 2007; van Steenbergen, Band & Hommel, 2011; Wadlinger & Isaacowitz, 2006). However, because we always displayed the schematics at the same distance from fixation, the breadth of attentional focus necessary to encompass the schematics was constant. Because of this limitation, we cannot make a strong claim about how our WM stimuli may have modulated the breadth of attention. Nonetheless, given the weight of the evidence from previous research, such an explanation for the current data merits further investigation using a more appropriate design.

The results of the current research support feature integration theory (FIT), a model of attention which posits that visual attention involves the combination of individual perceptual dimensions (e.g., colour and shape) into discrete objects (Treisman & Gelade, 1980). Given that the process of combining features should be more time consuming than simply processing a single feature, the observation that visual search for features is more efficient than visual search for objects substantiates the FIT (Scialfa & Joffe, 1998; Treisman, 1982). The observation in the current research that participants' RTs were influenced by the expression of the schematic faces provides further support for the FIT, as it demonstrates that participants were automatically combining the features comprising the expressions in addition to processing the nose. Another aspect of FIT that is supported by the current research is the claim that top-down processes can bias this process (Treisman & Gelade, 1980). For example, previously encountered faces are located more efficiently than novel faces in visual search (Persike, Meinhardt-Injac & Meinhardt, 2013; Tong & Nakayama, 1999). We found that WM contents matching schematic faces in expression interfered with the processing of the latter, reflecting a top-down influence on feature processing predicted by FIT.

These results are also consistent with the tripartite model of WM. The latest iteration of the tripartite model includes links between the visuo-spatial sketchpad and long-term memory, specifically semantic visual memory (Baddeley, 2000). Evidence for greater accuracy when recalling or recognising familiar objects relative to novel objects supports this component of the model (Buttle & Raymond, 2003; Curby, Glazek & Gauthier, 2009; Jackson & Raymond, 2008). The current data implies that different emotional expressions held in WM have distinct effects on attention consistent with those of other forms of representing the same emotions. For example, just as happy faces caused attention

to be more efficient in the current research, non-face pictures rated as positive are fixated on for a longer duration than negative pictures (Humphreys, Underwood & Chapman, 2010). This suggests that whilst holding a particular expression in WM, participants retrieved prior information pertaining to that expression from long-term memory.

One suggestion as to why happy faces in WM might make attention more efficient compared to angry faces is based on different appraisals for these two categories of expression. To elaborate, the appraisal model posits that the motivational relevance of a stimulus contributes to the formation of a reaction (Smith & Lazarus, 1993). This is illustrated in the physiological responses of people with phobias towards snakes toward pictorial representations of these animals (Dimburg, Hansson & Thunberg, 1998). The sequential models takes additionally takes into account the normative significance of a stimulus in this process (Scherer, 2001). For example, individuals with low self-esteem report lower self-worth in response to negative evaluations than individuals with high self-esteem do (Brown & Dutton, 1995). Given research indicating that certain expressions carry intrinsic value (Shore & Heerey, 2011; Averbeck & Duchaine, 2009), it is possible that participants in the current research appraised faces of different valences in distinct ways and therefore formed different responses to each.

However, it should be noted that mere exposure to an emotive stimulus is not enough for WM to drive attention capture. Specifically, previous research has found that emotion interacts with attention both when experimenters expose participants to it, as well as when they induce emotion in participants (e.g., Bayliss, Schuch & Tipper, 2010; Fenske & Eastwood, 2003; Horstmann, Borgstedt & Heumann, 2006). However, we found no effect of emotion on attention when participants simply named the emotion in a photo, and did not attempt to remember the emotion. This suggests that mere exposure is not enough for emotion to control the deployment of attention, in our dual-task paradigm participants were required to maintain emotion for a later recognition task. Rather, participants must actively maintain emotion in WM for it to control attention.

The present results also suggest that task difficulty is an important variable in emotion-attention interactions. Specifically, when we added a neutral expression to the set of possible emotions to report at the recognition stage of our dual-task paradigm, the effect of WM emotion on response latencies in the search task disappeared. Similarly, we observed lower accuracy in participants presented with a range of three (happy, neutral

angry), rather than two expressions (happy, angry), even when emotion was not relevant to recognition and participants only attempted to remember a single emotion on any trial. This is consistent with previous results demonstrating that task difficulty eliminates WM driven attention capture (Han & Kim, 2009), although in that task, it was the perceptual difficulty of the search task, and not the recognition task, that was manipulated. This finding implies that WM only biases attentional deployment when sufficient cognitive resources are available, and not when a relatively difficult task strains these resources.

The effect of task difficulty in the current research is consistent with the capacity model of attention. Specifically, the capacity model suggests that the demand on resources that the current situation imposes is a factor in the ongoing distribution of attention to external stimuli (Kahneman, 1973). For example, letters flanking a central target letter facilitate responding when they are identical as opposed to distinct only when experimenters presented the target alone, and not when it is embedded within a row of other letters (Cosman & Vecera, 2009; Experiment 2). That is, when the target was relatively easy to process participants also processed peripheral stimuli. However, when target processing consumed more resources, participants gave fewer over to processing peripheral stimuli. In our research, we found that when participants had to maintain three items as opposed to two, there was no effect of the emotion held in WM on the allocation of attention. In this context, consistent with the capacity model, we suggest that when the WM task was difficult, the participant assigned the majority of available cognitive resources to the maintenance of the memory stimulus. Thus, there were not sufficient resources to improve the efficiency of attentional allocation in the intervening orientation judgement task.

The influence of task difficulty in our research is also consistent with some aspects of the tripartite model, specifically the suggestion of a central executive that is responsible for a number of functions, one of which is the allocation of available cognitive resources between active tasks (Baddeley, 1996; Baddeley & Hitch, 1974). This element of the model is supported by evidence that high WM capacity individuals have a greater ability to switch between the rules of a task than those with a low WM capacity (Butler, Arrington & Weywadt, 2011; Kane, Bleckley, Conway & Engle, 2001). In the current research, participants who were required to retain three expressions did not exhibit the WM-attention interaction that participants who were required to retain only two expressions. In

the context of the tripartite model, it can be suggested that this is because retaining three expressions uses more WM capacity than retaining only two, and thus that there was less WM capacity left influence attention with three expressions in WM compared to two.

Emotion-Attention Interactions and Task-Relevance

The results of the current research suggest that the degree to which stimuli in WM are task-relevant is another factor determining whether they drive attention. Previous research has found WM-attention interactions occur even when the particular features in WM do not relate to the task-at-hand (e.g., Ansorge, Kiss & Eimer, 2009; Soto & Humphreys, 2009). However, other research suggests the opposite (Olivers, Meijer & Theeuwes, 2006). We found that emotional WM contents only influence attention when emotion is the feature on which recognition was tested. When identity was the task-relevant feature, no such influence was present. Furthermore, only when WM contents were not task-relevant did angry schematic faces capture attention more than happy schematics. This latter observation is consistent with work suggesting that when WM contents were task-relevant, the threat bias to angry faces was eliminated (Moriya, Koster & De Raedt, 2014). These findings suggest that only task-relevant WM contents influence attention, and that they have a large enough influence to eliminate stimulus driven attention biases.

This observation speaks to the validity of capacity models of attention. The capacity model of attention proposes that momentary intentions are one important influence upon the allocation of attention (Kahneman, 1973). Evidence that cues capture participants' attention when they learn that the cue will reliably predict the location of a subsequent target supports this suggestion (Bindemann, Burton, Langton, Schweinberger & Doherty, 2007; Lien, Ruthruff, Goodin & Remington, 2008). Because the emotion of the face held in WM only modulated attention when emotion was the feature that participants were required to maintain, we can suggest that the intention to maintain emotion was what allowed this aspect of the WM stimuli to access attention. Our results also speak to the relation between this and other influences on attention that the capacity model suggests, such as dispositional biases (Kahneman, 1973). Angry faces captured attention more than happy faces when emotion was not task relevant, mirroring an established dispositional bias (Eastwood, Smilek & Merikle, 2001; Lamy, Amunts & Bar-Haim, 2008; Feldmann-Wüstefeld, Schmidt-Daffy & Schubö, 2011; Hansen & Hansen, 1988). However, when emotion was task

relevant this bias was not present, suggesting that momentary intentions have a higher priority than dispositional biases as an influence on the allocation of attention.

The effect of task relevance is also informative of appraisal models of emotion. For example, the sequence model of emotion suggests that individuals check relevance of a stimulus to shape their emotional reaction to it, for example in the recruitment of motor responses (Leventhal & Scherer, 1987; Scherer, 1987, 2001). The tendency to orient immediately to novel stimuli reflects this (Knight, 1984). That positive emotion only influenced speed of responding when relevant to the task-at-hand in our research supports this facet of the sequence model of emotion. Furthermore, it suggests that the factor of relevance pertains to not just external perceived stimuli, but stimuli maintained in the course of an internal process.

To better understand how emotion in WM might interact with attentional systems, we examined underlying neural events produced by these stimuli. We designed an ERP study, in which we asked how WM-congruent stimuli that captured attention might be processed when they were not task-relevant. Importantly we designed the task to eliminate the need to orient attention in order to better observe processes occurring subsequent to the deployment of attention. Results indicate that non-task-relevant emotions interact with visual processing after the allocation of attention. Specifically, we observed lower N1 amplitudes to schematic faces possessing the same expression as a face held in WM than to schematics with expressions distinct from that displayed by the WM face. The N1 is greater in tasks that require a visual discrimination (e.g., "is the letter an a or b?") compared to tasks requiring a uniform denoting the onset of the display (Awh, Anllo-Vento & Hillyard, 2006; He, Fan, Zhou & Chen, 2004; Luck, 1995). Our reduced N1 therefore suggests more superficial processing of congruent emotional expressions than incongruent emotional expressions. This interpretation is consistent with studies showing that each repetition of a stimulus elicits a progressively weaker neural response (Buckner et al., 1998; Ishai, Pessoa, Bikle & Ungerleider, 2004; Rugg, Soardi & Doyle, 1995), and studies suggesting that after initial capture, attention is supressed to stimuli matching WM contents (Sawaki & Luck, 2010; 2011; 2013). These findings indicate that after the allocation of attention, participants process non-task-relevant emotional expressions matching WM more superficially than they do non-matching expressions.

Our findings are consistent with the sequential model of emotion. The appraisal model suggests that one factor early in perception contributing to the formation of a reaction to an external stimulus is its relevance to the perceiver (Leventhal & Scherer, 1987; Scherer, 1987, 2001). To illustrate, people are sensitive to whether a stimulus represents an environmental change, reflected in the observation of preferential orienting to novel stimuli (Knight, 1984). In the current research, when emotion was not relevant to either the memory or the orientation tasks, participants processed memory-matching schematics with less priority than non-matching schematics relatively early. This is in line with the prediction of a relevance check, as non-relevant stimuli should be de-prioritised for processing. Furthermore, in this view, non-relevant stimuli should not contribute to the formation of a motor response, consistent with the absence of a modulation of RTs by non-task relevant WM contents in either behavioural or electrophysiological iterations of our task.

Interestingly, even though WM-matching expressions receive more superficial processing than WM non-matching expressions, our results suggest that they still interfere with cognitive processing of an intermediate task. Specifically we found that the P2, an ERP component that is larger in the presence than in the absence of target features (Kim, Kim, Yoon & Jung, 2008; Luck & Hillyard, 1994; Potts, 2004), was larger to WM emotion matching schematic expressions than to non-matching expressions. This suggests that emotional expressions held in memory cause participants to identify irrelevant emotional expressions as relevant to the task-at-hand, even though in our task judging the orientation of the schematic's "nose" was the actual objective. Additionally, the no-go N2, which increases in amplitude in proportion with the difficulty of withholding a response (Bruin & Wijers, 2002; Nieuwenhuis, Yeung, Wildenberg & Ridderinkhof, 2003), was larger when the schematic expression matched the WM expression than when it was a non-match with the schematic. Research suggests that success in ignoring distractors leads to more efficient task performance (Rutman, Clapp, Chadick & Gazzaley, 2010; Vogel, McCollough & Machizawa, 2005; Zanto & Gazzaley, 2009), so the fact that schematic expressions matching WM contents were difficult to ignore suggests that they may have interfered with task-performance more than nonmatching expressions. The function of more superficial processing of WM-matching emotions may therefore be to maximise cognitive resources by minimising interference from non-task-relevant stimuli.

The observation of more superficial processing of, and interference by, WM matching stimuli is supportive of an attenuation model of attention rather than a filter model. To briefly summarise, whilst filter models suggest that unattended stimuli are prevented from entering short-term memory shortly after perception (Broadbent, 1958), attenuation models suggest that their signal is instead softened rather than eliminated (Treisman, 1960). If participants had been filtering rather than attenuating WM matching schematic faces, we would not expect their features to influence the P2 and no-go N2 components that occur subsequent to the N1, rather, they should have affected the N1 exclusively. This is also consistent with evidence that unattended but personally or semantically salient information interferes with the reporting of attended stimuli in both visual and auditory modalities (Flowers & Stoup, 1977; Moray, 1959; Treisman, 1964).

This attenuation of processing also provides some support for the argument that cognitive appraisals are not necessary for emotional processing (Zajonc, 1980), which was based on evidence that participants still evaluate stimuli presented briefly enough to preclude accurate recognition (Kunst-–Wilson & Zajonc, 1980; Moreland & Zajonc, 1977). More recent evidence from brain imaging studies supports this argument in demonstrating that the amygdala, involved in emotional processing (Williams, Morris, McGlone, Abbott & Mattingley, 2004; Thomas et al., 2001), is reactive to emotional faces presented so as to prevent awareness (Whalen et al., 1998; Williams et al., 2004). In both task-relevant and task-irrelevant versions of our task, the expression of the schematic faces was irrelevant to the goals of both the orientation and identity tasks. Yet, in both cases, participants processed these expressions, reflected in the modulation of RTs by their emotion, even when no evaluation of them was required. This suggests that emotional processing of these faces was occurring even when no explicit evaluation was occurring.

They also support the observation that individuals can override the implicit processing of emotion, as measured by amygdala activity, by the cognitive appraisal of stimuli (George, Driver & Dolan, 2001; Schaefer et al., 2002). For example, the amygdala activity associated with the perceptual matching of threatening pictures compared to the matching of geometric shapes is reduced when participants are instead required to assign the stimuli emotional labels (Hariri, Mattay, Tessitore, Fera & Weinberger, 2003). In our research, participants who held the personal identity of an emotional face in WM showed faster average RTs to angry schematic faces than to happy schematics. However, when

participants held the emotion of the same face in WM, RTs were faster when holding a happy face in WM regardless of schematic emotion. Thus, evidence for the suppression of emotional processing is apparent in both imaging and now our behavioural data.

Value Driven Attention Capture

The current results suggest that WM contents are instrumental in determining the allocation of attention to social cues. However, they also suggest that value is an additional mechanism by which people allocate limited attentional resources. We found that the extent to which genuine smiles influenced participants' choices in a decision-making task predicted the degree to which these smiles captured attention in a flanker task. This result is consistent with research finding that stimuli associated with high monetary rewards capture attention more than stimuli associated with low monetary rewards (Anderson, Laurent & Yantis, 2011; Della Libera & Chelazzi, 2006; Raymond & O'Brien, 2009; Rutherford, O'Brien & Raymond, 2010). However, our results also extend these findings by demonstrating a linear relationship between the intrinsic subjective desirability or value of a stimulus and the attention capture response, whereas previous research has examined only stimuli with artificially conditioned value in the laboratory.

Importantly, our research indicates that the subjective value of a facial expression, measured here in monetary terms, specifically drives attention capture by that expression. Thus, we observed no correlation between the extent to which participants preferred monetary rewards generally and the degree to which genuine smiles captured their attention. We also observed faster and more accurate responses to genuine smile targets than to polite smile or neutral targets. Previous research suggests that genuine smiles possess greater intrinsic value than polite smiles (Shore & Heerey, 2011), which may be due to the fact that they predict positive social outcomes (Jakobs, Manstead & Fischer, 1999), and elicit positive emotion in perceivers (Surakka & Hietanen, 1998). Therefore, our results suggest that facial expressions with high intrinsic value capture attention more than facial expressions with a comparatively low intrinsic value. Moreover, the extent to which these expressions capture attention correlates with the specific value of that expressions to an individual.

This finding adds to the body of evidence for the capacity model of attention. The capacity model identifies dispositions as being important factors in the allocation of

attention (Kahneman, 1973). The current results suggest that the extent to which people prefer certain genuine smiles predicts the magnitude of attentional resources they commit to their processing. Because we based our measure of value upon individual participants' choices, this result therefore affirms dispositional biases as a factor in determining the allocation of attention. Furthermore, the fact that the subjective value of genuine smiles predicted attention capture by genuine smiles, but that the subjective value of polite smiles did not predict attention capture by polite smiles, suggests that certain facial expressions have more dispositional influence than others do.

Interestingly, the data from our flanker task contradicts the suggestion and supporting research that positive emotions broaden the focus of attention or alternatively that negative emotions constrict the focus of attention (e.g., Fenske & Eastwood, 2003; Fredrickson & Branigan, 2005; Gable & Harmon-Jones, 2011; Horstmann, Borgstedt & Heumann, 2006; Huntsinger, 2013; Johnson, Waugh & Fredrickson, 2010). Specifically, if happy faces had led to a broadened focus of attention, we would expect a larger flanker incompatibility effect to happy targets than to angry targets, reflecting greater processing of incompatible flanking faces elicited by positive emotions compared to negative emotions. Instead, the observation of faster RTs to happy targets compared to angry targets suggests a constriction of participants' attentional focus. We might instead consider the observation that the zoom lens of attention can be constricted in order to maximise the resources that can be brought to bear on the spatial location focus and improve performance (Turatto et al., 2000). In this view, our findings instead support the suggestion that positive emotions, or at least happiness, increase efficiency in the recruitment of attentional resources.

The current results also provide support for both Baddeley and Hitch's and Cowan's WM models. To summarise, Baddeley and Hitch's tripartite model suggests that during WM processes, people can retrieve information from long-term memory to aid in processing (Baddeley & Hitch, 1974; Baddeley, 2000). Evidence that familiar objects are maintained in WM with greater success than unfamiliar objects supports this notion (Buttle & Raymond, 2003; Curby, Glazek & Gauthier, 2009; Jackson & Raymond, 2008). Cowan's model goes further to suggest that WM is constituted by activated long-term memory and that attention can be oriented to items within short-term storage (Cowan, 1988), supported by evidence of a greater priming benefit for semantically associated words than for words that are merely perceptually similar (Lesch & Pollatsek, 1993). Given preferences are consistent

across time, the fact that we observe an interaction between subjective value and attentional processing supports the link between WM and long-term memory posited by both of these models.

The current results also support appraisal models of emotion. The sequential model suggests that the normative significance of a stimulus, that is, the implication of the stimulus for an individual or their group, influences that individual's cognitive and physiological reactions to that stimulus (Leventhal & Scherer, 1987; Scherer, 1987, 2001). For example, one study found that participants were faster to locate images of infants compared to adults only when infants were of their own race, reflecting differential attentional prioritisation depending on perceived group membership (Hodsoll, Quinn & Hodsoll, 2010). Genuine smiles are important social cues, to the extent that participants predict and reciprocate them with greater speed than they do polite smiles (Heerey & Crossley, 2013). Moreover, greater reciprocation of genuine smiles predicts greater satisfaction with the interaction on the part of the interaction partner (Cappella, 1997; Heerey & Kring, 2007). The correlation between subjective value and attention capture for genuine smiles but not polite smiles may therefore suggest that the evaluation of the normative value of a stimulus is important in marshalling attentional resources.

Future Directions

This research focused on only one dimension of emotion, that is, its valence. However, another important dimension is arousal, a physiological process leading to alertness and readiness to respond (Colman, 2006). For example, research finds that participants are more likely to detect highly arousing emotional target words compared to low arousal emotional targets subsequent to the detection of an initial target (Anderson, 2005; Keil & Ihssen, 2004). Anderson (2005) suggested that this might be because arousing stimuli are less susceptible to decay (i.e., extinction from short-term memory). Consistent with this suggestion, other research finds that compared to neutral words (e.g., "desk"), arousing words (e.g., "suffer") presented at peripheral visual locations are more accurately remembered after a 24-hour delay (Sharot & Phelps, 2004). Additionally, participants recall emotionally arousing pictures more easily than pictures low in arousal a week after presentation (Buchanan & Lovallo, 2001). These observations imply that high arousal stimuli are more likely to move from short- to long-term memory than low arousal stimuli,

supporting the idea that they are less susceptible to decay. Perhaps if we had used highly arousing emotional stimuli, we might not have observed reduced processing of WM-matching schematics, because these would have been more likely to remain in short-term memory.

Our finding of a relationship between the subjective value of a genuine smile and the extent to which this expression captures attention also presents an interesting future line of investigation. For example, could abnormal expression-value associations underlie social anxiety? Research finds that individuals with social anxiety are more sensitive to negative social appraisals (Mansell, Ehlers, Clark & Chen, 2002; Veljaca & Rapee, 1998), orient attention efficiently to negative expressions (Eastwood et al., 2005; Mogg & Bradley, 2002), and even avert attention from positive expressions (Mogg, Bradley & Philippot, 2004; Pishyar, Harris & Menzies, 2004). It would be interesting to investigate whether people with social anxiety show reduced values for genuine smiles or alterations in the value of negative stimuli and whether this predicts differences in attentional allocation to such stimuli. If this turned out to be the case, such a finding would have significant implications for the treatment of this debilitating disorder.

Limitations

One possible shortcoming of the current research is its reliance on schematic representations of facial expressions (especially in Chapters 2 and 3). Specifically, whereas disrupting processing of naturalistic representations of faces (e.g., photos, paintings) by inversion or misalignment does not impair automatic holistic processing, this bias is diminished by these methods when the stimuli are schematic faces (Prazak & Burgund, 2014; Sagiv & Bentin, 2001). It might be that, in using schematic faces, we elicited weaker face-recognition-associated visual biases than had we used naturalistic representations. This may have resulted in our failure to observe an influence of non-task-relevant WM emotion on RT measures of responding. Nonetheless, participants recognise different emotional expressions in schematic faces with a degree of accuracy observed using photographs, even when disrupted (Prazak & Burgund, 2014). Nonetheless, given that we were interested in the interaction between perceived and memorised facial expressions, our schematic stimuli suggest that such results may be driven by conceptual similarity, rather than the requirement for more exact stimulus representations.

Another limitation of the present thesis is that the WM task does necessitate the memorisation of emotion when it was not task-relevant, as identity was the tested stimulus dimension. Considering optimal recognition-performance is often dependent on preventing irrelevant information from entering WM (Rutman, Clapp, Chadick & Gazzaley, 2010; Zanto & Gazzaley, 2009), this means that the failure to observe WM-attention interactions may actually be due to participants discarding emotion before presentation of the schematic faces, as this information did not aid in identity recognition. However, participants in our task maintained only one stimulus at a time, meaning we likely did not approach the limit of WM capacity. Moreover, we note that participants presented with three expressions to encode were less accurate than participants presented with two, regardless of the task-relevance of emotion. This suggests that participants carried information about the different expressions to the recognition stage, despite its lack of task-relevance.

In addition to discarding emotion, participants could have used alternative strategies to aid in performance of the dual-task, which may have rendered visual encoding of the expression of the stimulus faces unnecessary. As an example, participants could have assigned names to the different identities of the WM faces in order to aid in task performance. One method by which other researchers have impaired verbal processing is to ask participants to repeat irrelevant speech (e.g., words or letters), known as "articulatory suppression" (Richardson & Baddeley, 1975). The effect of this is to leave little capacity to accommodate verbal labels for visual stimuli, an assumption supported by research showing that inner speech can impair performance in a task involving letters as cues to switching between tasks (Miyake, Emerson, Padilla & Ahn, 2004). Because our participants were not engaged in this way, they could have stored the individual identities by assigning names, thus circumventing visual encoding of their expression. This may alternatively explain the failure of WM for irrelevant emotion to interact with attention in our task. Again, we point to the effect of the number of expressions a participant was required to encode across the task on recognition accuracy in order to satisfy this concern. If participants were engaging in verbal strategies, there would have been no effect of facial expression on recognition accuracy when emotion was not task-relevant. A specific manipulation of this memory strategy might be used to rule out its influence in a future study.

Conclusions and Implications

This work aimed to understand the means by which people allocate limited attentional resources to stimuli with emotional value. Our results suggest that emotional information in WM guides attention, but only when relevant to the task-at-hand, and when sufficient resources are available for it to do so. When emotion is not task-relevant, WM actually promotes more superficial processing of congruent expressions. This suggests that WM controls attention to emotional stimuli in a manner that is situationally flexible, as well as preserving resources for current tasks. The current data also suggest that the extent to which an expression of emotion captures attention depends on the subjective value of that expression. This implies that attention to facial expressions is sensitive to their utility to the individual perceiving them, providing the greatest influence over the allocation of attentional resources to the most valuable expressions. Overall, these results suggest that the semantic associations play an important role in the efficient allocation of attentional resources to the most salient and useful expressions of emotion.

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