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Effects of Emotional Content on Working Memory Updating: Proactive Interference and Resolution

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Effects of Emotional Content on Working Memory Updating: Proactive Interference and Resolution

by

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Each person whose signature appears below certifies that this dissertation in his/her opinion is adequate, in scope and quality, as a dissertation for the degree Doctor of Philosophy.

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ABBREVIATIONS

WM	Working Memory
PI	Proactive Interference
PRI	Prepotent Response Inhibition
aMCI	Amnestic Mild-Cognitive Impairment
A-V-L Store	Verbal-Linguistic Store
ARAS	Ascending Reticular Activating System
CSI	Cue-Stimulus Interval
CTI	Cue-Target Interval
ISI	Inter-Stimulus-Interval
IFG	Inferior Frontal Gyrus
ERPs	Event-Related Potentials
MS	Milliseconds
IAPS	International Affective Picture System
DLPFC	Dorsolateral Prefrontal Cortex
OFC	Orbitofrontal Cortex
MFG	Middle Frontal Gyrus

ABSTRACT OF THE DISSERTATION

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by
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The *working memory (WM)* system refers to the structures and processes supporting the encoding, maintenance, manipulation, and retrieval of information to be used for goal-directed behavior. *Proactive interference (PI)* is often experienced when information to be processed shares physical properties with information that is no longer relevant. The working memory system may then process such information less efficiently (i.e., slower processing time) and less accurately, and control processes involved in interference resolution become triggered in order to maintain performance. The current study investigated the effects of emotional content on interference resolution by using a working memory updating paradigm. Specifically, an *n*-back task with lure trials was employed to systematically introduce interference effects. Low arousing neutral images and highly arousing negative images were used to study interference resolution under two emotional conditions. The effects of emotional content on interference resolution were further studied when the emotional content was task-relevant (Experiment 1) or task-irrelevant (Experiment 2). Given the assumption that highly arousing emotional stimuli captures attention automatically, it was predicted that while emotional content would facilitate interference resolution when it was task-relevant, it would hinder interference resolution when it was task-irrelevant. Results showed reliable

interference effects in both Experiment 1 and 2. Two types of interference effects were analyzed; namely, the n + 1 interference effect (mismatch vs. n + 1 lure) and the n – 1 interference effect (mismatch vs. n – 1 lure). While Experiment 1 showed an interaction between interference effects and emotional valence, Experiment 2 failed to show a significant relationship. Specifically, Experiment 1 revealed that while negative valence hindered interference resolution efficiency (i.e., slowed response times) when interference was produced by no-longer relevant (n + 1 lures) information, it facilitated interference resolution when interference was produced by not-yet relevant (n – 1 lures) information. Overall, when the affective information is task-relevant (Experiment 1), it appears to have both facilitating and hindering effects on proactive interference resolution depending on the stage of processing of such representations in working memory. However, when the affective information is not task-relevant (Experiment 2), it does not appear to have significant effects on proactive interference resolution.

CHAPTER ONE

INTRODUCTION

The term *working memory* (WM) came about in the 1960's to describe memory that is readily available for the execution of plans (Miller, Galanter, & Pribram, 1960). In general, the working memory system refers to the structures and processes supporting the encoding, maintenance, manipulation, and retrieval of information to be used for goal-directed behavior. Working memory is a construct that is critical for the understanding of the human mind and behavior. Nearly every task we perform in our everyday lives depends on the integrity of this system to some degree. Accordingly, adaptive behavior is supported by the ability to operate on the contents of working memory through executive processes, which is the focus of more recent investigations (D'Esposito, Postle, Jonides, & Smith, 1999; Levens & Phelps, 2008, 2010). This refers to the processes that support the allocation of attention on task-relevant information while inhibiting task-irrelevant information, and therefore adapting to task demands (J. Jonides, Smith, Marshuetz, Koeppe, & Reuter-Lorenz, 1998; Levens & Phelps, 2008, 2010). This functional account of working memory is most helpful in that it includes any processing mechanisms supporting the temporary availability of information (Cowan, 1999). Importantly, this account emphasizes the interactions between memory and attention such that attended information is preferentially processed in working memory. According to this account, voluntary (executive control/'top-down' control) and involuntary (automatic orienting/ 'bottom-up') processes jointly control the allocation of attention (Cowan, 1999). Thus, information can enter the focus of attention through effortful control (i.e., non-novel task-relevant information) or automatically (i.e., novel, relevant, or inherently significant information) through the orienting response. Working memory is, however, a system with limited capacity,(Baddeley, 2012; Cowan, 2000; Cowan, Johnson, & Saults, 2005; Oberauer, 2002), and when tasks involve the continuous processing of large amounts of information, an updating process must take place (Cowan et al., 2005; Oberauer, 2001; Szmalec, Verbruggen, Vandierendonck, & Kemps, 2010). Thus, working memory not only allows individuals to hold information and maintain it readily accessible for use and manipulation of its contents, but also to update and accommodate new information (Kessler & Meiran, 2008; Szmalec et al., 2010). Furthermore, the updating process is inherently susceptible to *proactive interference (PI)* or interference from previously relevant information (Szmalec et al., 2010). Specifically, as working memory is often measured through recognition paradigms, features shared between no-longer relevant information and the information currently being processed will likely raise a familiarity signal that could lead to a false recognition response (Gothe & Oberauer, 2008; Oberauer, 2001; Oberauer & Lange, 2009; Szmalec et al., 2010). Thus, working memory also involves cognitive control mechanisms that allow us to keep relevant information in mind and to protect it from interference while performing cognitive tasks (Baddeley, 2010), and in particular when tasks require the constant updating of information (Szmalec et al., 2010). Hence the resolution of proactive interference in working memory is crucial in protecting the integrity of new information being processed and supporting accurate and efficient performance, which could further be important for higher order cognitive functioning (J. Jonides & Nee, 2006; Szmalec et al., 2010).

Adaptive behavior is further fostered by the prioritization of attentional resources to information that is relevant to the task at hand or has salient characteristics, which can further affect working memory performance. Affective information is salient likely because of an inherent biological significance giving rise to appetitive and defensive motivational systems (Bradley, Codispoti, Cuthbert, & Lang, 2001). However, the literature examining the effects of emotional content on working memory is mixed. Emotional content has been inconsistently found to have either no effect, to facilitate, or to hinder working memory performance, with such effects varying according to the stimuli and the specific task used (Kensiger & Corkin, 2003; Levens & Phelps, 2008). In addition, most of these studies tend to focus on working memory maintenance and capacity components. However, as mentioned earlier, working memory also involves executive and cognitive control processes that facilitate the resolution of interference from irrelevant information. Thus, in order to further clarify the effects of emotion on working memory, it would be important to also look at the effects of affective information on interference resolution.

Overall, affective stimuli can have higher levels of saliency compared to neutral stimuli, and thus produce an ‘automatic’ orienting response that could facilitate its processing (Levens & Phelps, 2008, 2010). Thus, affective content could potentially facilitate the resolution of interference when it is relevant to a task. However, when highly arousing affective information is irrelevant to the task, it may affect the ability to deal with interference in working memory. Specifically, the attentional orienting to salient or threatening stimuli could prove detrimental and maladaptive if it attracts attention away from relevant information. A ‘hypervigilance’ effect with regard to negatively valence information or possibly threatening stimuli has been studied in the psychopathology of anxiety disorders (Mathews & MacLeod, 2002). For example, difficulty in disengaging attentional resources from threatening information has been linked to the etiology of anxiety disorders (Mathews & MacLeod, 2002). Furthermore, anxious individuals are more prone to experience, and slow to resolve, interference when neutral relevant targets are embedded among negative valence distracters in executive tasks (Mathews & MacLeod, 2002; Williams, Mathews, & MacLeod, 1996). While these effects have been noticed in the emotional literature with anxiety disorders, the effects of irrelevant emotional content on working memory in non-anxious individuals have been less observed (Levens & Phelps, 2008).

Thus, the aim of the current investigation is to further understand the effects of emotional content on interference resolution within the working memory system when this content is either relevant or irrelevant to the task. In the current study, an *n*-back task with emotional (i.e., negative) and neutral pictures from the International Affective Picture System (IAPS) (Lang, Bradley, & Cuthbert, 2005) was used. The *n*-back task is an updating recognition task, which has been used to measure working memory (Jaeggi, Buschkuehl, Perrig, & Meier, 2010; John Jonides et al., 1997; Szmalec et al., 2010). In a typical *n*-back task a participant is asked to decide for each item in a list presented in a serial order, whether it matches the item that was presented *n* positions before. Thus, the set of items presented *n* positions prior to the current item must be remembered (and their serial order) for successful completion of a trial. Since the task is continuous, every trial moves to the next target item and the set to be remembered changes accordingly. The oldest item becomes irrelevant and must be discarded from the memory representation while the new item is added to the set. Furthermore, the *n*-back task to be used in this particular study contains lure trials, which systematically introduce proactive interference (Szmalec et al., 2010), and thus provides the opportunity to more directly measure the effects of emotional content on interference resolution. Specifically, a 2-back task was used including *lure* trials in which a current item does not match the *n*-back item but matches one of the items in close proximity to the *n*-back item (*n* +1 or *n*-1 in a 2-back task). The *interference effects* were measured as the difference between mismatch trials that contain lure and those that do not (i.e., non-lure mismatch trials). These interference effects are observed as both slower and less accurate performance for the lure trials (Szmalec et al., 2010). It was hypothesized that highly arousing emotional content that is task-relevant (Experiment 1) would facilitate interference resolution, which would be represented by a reduction of the interference effect for these stimuli compared to neutral stimuli, leading to better performance. Conversely, it was hypothesized that highly arousing emotional content that peripheral to the task (Experiment 2) would hinder interference resolution leading to worsening of performance when compared to its neutral counterparts. These hypotheses were tested in two separate experiments. Experiment 1 included the emotional pictures as the actual contents to be processed in a 2-back task. Experiment 2 included the emotional pictures as background contexts that were peripheral and thus irrelevant to the performance of the 2-back task. Overall, accuracy and reaction time data was compared between interference and non-interference conditions.

In a tentative stance, this study could not only further help clarify the literature and inform theory on the effects of emotional content on working memory, but further evidence that the task used could potentially also serve as a proxy for studying working memory when the cognitive system becomes vulnerable as it is the case in certain disordered populations (e.g., schizophrenia, mild-cognitive impairment [MCI]). Specifically, in two different studies involving a similar *n*-back task (without lures), using emotional and neutral pictures, it was shown that emotional content facilitated performance in individuals with schizophrenia (Becerril & Barch, 2011) and MCI (Döhnel et al., 2008) but had no effect on healthy controls. Thus, it has been suggested that tasks that do not involve significant cognitive conflict (e.g., lure trials) are not sensitive to the effects of emotional content when performed by healthy individuals (Levens & Phelps, 2008). It can then be assumed that introducing conflict in the form of proactive interference systematically in working memory tasks when studying normal populations could mimic the conflict experienced by individuals with more vulnerable cognitive systems. Thus, the effects of emotion on interference resolution in cognitively vulnerable populations could be studied using normal individuals that are medication naïve and do not have the comorbidities often found in clinical populations.

CHAPTER TWO

BACKGROUND

Relevant Major Structural and Functional Theories of WM

Several different accounts of working memory have been described in the literature that can generally be grouped into structural/component-based models (Atkinson & Shiffrin, 1968; Baddeley & Hitch, 1974) and functional models (Cowan, 1999; Oberauer, 2002). The former models will be briefly described in this section given that these have generated significant research and remain prominent in the literature. However, the current investigation for the most part adopts the perspective of a functional definition of working memory as it focuses on executive control rather than storage mechanisms and it emphasizes the interaction between attention and working memory systems.

Structural WM Theories

The first widely accepted modern model of memory was proposed by Atkinson and Shiffrin (1968). They described the memory system as comprised of three basic structural divisions including the *sensory register*, the *short-term store*, and the *long-term store*. Basically, sensorial information is first processed by the *sensory register*, and it decays at rate of about 500 milliseconds unless encoded into the *short-term store*. In the short-term store information may then also start to decay over a period of about 15 to 30 seconds unless it is can be slowed down by the usage of controlled cognitive processes (e.g., rehearsal mechanisms). However, some information may reach the long-term store and may be held permanently. Significantly, this model resembles a ‘dichotomy’ in memory such that the short-term store and the long-term stores are understood as conceptually and physiologically separate and independent from each other. Furthermore, according to Atkinson and Shiffrin (1968), an individual has control of the *flow* (flow is said to be more like the 'copying' of information rather than actual 'transfer' of contents) of information among the three structural systems, and this flow can also be multidirectional in that these systems may interact with each other at any point. This model further proposes that the short-term store also represents working memory. In general, the sensory register is 'scanned' through cognitive control processes (that also conducts a search of associated long-term store), and information is then selected into the short-term store. Information coming from the sensory register is coded into representations that can be independent from the form of the sensory input (e.g., words presented visually could be encoded as an auditory representation in the short-term store). However, according to the authors, the storage of information in the short-term store is modality dependent such that auditory representations are stored in an auditory-verbal-linguistic store ("a-v-l store"). Information in the short-term store can also come from the long-term store through cognitive control mechanisms, and this often happens in high-order processing (e.g., problem solving, hypothesis testing, 'thinking' in general) (Atkinson & Shiffrin, 1968). With regard to 'control processes' (e.g., schemes, coding techniques, mnemonics), the authors mentioned that though these are not permanent features of memory since they are highly variable with different factors (e.g., instructions, tasks, individual's past history), control processes are nonetheless dependent upon the memory structures (i.e., sensory register, short-term store, long-term store). Overall, control processes in the short-term store include *search, rehearsal, or coding processes*

(Atkinson & Shiffrin, 1968). Search processes involve an exhaustive serial search or comparison of representations in the short-term store (Atkinson & Shiffrin, 1968). Rehearsal processes involve covert rehearsal mechanisms that delay the rate of decay of the information from the short-term store (Atkinson & Shiffrin, 1968). Coding processes involve "alterations and/or additions to the information in the short-term store as the result of a search of the long-term store" (Atkinson & Shiffrin, 1968). With regard to the neural substrates of the hypothesized model, Atkinson and Shiffrin (1968) only referred to the distinction between short- and long-term memory stores. Such dichotomy in the memory system has been mainly supported by studies of hippocampal lesions resulting in the inability to add new information to the long-term store, with no relative disruption of the functions involved in the sensory register and short-term memory stores, and preservation of information already in the long-term store.

Baddeley and Hitch (1974) studied the concept of short-term memory (STM) in response to criticisms of the dominant Atkinson and Shiffrin (1968) model with regard to the structure and function of the short-term memory store. They refuted the assumptions that short-term memory equated to the construct of working memory and that it is comprised as single unitary store. Thus, (Baddeley & Hitch, 1974) proposed a three-component system that later evolved into a *Multi-Component Model* of *working memory*. In his most recent account, Baddeley (2012) described working memory as a system that includes multiple components; namely, the *phonological loop*, the *visuo-spatial sketchpad*, the *central executive*, and the *episodic buffer*. The visuo-spatial sketchpad and the phonological loop are described as two storage components in support of the storage of different modes of information (i.e., visual or acoustic). Thus, while the visuospatial sketchpad stores information in the visual modality and its location in space (spatial information), the phonological loop supports storage of information in the spoken or verbal modality. The central executive seems to be a more complex system, and in fact Baddeley (2012) himself mentioned to have neglected this topic for that reason. The central executive is described as an attentional control component, and it is typically recruited by attentionally demanding tasks requiring more than just simple maintenance. Baddeley (2012) described four specific functions of the central executive, including the ability to focus attention, the capacity to divide attention, the capacity for task switching, and the capacity to interface with long-term memory. As explained by Baddeley (2000, 2012), given that the central executive proposed by his model does not include a storage capacity, he decided to add a fourth component that allows for the storage of multi-modal integrated information. The fourth component is the *episodic buffer,* which hypothetically allows for the storing of integrated episodes with combined visual, spatial, and verbal information (Baddeley, 2000). In general, it functions as a buffer store in that it allows for the interaction between all the different components of working memory, and it also allows working memory to interface with information from perception and long-term memory (Baddeley, 2000, 2012). In summary, this component allows for information from the two storage systems (the visuospatial sketchpad and phonological loop) and from long-term memory to be stored as an *episode* as opposed to disintegrated pieces of information (Baddeley, 2000, 2010, 2012). Importantly, much like the other two storage components, the episodic buffer is described as a passive storage system with limited capacity (about four chunks), and information in this store can be accessed through conscious awareness by the central executive (Baddeley, 2000, 2012). Thus, while the episodic buffer supports storage of integrated information (chunks or episodes), given that it is proposed to be a passive storage, the actual binding of information is not done by the buffer itself (Baddeley, 2000). With regard to the binding process, Baddeley (2012) summarized the findings of several investigations as suggesting that it involves the active manipulation of information stored in the episodic buffer, but the assumption remains that the binding process itself takes place outside of the buffer proper. Furthermore, Baddeley (2012) suggested that the buffer could be regarded as resulting from a ‘fractionation’ of the central executive into separate attentional and storage systems, which together represent the contributions of top-down (i.e., peripheral) and bottom-up (i.e., executive control) systems, respectively. With regard to neural correlates of working memory, Baddeley (2012) questioned the reliability and validity of methods of anatomical localization (e.g., neuroimaging), in particular the usefulness of such approaches in providing a firm theoretical basis for the working memory system given its complexity and the fact that it is still not completely understood with regard to its temporal structure of activation. Baddeley (2012), admitted that in constructing his theoretical model, he mainly focused on the top-down system in attempts to first understand the contributions of such peripheral systems. Such focus differs from that of other influential models such as the *Embedded-Processes Model* described later in this section, which focuses more on the executive and attentional aspects of working memory (Baddeley, 2012). Thus, Baddeley (2012) considers such alternative approaches as complementary and consistent with his model rather than competing frameworks, with differences in ‘emphasis’ and ‘terminology’ (Baddeley, 2012). The *Embedded Process Theory*, according to Baddeley (2012), is mainly concerned with the interaction between the central executive and the episodic buffer, though it uses different terminology. Overall, given that the goals of the current investigation are most in line with the attentional and executive aspects of working memory, concepts and terminology from this latter model are preferred and are described in the remainder of this section.

Functional WM Theories

In a more recent major working memory theory, Cowan (1999) introduced the *Embedded-Processes Model,* a functional model of working memory. In this model, working memory is not separate from long-term memory, but it is rather embedded within it. Within long-term memory as a whole, working memory involves an activated subset of long-term memory, which further includes a subset of information currently in the *focus of attention* (Cowan, 1999). In general, the flow of information involves stimuli entering the *sensory store*, which activates a subset of long-term memory, and from which only a subset of this activated long-term memory enters the focus of attention. This flow of information is assumed to be carried out conjointly through voluntary and involuntary cognitive processes (Cowan, 1999). Contrary to Baddeley's model, Cowan's model assumes that in describing the function of working memory, the modality or form of representation of a particular stimulus is irrelevant to its processing within the system (Cowan, 1999). Essentially, Cowan's model postulates that the basic mechanisms of working memory (e.g., encoding, maintenance, and retrieval) are parallel regardless of the characteristics of a stimulus (Cowan, 1999). Thus, it could be said that, when information enters the brief sensory store, it activates features of long-term memory; and though information coming into the sensory store may be processed according to their modality (e.g., visual information is processed within the visual systems) and may activate representations stored in different areas of the brain, the functional process of activation itself is analogous regardless of the modality of information. These activated features form a type of ‘code’ or the encoding of the stimulus (Cowan, 1999). In this process, involuntary (e.g., orienting of attention toward a stimulus) or voluntary (e.g., effortful control of attention) control mechanisms can bias or strengthen the activation of features leading to more stable memory representations or encoding of these features (Cowan, 1999). Thus, according to this model, some unattended information, and in particular physical characteristics of certain stimuli, may still leak into the system and create activations that are further encoded, and which may even enter the focus of attention without any effort or awareness. However, information that is more mnemonic or categorical in nature requires more of the attentional control mechanisms and awareness in order to be processed through the system. In general, the two other major components of this system as described by Cowan (1999), include *maintenance* and *retrieval*. *Maintenance* is described as the process of reactivating or keeping an item within the focus of attention (Cowan, 1999). *Retrieval* is described as the process of registering relevant information into the focus of attention before it is forgotten, while inhibiting interfering irrelevant information (Cowan, 1999). Thus, both of these processes require cognitive control mechanisms. In Cowan’s model, the fundamental mechanisms are those involved in the control of the focus of attention. He describes these mechanisms as those of orienting, habituation, and central executive processes (Cowan, 1999). In general, the central executive processes in Cowan’s model can be said to parallel Baddeley’s *central executive* functions. Cowan proposes that while the mechanisms of orienting and habituation may give way to an effortless mode of attention that allows the processing of unattended information (e.g., *bottom-up attentional orienting*), the central executive involves effortful processes that controls the orienting of attention (e.g., *top-down attentional control*) (Cowan, 1999). However, Cowan explains that both of these mechanisms work together to optimize the control and regulation of information in working memory (Cowan, 1999). Furthermore, within the functions of the central executive in the control of attentional resources, it is noted that it is possible for attention to also be directed away (i.e., inhibition) from information in the service of goal-directed behavior (e.g., need for counteracting *negative priming* effects), and it is in using the same resources as attentive processing in working memory that inhibition is possible (Cowan, 1999; Engle, Conway, Tuholski, & Shisler, 1995). With regard to limits in capacity, Cowan (2000) states that activation of memory is time limited (e.g., 2 to 30 s) and the focus of attentions has a capacity limit of about four chunks. These limits in working memory capacity are further reduced in tasks that require the constant updating of its contents such as in an '*n*-back task', in which every item must be compared with the item that appeared *n* items ago in the continuous sequence (Cowan, 2000). With regard to neuroanatomical correlates of working memory, Cowan (1999) did suggest some possible neural systems underlying the various components and processes of his model. Beginning with the brief *sensory store*, he suggested that the supporting areas involved modality-specific sensory cortex. Then, he suggested that diverse areas of the association cortex likely mediate *activated memory*. Storage was then suggested to be supported by diffused cortical areas of the brain for *automatic long-term storage* and *attention-related long-term memory storage*, with the latter also including additional critical involvement of the hippocampal area. Furthermore, the c*entral executive* was obviously suggested to involve the prefrontal cortex. The ascending reticular activating system (ARAS) flowing through the thalamus was suggested to support the *innervation or source of attentional activity*. Areas of the parietal lobes with input from the frontal lobes, the ARAS, and sensory systems were suggested to support the *focus of attention or awareness,* and the process of *entry of information into the focus of attention or awareness* occurring via the thalamus. Lastly, while the *orienting of attention* was suggested to involve the locus coeruleus, various cortical areas along with hippocampal involvement were suggested to support *habituation*. With respect to differences between Baddeley's Multicomponent Model and the current Embedded-Processes Model, the latter was described to be more 'unitary' than the former, but not purely a 'one system model' (Cowan, 1999); rather, it was described as having both unitary and non-unitary features (Cowan, 1999). In general, the current model was said to be more unitary than that of Baddeley's model in that it does not propose the storage of information (i.e., phonological and visuospatial) to be in separate components (Cowan, 1999). Information from different modalities (e.g., phonological, visual, spatial, etc.) is suggested be processed by the same principles without requiring the inclusion of separated storage systems (Cowan, 1999). Cowan (1999) explained that in order to think of the working memory system as a whole, he has opted to ignore differences between modalities since his goal is to reach a very general level of analysis. Overall, Baddeley's *Multi-Component Model* and Cowan's *Embedded-Processes Model* do appear to be largely complementary with differences in focus and terminology.

Furthermore, Cowan's model was adopted and extended by Oberauer (2002) in his *Three-Embedded Components Model* of working memory. The author described three functional regions or stages of representations in working memory that are characterized by their state of accessibility for processing, with each region being more accessible than the prior one. Like in Cowan's model, Oberauer (2002) described the first region as the proportion of *activated long-term memory* that is stored as 'to-be-remembered' information but is not relevant for processing in an on-going task, and thus currently not selected as candidate for further processing. Then, he described the *region of direct access*, which only holds a limited subset of relevant information or chunks that have been selected as candidates for further processing and need to be readily available for use in the cognitive processing that is ongoing. This latter region is similar to Cowan's description of information in the focus of attention. However, Oberauer (2002) described the *focus of attention* as an additional third region, which is limited to only the one item or chunk that is the target for current processing in any given cognitive operation. Thus, the term *focus of attention* as defined in this model is characteristically much more limited in capacity. According to Oberauer (2002), this is an important distinction, because working memory capacity as measured by various tasks often refers to the region of direct access or the focus of attention as conceptualized by Cowan. Oberauer (2002) used a *memory-updating* paradigm to investigate the proposed model of three different functional states of information in working memory. He argued that the nature of the different sources that limit capacity in working memory could be dissociated between two different states of accessibility that represent and dissociate the region of direct access and the focus of attention. Oberauer (2002) proposed that the limits in capacity in working memory could be dissociated between storage and processing, such that they can be independent from each other as long as processing does not require access to the memory contents. However, according to the author, when the processing requires access to memory contents such as in manipulation, then capacity limits arise from a selective process that puts the contents in the region of direct access in competition such that items must be rejected in order for one to be selected to enter the focus of attention. Also, the author proposed that representations from the activated part of long-term memory could only be accessed indirectly to be brought into the region of direct access and become candidates for selections for the focus of attention by means of intermediate retrieval structures. In a first experiment, participants were first instructed to memorize a set of digits presented in different frames simultaneously in two rows of either one or three frames each. Two conditions were created such that the rows were either both considered 'active' (active-active/AA) or one row was 'active' and the other 'passive' (active-passive/AP). For active row(s), participants were requested to perform a sequence of nine arithmetic operations on the initial values and to update them with the new values after every operation. For the passive row, participants did not perform any operations. Then participants had to recall the final values for each frame randomly probed (i.e. updated final values for the active row(s) or initial values for the passive row). Results showed longer reaction times when both rows were active compared to when one row was active and the other was passive, which was interpreted to support the assumption that active sets were held in the region of direct access while passive sets were stored in long-term memory for future recall. Thus, having a passive row did not occupy the resources in the region of direct access, thus resulting in faster overall reaction times. According to the authors, results further supported the assumption that active and passive sets do not compete for the same limited capacity in that the accuracy for the active-passive combination was higher and this condition did not show an interaction with set-size, while the active-active combination did show a decrease of accuracy with overall memory load. However, recall response times were slower for the passive set, which was interpreted to indicate that these values had to be accessed indirectly in long-term memory through retrieval structures, which delayed their recall. Furthermore, the time to moving among frames to perform operations (switching costs) was a function of condition, such that switching costs were higher when an additional active set, as opposed to an additional passive set, was present. This finding was interpreted to support the assumption that capacity is a function of difficulty of selecting on item for processing among an increasing number of candidates, but not with the number of non-candidates held in long-term memory. Thus, the authors further interpreted these results to represent the time it takes the focus of attention to move from one item to another in the region of direct access. Overall, the data from this experiment along with consistent results in a second experiment, was interpreted to support the proposal of a highly organized structure of functional states in working memory; such that the representation in the focus of attention has been selected for processing, while the representations in the region of direct access represent the selection set, and representations in the activated part of long-term memory are available in the background.

Oberauer (2002) alluded to the issue that his model is not in disagreement with Baddeley's model, and though he makes no reference to structural distinctions, he noted that the central executive is a likely candidate for holding information that is selected for active processing (e.g., region of direct access) assuming that it also has a storage capacity of its own. In general, this parallelism can be improved by the inclusion of the episodic buffer which does have storage capacity and is considered a ‘fractionation’ of the central executive, such that the central executive operates on the contents of the buffer directly (Baddeley, 2012). Furthermore, with respect to the interpretation of the findings by Oberauer (2002) as suggesting two separate directly accessible functional regions (i.e., region of direct access and focus of attention), Cowan et al. (2005) suggested that the differences likely reflect situational factors rather than a difference in structure of working memory. Specifically, the authors argued that the task used by Oberauer (2002) is probably tapping into an additional characteristic feature of the focus of attention that reflects a continuous distribution of attention among its contents with sensitivity to their relative relevance. In other words, the focus of attention as described by Cowan et al. (2005) likely includes both the area of direct access and the focus of attention regions described by Oberauer (2002), thus the contents of these two regions are within the focus of attention but the current target is preferentially processed given its greater relevance to the task at hand.

A more recent development to the concentric model of working memory including the three-states of activation put forth by Oberauer (2002) concerns the adoption of dual process-theories, which was proposed as a “dual-process model” for recognition in working memory (Gothe & Oberauer, 2008; Oberauer & Lange, 2009). This model proposes that recognition in working memory can be dissociated into two retrieval processes, including *familiarity* and *recollection* as sources of information for recognition (Gothe & Oberauer, 2008). In general, this model proposes that while familiarity depends on activation in long-term memory, recollection requires the retrieval of the information in the region of direct access to be brought into the focus of attention for comparison to the target (Gothe & Oberauer, 2008). The fact that dual-process theories have been most commonly applied to recognition in long-term memory makes it important to review these theories in such context before continuing its discussion in relation to working memory. Thus, the next section summarizes the leading dual-process theories of recognition memory.

Dual-Process Models

Formal Dual-Process Models of Recognition Memory

In the memory literature, and in particular in long-term memory research, dual–process models have been successfully used to describe the underlying dynamics of recognition memory. The main assumption these models make about recognition memory is that it consists of two processes, namely—*familiarity* and *recollection*. In general, while familiarity is often defined as a recognition process that does not involve the retrieval of source or contextual information, recollection is said to involve the retrieval of source or contextual information (Yonelinas, 2002). It is assumed that both recollection and familiarity function independently and occur in parallel; however, while familiarity refers to a faster and more automatic memory strength process, recollection is slower and involves more effortful and controlled conscious retrieval of details about a specific event or episode (Yonelinas, 2002).

Although dual-process theories have been successfully applied to describe and examine recognition data, the core assumptions of the models based on these theories have been also the subject of a great deal of debate (Squire, Wixted, & Clark, 2007;

Wixted, 2007a, 2007b). This debate has given rise to a new kind of dual-process model that while it argues that a single-process signal detection procedure can be used to account for recognition data, it also suggests that recognition memory is based on the two memory processes of recollection and familiarity (Wixted, 2007a). With regards to conventional dual-process models, the assumption that has been subject to much controversy is the conceptualization of the recollection process as an 'all-or-none' or categorical process rather than a 'strength-based' or continuous memory signal process like familiarity. For example, Yonelinas (2002) describes recognition processes as involving two parallel and independent memory processes, in which familiarity reflects a strength-based process that accumulates quantitative information and recollection reflects a threshold retrieval process of qualitative information. Furthermore, this account also assumes that while recollection depends on hippocampal integrity specifically, familiarity depends on the integrity of additional temporal lobe structures. Contrary to this account, Wixted (2007a) proposed that recollection is also a continuous or graded process and assumes that both familiarity and recollection can be based on weak and strong levels of confidence and that both can contribute to the recognition response choice. Mickes, Wais, and Wixted (2009) tested the latter prediction by using a source recognition paradigm along with confidence ratings and found that recollection was associated with both low and high levels of confidence. Thus, they interpreted these results as evidence supporting their proposal that recollection is a continuous process. The authors further suggested that this account is consistent with data suggesting that recollection and familiarity processes are supported by hippocampal activity. Furthermore, in a more recent study, Ingram, Mickes, and Wixted (2012) investigated the continuum nature of the recollection process by using a modified version of the ‘remember/know’ procedure that included confidence ratings and source recognition as well. They found that both familiarity- and recollection-based recognition could be based along a continuum of confidence levels. Based on these results, the authors concluded that recognition judgments could be successfully modeled by a single-dimension of memory strength. However, they added that this does not mean that recognition memory is only based on a single memory process, but rather they argued that their data provides evidence of the existence of two continuous processes that can be ‘aggregated’ on a one-dimensional model.

Dual-Process Model of WM

More recently, as described previously, dual-process theories have been explored within the working memory literature and short-term recognition. These theories may help explain the issue of interference in working memory. However, it is important to first discuss what the key components of these theories may mean in the area of working memory. Gothe and Oberauer (2008) suggested that, as in long-term memory, recollection and familiarity processes might also influence working memory, but that the sources of evidence differ from those in long-term memory. In this view, *familiarity* is assumed to arise from the level of activations in long-term memory that are produced by a target. *Recollection*, then, is assumed to involve retrieval of the contents and their context representations in the direct access region of working memory. The authors explain that since working memory paradigms usually test for short lists immediately after presentation, then these can be searched exhaustively. In order to investigate how recollection and familiarity processes are combined to arrive at a single response choice, Gothe and Oberauer (2008) tested two traditional models of recognition based on dual-process theories. They analyzed response data in regard to 'speed-accuracy trade-offs' within a *modified Stenberg recognition task*. The task involved the presentation of two short memory lists in two different color fonts for each list. Then a cue was presented within a rectangle of either color so as to indicate which list would be relevant. The cue was either an item from the relevant list (positive), a new word not on any of the lists (negative), or a word from the irrelevant list (intrusion). According to the authors, for positive responses both familiarity and recollection worked together converging to accumulate information indicating that the word was part of the relevant list. Similarly, for new words, it was assumed that both processes would converge to indicate that the word was not on any of the lists by only signaling 'low-familiarity' and no recollection of episodic details. Conversely, intrusions would signal 'high-familiarity' such as that of a positive word but no recollection of episodic details, which the authors interpreted as having both processes in conflict. Furthermore, the speed-accuracy trade-off was introduced with a response-deadline method in which a tone is presented at different times after the onset of the cue, which prompts the participant to respond. Thus, this method forces participants to respond at different times during the retrieval process. Then, in order to analyze the speed-accuracy trade-off, functions are created by plotting the probability of 'accepting' (i.e., saying 'Yes' to) the different types of cues against processing time. The authors then tested two models of recognition in working memory that resembled core assumptions in regard to recollection and familiarity processes in either Yonelinas' or Wixted's models of recognition in long-term memory. First, in an

Integration Model resembling Wixted's model of recognition in long-term memory, both familiarity and recollection were assumed to progressively accumulate evidence throughout the course of recognition (Gothe & Oberauer, 2008). Furthermore, in this model, although the two recognition processes are assumed to work in parallel, the familiarity process is assumed to onset earlier and to have a faster course than recollection. Also, information accumulating from the two processes is integrated across time and both have the same influence on the selection of a response. In contrast, the *Dominance Model*, which resembles Yonelinas' model of recognition in long-term memory, assumes a qualitative difference between familiarity and recollection in regards to the information derived from each process (Gothe & Oberauer, 2008). According to this model, while familiarity is a continuous process as in the integration model, recollection is a 'threshold-like' process. However, according to the authors, in order to reach the critical threshold, a continuous accumulation of recollective information is carried out. Also, according to this model, familiarity has an earlier onset than recollection, but once the critical threshold for recollection is reached, the recollection process takes over and is the primary source of information for recognition rather than both processes contributing to the decision. Thus, if the threshold for recollection is not achieved at any point, the response will be based solely on familiarity (Gothe & Oberauer, 2008). According to Gothe and Oberauer (2008), the results showed that both of these models provided a 'good fit' to the short-term recognition data according to the 'speed-accuracy trade-off' functions using a 'response-deadline method'. Thus, the authors concluded that although the integration model provided a slightly better fit, the difference was too small to declare this model as the ‘better’ model and thus both models could be used to describe and investigate the ‘retrieval dynamics’ in working memory.

Furthermore, Gothe and Oberauer (2008) tested a new model based on dual-process theories that integrates the “Three-Embedded Components” theory of working memory in order to investigate the relationship between ‘activation’ and ‘binding’ processes in working memory. As described in previous sections, the three components in this framework include the activated portion of long-term memory, the region of direct access, and the focus of attention (Oberauer, 2002). In general, the authors suggested that while familiarity is based on activations in long-term memory, recollection is based on the retrieval of bindings from the region of direct access. Thus, the authors argued that the difference between activation and binding processes could be represented in recognition as the difference between familiarity and recollection. In this study, the authors used a *modified Sternberg paradigm* that allows for the dissociation of familiarity and recollection processes. In this task, participants are presented with two short lists and instructed to memorize them. The two lists are presented together on the screen, but they differ in their physical features (e.g., font color and spatial position). After the encoding (6 sec passive encoding) trial, one of the lists is indicated as relevant by presentation of a cue, followed by the probe, and participants are required to make a recognition response choice as fast as possible deciding whether or not the probe was part of the items of the cued/relevant list. Interference is produced by the presentation of probes belonging to the non-cued/irrelevant list, which was assumed to carry a familiarity signal that calls for activations in long-term memory. This familiarity signal and rejection of such items was assumed to be done through employing recollection processes that may include an exhaustive comparison of the probe with each of the items in the relevant list or recollection (episodic retrieval) of having seen the probe in the irrelevant list. Thus, according to the authors, familiarity would be represented in performance by higher errors rates and longer reaction times to probes from the irrelevant lists when compared to new ones. The authors then tested, and for the most part found support for six assumptions about their model. These assumptions were: (1) familiarity and recollection underlie recognition; (2) familiarity is based on the level of activation in long-term memory matching the probe; (3) recollection is based on the retrieval of bindings in the region of direct access; (4) capacity limits in the region of direct access arise from interference between bindings/contents; (5) recollection processes retrieve binding information automatically; and (6) bindings in working memory can give rise to more stable associations in long-term memory. Overall, the authors found supporting evidence for their dual-process model, in that a single process model could not account for their results. This model however, for reasons of simplicity, is described as reflecting more of the Wixted (2007a) dual-process account in that it assumes that familiarity and recollection both contribute to the recognition decision through a combined single continuous signal (Gothe & Oberauer, 2008).

In a subsequent study, Oberauer and Lange (2009) aimed to further specify the relationship between activation and binding in working memory and investigate their unique effects on the recognition decisions using a dual-process model. Furthermore, the three embedded components of working memory (Oberauer, 2002) were described in accordance to the hypothesized relationship between activation and binding under the proposed framework. First, the *activated part of long-term memory* was described as including the set of all activated representations, and individual representations elicit a familiarity signal that corresponds to its level of activation and degree of match with the probe regardless of bindings. Second, the *region of direct access* was described as including the subset of the activated representations that involve temporary bindings to a common coordinate system (e.g., a temporal or spatial context) that can be accessed by the recollection process. Third, the *focus of attention* was described as including the single representation that is selected for manipulation, and retrieved representations of bindings can be brought about thorough recollection. Again, a *modified Sternberg paradigm* (Gothe & Oberauer, 2008; Oberauer, 2001) was used to dissociate the familiarity and recollection processes. Specifically, two short lists (Exp.1 = 2 item lists; Exp.2 = X item lists, Exp.3 = X item lists) were presented so that they could be distinguished by their respective color and position on the screen, followed by the presentation of a probe after a variable cue-stimulus interval (*CSI* of 100ms or 2s), and instructions were given to decide whether the probe was in the relevant list and accuracy was emphasized over speed. A conflict between the familiarity signal and recollection was assumed to arise when the probe matches an item in the irrelevant list, resulting in longer reaction times and higher error rates when compared to new probes. Thus, the size of such differences reflects the relative contribution of the familiarity signal and recollection to the response choice, such that the difference would be highest when there is a strong familiarity signal and a weak recollection. In this study, the materials were non-word trigrams (e.g., BOL, KUG, FEG, etc.) with two different consonants in order to be able to investigate ‘lower-level’ (i.e., phonemes bound together in a certain order to form a pronounceable string) and ‘higher level’ (i.e., bindings between non-words to form a list) bindings. In Experiment 1, three kinds of intrusion probes were compared including original trigrams (e.g., FEG) from the irrelevant list, recombined trigrams (e.g., FEX) from the irrelevant list, and recombined trigrams from the relevant list. Recombined trigrams were composed of letters from the different items on a list. Also, in Experiment 1, four trigrams were repeated more often throughout the experiment (each trial contain one of the repeated items) and were also used as probes in some trials as either from the relevant list or the irrelevant list in their original form to create a familiarity signal trace for these non-words. Results showed that reaction times were faster and accuracy slightly higher for the longer CSI. Reaction times were longer and accuracy lower (i.e., more false alarms) for all the intrusion probes compared to new probes, with larger differences for the relevant list recombined probes, followed by the irrelevant list original probes and then the irrelevant list recombined probes. Furthermore, performance improved for the intrusion probes at the longer CSI compared to new probes, and more so for the irrelevant list intrusion probes, which supported the assumption that irrelevant representations are deactivated gradually over longer CSIs reducing its familiarity signal. However, the high false-alarm rate for the relevant list recombined probes was not reduced at the longer CSI, which further supports the assumption that the relevant list is not deactivated over time. The authors concluded that the finding of significant intrusion effects for recombined probes (relevant and irrelevant list probes) indicated that familiarity could arise at least in part from low-level representations (letters in trigrams) of whole items, supporting the assumption that familiarity arises from activation of long-term memory representations. A familiarity signal arising from higher-level representations (whole non-words) was also evident in that interference effects for irrelevant list probes were slightly larger for the original compared to the recombined probes; however, this finding was said to also alternatively indicate ‘errors’ of recollection if the irrelevant list items are not completely removed from recollection and its match to the irrelevant contents is mistaken as a positive match. Finally, the frequent repetition on the four non-words contributed to a higher hit rate, but no reliable significant intrusion effects were observed. In another experiment (Experiment 3) Oberauer and Lange (2009) investigated the assumption that bindings are accessed and used automatically by recollection. The same basic procedure was used as in Experiment 1, but participants were instructed to accept a probe, regardless of the conjunction of letters, if a trigram of the relevant list contained all the individual letters, so that the task could be performed without the need to bind letters into larger units (i.e., non-words rather that list of letters). Thus, probe types included positive relevant list probes (i.e., single consonants, original trigrams, and reordered trigrams), new probes (single new consonants and new letters trigrams), irrelevant list probes (single consonants, original trigrams, and reordered trigrams), and mixed probes (trigrams consisting of one/two letters from the relevant list and one/two letters from the irrelevant list). Speed and accuracy were equally stressed. In general, the results showed that the relevant list recombined trigrams were significantly harder to positively identify than original trigrams, which was interpreted as evidence to support the assumption that bindings between letters are constructed and used for the recognition decisions regardless of their utility. Similarly, original trigrams were easier to positively identify compared to single-letter probes, even when single letter probes only require one match as opposed to three for trigrams, thus supporting the assumption that non-words are more easily accessible as units rather than as separate letters. Furthermore, intrusion effects were higher for recombined trigrams compared to original trigrams, which was described as providing evidence for the assumption that familiarity is uniquely dependent on feature matching and independent of feature bindings into trigrams. Overall, the findings were said to support the dissociation between recollection and familiarity, with the former accessing binding representations in the region of direct access, but not the latter. However, it was suggested by the authors that it is likely that recollection initially accesses whole items to bring to the focus of attention, and when necessary, it takes a second analysis that decomposes the item into individual features resulting in longer reaction times.

In summary, in the current paper, the structure of working memory is conceptualized in terms consistent with the *embedded process model* (Cowan, 1999) and the *three-component working memory framework* (Oberauer, 2002), which are more consistent with a dual-process account of recognition (Gothe & Oberauer, 2008; Oberauer & Lange, 2009). Overall, working memory is comprised of the *activated long-term memory*, the *region of direct access*, and the *focus of attention*. Activated long-term memory is not bound to capacity limitations and its level of activation gives rise to a familiarity signal that is sensitive to feature matching between a test cue and activated representations in long-term memory. The region of direct access is limited in capacity and stores bindings between representations in working memory and their context, and these can be accessed and brought to the focus of attention through a recollection process. Hence, the previous studies demonstrated that a dual-process approach can adequately account for short-term recognition in working memory, and the processes of familiarity and recollection can be dissociated in working memory paradigms. This is important because it provides a framework that better captures the role of working memory in higher cognitive operations that are critical for adaptive functioning. Such is the case in paradigms in which the information follows a sequential course requiring the working memory system to be able to process and update information continuously. This *updating* process thus also requires the system to be able to efficiently establish and alter association quickly, which makes this process highly vulnerable to interference effects in the face of conflict if it relies primarily on a fast familiarity signal. Thus, the broad issue of interference in working memory, and in particular within the models discussed in the current paper, are discussed in the following section, followed by the discussion of interference as it pertains to the updating process in working memory.

Irrelevant Information in WM

The issue of interference in working memory has been addressed within the different theoretical frameworks presented earlier, either directly or indirectly when discussing the assumptions on limitations in capacity established by the different models. For example, Atkinson and Shiffrin (1968) mentioned that information in the short-term memory store is mainly subject to be lost when rehearsal is prevented by an interfering task and the memory trace does not achieve an adequate strength. Thus, in their model, *memory decay* would be the primary mechanism of interference, and interference resolution would be supported by control processes involved in the shielding of working memory representations from decaying, as well as those involved in maintaining information activated longer (Atkinson & Shiffrin, 1968). Atkinson and Shiffrin (1968) described control process in the short-term store as including *search, rehearsal, or coding processes.* First, the authors described search processes to involve an exhaustive serial search or comparison of activated representations in working memory. Second, rehearsal processes were proposed to involve covert rehearsal mechanisms that extend the period of activation of the information in working memory. Third, coding processes were assumed by the authors to involve the formation of representations (e.g., activation of associations) in working memory through activation of long-term memory traces. According to the authors, all these processes can help in protecting the contents of working memory from decaying. Similarly, Baddeley (1976) adopted the assumption that *forgetting* in the short-term memory system was a primary factor of *trace decay*, but he acknowledged the possibility that other sources of interference likely also play a role (Baddeley, 2012). In addition, Baddeley (2012) stressed that his multimodal framework does not directly address interference, but noted that the assumption of a limited-capacity store in itself implies the existence of interference of some sort (e.g., *displacement*, *overwriting*). However, he argued that given the broad nature of his model, forgetting could be explained by either decay or interference equally well. Overall, the specific sources of interference and the associated processes of control of interference (as well as terminology) proposed by different theoretical frameworks vary with their specific assumptions, as well as may depend on the specific paradigm(s) and instructional set(s) used. Thus, in discussing particular sources of interference and interference control processes, it is crucial to note that any specific mechanisms may be dependent on the particular experimental task, instructions, and the subjects' own individual factors. Having said this, with respect to the broad theoretical framework reviewed in the current paper, Cowan (1999) suggested that interference could result from residual activations in long-term memory if these are primed by stimuli currently in the focus of attention. It is assumed that previously encountered information after being removed from the focus of attention or awareness nonetheless continues to produce activations in long-term memory (i.e., 'habituation of orienting') (Cowan, 1999). Also, according to Cowan et al. (2005), interference can occur when to-be-remembered information is outside of the focus of attention (e.g., capacity was exceeded) and needs to be retrieved from long-term memory. The assumption being that representations in working memory become vulnerable to interference from other recent similar information or information encoded in a similar context (e.g., material presented earlier in the task). In general, interference resolution in working memory can be achieved conjointly through mechanisms of the 'central executive' which direct attention and control voluntary processing, and mechanisms involved in the automatic recruitment of attention (i.e., the attentional orienting response) and its habituation (Cowan, 1999). The mechanisms of control that modulate the focus of attention then function as 'an attenuating filter' such that, although both unattended and attended stimuli activate some elements of memory, activation is enhanced for attended stimuli or stimuli that recruits attention (Cowan, 1999). In summary, stimuli can enter the focus of attention through effortful attentional control exerted by the central executive or through an *orienting response* that can be elicited by features of stimuli including relative novelty or significance (Cowan, 1999). Voluntary processes can then be assumed to allow for the selection of relevant information and the potential removal of irrelevant contents. Furthermore, automatic recruitment of attention can also potentially facilitate processing of new or significant stimuli through the orienting response and filter out old/unchanged stimuli through habituation.

Furthermore, investigations into the sources of interference in working memory, Cowan et al. (2005) suggested that interference occurs when information to be retrieved is outside of the focus of attention (i.e., long-term memory), and information that needs to be retrieved from long-term memory becomes vulnerable to interference (i.e., proactive interference) from other recent similar information or information encoded in a similar context (e.g., material presented earlier in the task). The authors studied the effects of proactive interference (PI) on working memory capacity and found that these effects (i.e., lower accuracy and longer reaction times) occur mostly when capacity in the focus of attention has been significantly exceeded. Specifically, the authors gave participants lists of words (either 3, 4, 6, or 8 words) from a single semantic category, with words presented either concurrently or sequentially; after all the words were presented, a probe word (i.e., target/non-target) from the same semantic category appeared on the screen and participants were instructed to indicate whether or not the word was in the list. Proactive interference was manipulated within each block of experimental trials such that the first four trials included words from four different categories (low-PI condition), followed by four trials that included words from one single different category, and the last four trials included words from the same category as the previous four trials (high-PI condition). The results showed that accuracy dropped at higher set sizes (i.e., 6 and 8) of the high PI compared to the low PI condition for non-target trials (i.e., false positives). There was no effect of PI on target trials as accuracy dropped at similar rates for both high and low PI conditions with higher set sizes (i.e., 6 and 8). Similarly, reaction times were longer for the higher set sizes (i.e., 6 and 8) of the high PI compared to the low PI condition for non-target trials. Also, for the most part, there was no effect of PI on reaction time of target trials for most set sizes (i.e., 3, 4, 6) as latencies were longer with increasing set size for both low and high PI conditions. Only at the highest set size (i.e., 8) did the latency in reaction for target trials became higher for the high PI compared to the low PI condition. Thus, the authors concluded that proactive interference effects are mostly evident in list lengths surpassing the limits in capacity (i.e., four chunks) of the focus of attention. More broadly stated, in working memory, proactive interference can affect processing when the system becomes saturated, and therefore must resort to retrieve information from activated long-term memory, which then becomes susceptible to interference from representations that remain activated given that they were recently encountered.

Furthermore, with regard to dealing with irrelevant information within the Cowan's model, it has been proposed that the irrelevant contents would need to be removed from the focus of attention, or the 'no-longer relevant' contents would need to be deactivated from the long-term memory, such that capacity would not be maxed out and the no-longer relevant information in long-term memory would not interfere with processing of relevant information (Oberauer, 2001). Specifically, Oberauer (2001) investigated how irrelevant information is removed from working memory. A *modified Sternberg task* was used to look at familiarity and recollection. Participants were given two lists of words presented simultaneously, and these lists varied in set-sizes (i.e., either one or three words on each list). Then a cue was provided to indicate which of the two lists was relevant for the recognition task (for Experiment 2, though participants were also cued on list relevance for recognition task, they were instructed to keep both lists in memory). Then a probe was presented (three types: word from relevant list/'true positive'; word from irrelevant list/'intrusion'; new word/'true negative') at various cue-stimulus intervals (CSIs; six intervals ranging from 100ms to 5s), and participants were asked to say whether or not the probe was one of the words from the relevant list. The authors tested several hypotheses with regards to effects of CSI lengths and set sizes on capacity and ultimately aimed to discriminate between the focus of attention and the activation of information in long-term memory. They found that irrelevant set-size effects on reaction times disappeared with longer CSIs (Experiment 1). However, if participants were told that they had to remember both lists (i.e., relevant and irrelevant) for a subsequent recall test, the effect was still apparent with longer CSIs (Experiment 2; though it was attenuated). Thus, they concluded that removal of irrelevant contents from the focus of attention (or the region of direct access) is time dependent but successful at longer CSIs; however, contents are not completely removed if participants are told to remember the irrelevant contents as well. The authors noted that reducing the activation of no-longer relevant representations in long-term memory is a slow process (still significantly apparent at 5s post cue) compared to removal of irrelevant contents from the focus of attention (no longer apparent at 1s; if no instruction was given to remember the irrelevant list as well [Experiment 1]). The results discriminated between activation in long-term memory and the focus of attention with a time course difference and regarding their respective dynamics in deactivation/removal of irrelevant information.

Furthermore, the findings that both the 'irrelevant set-size effect' and the 'intrusion effect' depended on the size of the relevant list (i.e., irrelevant set-size effect significant only with largest relevant set-size; larger intrusion effects for largest relevant set-size) were interpreted to indicate that removal/deactivation of irrelevant material (inhibitory processes) and retention of relevant material in working memory both draw from the same cognitive resources. This is in line with the assumption by Cowan (1999) that inhibition likely uses the same resources as attentive processing in working memory such that within the functions of the central executive in the control of attentional resources, it is possible for attention to also be directed away (i.e., inhibition) from information in the service goal-directed behavior (Cowan, 1999; Engle et al., 1995). Furthermore, Oberauer (2001) alluded to the 'dual-process' models of recognition as being in accordance with the his proposed configuration of working memory. Such models propose that two distinct independent processes (i.e., familiarity and recollection) support recognition and work in parallel to inform response selection (Yonelinas, 2002). With regard to these models in working memory, Oberauer (2001) proposed that familiarity involves a signal-based match process between the probe with representations in long-term memory activated above baseline, and the strength of the signal is a function of similarity and level of activation. Contrary to familiarity, recollection was proposed to involve the retrieval of episodic information including the association between a probe and contextual information (i.e., spatial and temporal relations) in which it was previously encountered. Thus, according to the author, a general account for the current working memory model based on dual-process theories involves the assumption that familiarity and recollection processes work in parallel (though at different rates of time) to inform response selection, such that the outcomes of a familiarity signal strength and a recollection process accumulate until a response criterion is achieved based on convergent evidence. Thus, as suggested by Oberauer (2001), when the evidence provided by the familiarity signal and the recollection process is consistent with each other, such as when the probe elicits a strong familiarity signal and is remembered to have been in the relevant list (i.e., positive probes) or when the probe elicits a weak familiarity signal and is not remembered to have been in the relevant list (i.e., negative probes), then no conflict needs to be resolved so that a decision is achieved and a response selection is made relatively fast. However, when the familiarity signal is high, but the recollection process is not consistent with the signal (i.e., intrusion probes), a conflict arises and reaction times are slowed to allow recollection to override such signal (Oberauer, 2001).

With regard to resisting the effects of *proactive interference (PI)* in working memory, it is important to note that inhibitory control can be dissociated from other forms of inhibitory control that act upon perception (i.e., resistance to perceptual distractor interference) and response control (i.e., response conflict and pre-potent response inhibition) as measured in the attention and cognitive control literature (e.g., flanker task, spatial Stroop/color-word Stroop task, stop-signal task, go/no-go task, negative priming task) (Bissett, Nee, & Jonides, 2009). For example, Bissett et al. (2009), investigated the relationship between PI in working memory and pre-potent response inhibition (PRI). In an experiment (Experiment 1), the authors used a combined working memory and PRI paradigm (directed-forgetting task/stop-signal task). In this task, the initial study list was composed of four letters presented for two seconds. After a three second delay, only two letters from the initial study set were presented again, and participants were instructed to remove these letters from the original list while retaining the two remaining letters in memory. After another one second delay, a test cue (i.e.

‘positive’ = from to-be-remembered letters, ‘forget’ = from to-be-forgotten letters, or ‘control’ = new letter) was presented and participants were asked to respond whether or not it was from the remaining letters of the target set. PI was measured as the differences between forget and control trials. Furthermore, if a stop signal (a one second tone) was presented shortly after the test cue, participants were instructed to refrain from responding (PRI condition). Overall, the results showed robust PI effects, but no interaction was observed between these effects and PRI. Thus, this was interpreted to support the hypothesized assumption that resistance to PI and PRI represent two distinct and separate inhibitory processes. The authors proposed that their results support an interference-control taxonomy that distinguishes control over memories and control over prepotent responses. The authors concluded that resistance to PI is dissociable from other forms of interference control (e.g., response conflict and resistance from distraction) at the behavioral and neural level. The latter being, as reported by the authors, activations in the left inferior frontal gyrus as measured by fMRI, which activations have been shown to also overlap with other resistance to interference tasks.

In summary, according to the embedded-processes (and concentric) model(s) of working memory, interference effects of irrelevant information can generally arise from capacity limits in the focus of attention (or region of direct access) and from residual activation of irrelevant information in long-term memory (Oberauer, 2001, 2002). The former can be more quickly resolved by removal of the irrelevant contents, unless task demands require their retention (Oberauer, 2001). Interference effects of irrelevant information resulting from their residual activation in long-term memory (i.e., PI) can be attenuated but at a slower rate of processing and these effects are more evident when capacity limits are maximized or exceeded (Cowan et al., 2005; Oberauer, 2001). More relevant to the current study, PI can then be assumed to arise when activated representations in long-term memory generate a fast familiarity signal which conflicts with the evidence from a more reliable (though slower) process of recollection; however accurate performance can be achieved if recollection overrides the misleading familiarity signal, but this will result in longer response times (Oberauer, 2001). This interpretation is further consistent with the embedded-process model described by Cowan (1999) and the model's proposed assumptions with regard to the links between memory and attention. Specifically, it was suggested that previously encountered material continue to produce activations in long-term memory even after being removed from the focus of attention or awareness, which was attributed to involuntary processes involved in the 'habituation of orienting' response. Furthermore, it was also suggested that control of the focused of attention is conjointly driven by involuntary (i.e., automatic attentional orienting) and voluntary processes (i.e., central executive control), which seems highly consistent with the assumption by Oberauer (2001) that familiarity and recollection processes work in parallel in the service of task performance. Overall, working memory is an adaptive system that helps us maintain and manipulate information, and it does so in the face of interference. Furthermore, it allows us to deal with streams of continuously changing information in the service of a behavioral goal by allowing for the constant discarding of old information and accommodation of new input. However, such rapid and frequent updating of information in working memory also makes the system vulnerable to interference as it becomes increasingly more difficult to parse out between relevant and no-longer relevant information with such a rapidly changing environment.

Also, the process of updating information in working memory is crucial in sustaining and achieving higher cognitive and behavioral goals, but it also makes the system vulnerable to PI effects that are more difficult to overcome. Thus, looking at how the updating process deals with PI can potentially also lead to a better understanding of its underlying dynamics.

WM Updating and Proactive Interference Resolution

Processing of information in working memory is a fluid and adaptable operation often involving the continuous *updating* of its contents when individuals are presented with vast amounts of information that would otherwise exceed the limited capacity of the system. It becomes crucial for the system to allow for the selection and maintenance of relevant information and the discarding of irrelevant (or no-longer relevant) information in order to enable us to deal with rapidly changing environmental demands. The rapid and continuous updating of information is then inherently subject to interference, as representations of previously relevant but no-longer relevant information become a significant source of *proactive interference*. Despite the crucial role that working memory updating is believed to have on cognition and adaptive behavior, it remains poorly understood. In investigating how the updating process maintains a balance between flexibility and stability, two coexisting updating processes have been suggested including a local and a global updating process (Kessler & Meiran, 2008). These different updating processes are said to operate to both allow for the flexibility of integrating new information (local) and protecting and stabilizing the newly created representation (global) (Kessler & Meiran, 2008). Generally, the local process is suggested to help ‘unbind’ a current representation in order to allow for the updating of individual items, and the global process is suggested to then be involved in ‘binding’ the modified items together into a new ‘updated’ representation (Kessler & Meiran, 2008). However, more recently, the ‘local-global’ updating account has been challenged and a new model was proposed involving a process of switching between the operation modes involving maintenance and updating in support of the continuous updating of working memory representations, and this process is suggested to adequately account for processing time in updating tasks (Kessler & Oberauer, 2014). Specifically, Kessler and Oberauer (2014) argued that the finding by Kessler and Meiran (2008) interpreted as evidence for a global process (i.e., a slowing in reaction time when updating part of a set compared to updating the entire set) could be better accounted for by an ‘update-switch’ model. This model assumes that the number of switches from maintenance to update processing modes (maintenance being the default mode) can be calculated and account for the differences in reaction times between updating a subset and the entire set. Specifically, the authors tested such a model using the original data by Kessler and Meiran (2008), and found support for a model explaining the data in such a way that while updating of the entire set is achieved through one switch at the beginning of the list from maintenance to update mode, updating of a subset of the list is achieved through multiple switches between updating and not updating. Thus, the latter results in longer processing times. Overall, Kessler and Oberauer (2014) concluded through a series of experiments that the processing time in working memory updating can be explained by a general model including time costs of switching between updating and maintenance. Specifically, the authors concluded that the model involves an initial forward scanning, and then the overall updating time is a function of the number of the switches required between maintenance and updating modes in working memory. Furthermore, the authors suggested that while the stability and shielding of working memory contents is supported by a ‘maintenance mode’, the flexibility to modify representations is supported by an ‘updating mode’. However, Kessler and Oberauer (2014) made no reference to any specific mechanisms involved in the control of proactive interference in the updating process.

However, Ecker, Oberauer, and Lewandowsky (2014) suggested that interference resolution is achieved through the active removal of the no-longer relevant information, and they proposed that this removal process is the fundamental component of working memory updating. The authors further suggested that the logical components of working memory updating would involve a removal process and an encoding process, such that information that is no-longer relevant could be removed and new relevant information could be encoded. The authors used a task that was assumed to allow for the dissociation of the proposed components. Specifically, participants were presented with a row of three frames containing letters (encoding stage; 2s); followed by multiple (1 to 21) successive updating steps (updating stage; replacing either one to three letter), which were each preceded by a cue signaling the items to be updated (cue-target intervals [CTI] varied from 200 ms to 1500ms); and then participants were requested to recall the final set (recall stage). Presentation of the cue signaling the items to be updated was assumed to allow participants to remove the respective contents prior to the encoding of new items. Thus, they could separate the updating process form the encoding process and measure its efficiency under the directed forgetting instructions. Experiment 2 had a third CTI (3000ms) and no full-frame updates. Experiment 3 included only two-frame updates and the occasional repetition of an item across two successive updating steps within the specific frame. In general, the longer CTI periods yielded significant reductions in reaction times for the subsequent updating, which were interpreted as evidence for the active removal as the core process in working memory updating. Repetition of items also showed reduction in reaction time and these effects were not evident for the long CTI. These results were then interpreted to support the idea that with a long CTI, participants both search for, and remove the first item to be updated as opposed to just searching for, without removing the item. The authors further suggested that under directed forgetting instructions in working memory paradigms, the removal process completely eliminates proactive interference, which contrasted with studies that do not apply directed forgetting and find that proactive interference is long-lasting and highly resistant to decay, strongly support the existence of an active removal process.

Thus, according to the previous studies, the working memory updating process involves switching between two modes of operation in order to both protect the memory contents and allow for information to be updated as it moves through a stream of continuous information. Furthermore, in updating the contents of working memory, information can be completely removed through an active removal process that entirely eradicates proactive interference from the removed information. However, this ‘active removal process’ seems to be specific to updating under directed forgetting paradigms. Healey, Campbell, Hasher, and Ossher (2010), also examined two alternative theories about the way the cognitive system deals with interference and arrives at a resolution during memory retrieval. These alternative theories were (a) suppression of competing responses, and (b) facilitation of processes that directly enhance the accessibility of target information. They conducted a series of experiments using a *word-naming task*. Four conditions were created—namely, an *interference*, a *no-resolution*, a *no-conflict*, and a *baseline* condition. The authors compared reaction times for naming target or competing words under interference conditions with or without resolution against a no-conflict and a baseline condition. They found that the reaction times for reading the competing words under the interference condition in which participants had to use interference resolution processes was slower than the reaction times for reading the target or competing words under the other conditions. These results were interpreted as evidence for the use of suppression of the competing words during interference resolution, which makes the words less accessible during the subsequent naming task. Furthermore, in the 'no-conflict' condition, a priming effect was observed, which was not present in the conflict resolution condition. According to the authors, this gives further support to the proposal that in resolving interference, the participant uses suppression and this eliminates any priming effect by bringing the competing word to the same level as new words during the naming task. Finally, in a second experiment, the authors ruled out the possibility that the slower reaction times for the competitor words were due to the forming of an association between target and competitor words. Such association would slow down reaction times during retrieval by having to break the association in order to name the competitor only. Furthermore, in this second experiment, the authors also found no evidence for the possibility that interference resolution involves both suppression of competitors and facilitation of targets, since there was no evidence of such facilitation. Finally, the authors concluded that these results provide direct evidence for the use of inhibitory mechanisms in interference resolution. These results appear to be broadly in accordance with Ecker et al. (2014) in that inhibitory processes are important in interference resolution. However, the Healey et al. (2010) mentioned that suppression and facilitation of information are both cognitive control strategies that could be task dependent and may also be subject to individual factors. Thus, these strategies represent some of the mechanisms by which the cognitive control system works to aid recognition in working memory.

Furthermore, more relevant to the current study is a discussion of an investigation by Szmalec et al. (2010) on the nature of proactive interference resolution. This investigation employed an *n*-back paradigm, which was adopted for the current study. The authors used the *n*-back paradigm as a measure of working memory updating. Specifically, participants were presented with a continuous stream of items (i.e., letters or dots in a grid) presented one at a time (sequentially), and they were required to decide whether or not each item matched the item presented *n* positions before. Interference was systematically introduced in this procedure by the use of *lure trials* in which the probe did not match the item in the *n*-back position (i.e., mismatch), but it matched an item on the current string of items in close proximity positions to the *n*-back item. Interference was then measured as the difference in performance between *new-mismatch trials* and *lure-mismatch trials*, and responses to the latter were slower and less accurate. In this paradigm, then it was assumed that *n* items would need to be remembered in serial order. With regard to updating, every time a new item appeared on the screen, the set of *n* items needed to be updated in a way that the oldest item was discarded (i.e., unbound) from the string, the current item was then assigned (bound) to the most recent position in the string, and the items in between were also reassigned to their respective positions on the string (i.e., *serial-order position*). Thus, in this paradigm, interference could arise from items in the string that are considered *to-be-remembered* items, and items that are *no-longer relevant* and should have been discarded. The authors hypothesized that interference reflects a competition between a familiarity assessment process (matching of the item's identity or features to the degree of activation of a representation in long-term memory) and a recollection process (analytic search of the item and its context in the region of direct access). Thus, proactive interference was assumed to arise from conflict between these two processes (or sources of information) when their respective outcomes did not match. The authors suggested that the resolution of interference must involve the prioritization of the recollection process over that of the assessment of familiarity of a stimulus. However, as suggested by the authors, the updating process itself may inhibit the recollection process from taking over the familiarity signal by preventing the strong binding of contents in working memory in order maintain the flexibility to replace them. Lastly, according to the authors, the dealing with, and resolution of interference in the *n*-back task with lures involves mechanisms of top-down cognitive control within working memory. In summary, this study showed that resolving interference in an *n*-back updating paradigm with distractor trials, requires a particular combination of cognitive control processes including the effortful retrieval of episodic information such as item identity and sequential order. More broadly stated, proactive interference is created by competition of a familiarity-based signal and a recollection process when these processes produce conflicting information (e.g., lure trials), and the resolution of proactive interference can be mediated by the prioritization of a recollection process over a familiarity signal.

Similarly, in an important review of the literature by J. Jonides and Nee (2006), it was suggested that in protecting the contents of working memory against proactive interference, conflict between competing representations must be resolved through the process of *interference resolution*. Specifically, the authors explained that a familiarity signal of an old-target item that is currently presented as a non-target item conflicts with the recognition decision. This effect has been shown to be robust in the *recent-probes paradigm*, and according to the authors, it correlates with the subjective experience of the *dysexecutive syndrome*. The authors noted that the interference effect (difference between recent and non-recent mismatches) in this paradigm has been more consistently associated with activations in the left inferior frontal gyrus (left-IFG; Broadmann's area 45) among other regions (e.g., intraparietal sulcus, precuneus, right lateral prefrontal cortex, frontopolar cortex), which they interpreted to indicate its key involvement in interference resolution. They further supported this interpretation by reviewing data on lesion studies of two patients with damage to this area and showed significant susceptibility to proactive interference. The authors also mentioned that other studies have shown significant susceptibility to proactive interference in frontal patients. Furthermore, as reviewed by the authors, comparisons between young and old adults' performance on the recent-probes paradigm has revealed that the older adults have more difficulty resolving interference and show reduced activation in the left-IFG. However, the recent-probes paradigm does not involve an updating process as the *n*-back task does. J. Jonides and Nee (2006) also reviewed studies on proactive interference employing an *n*-back paradigm with *lure trials*. These studies, similar to Szmalec et al. (2010), introduced interference by placing lures matching items in neighboring temporal positions to the *n*-back item in non-match trials, thus as with the recent-probes paradigm, item familiarity increased the tendency to identify the trial as a match (J. Jonides & Nee, 2006). In general, as reported by the authors, the *n*-back with lure trials paradigm also produced activations in the left-IFG. Thus, the *n*-back task can be said to measure proactive interference when mismatch lure trials are included and compared to mismatch trials that do not have lures. Other, updating paradigms, including the *n*-back with no lure trials, are therefore assumed to not include significant proactive interference when performed by healthy individuals, thus proactive interference resolution is best measured in paradigms involving systematic manipulation of interference effects. Furthermore, J. Jonides and Nee (2006) noted that the interference trials involve a conflict between a high familiarity signal from previously seen items and a lack of contextual information indicating that these items provide a current match to the target item. The authors also suggested that conflict in proactive interference is different and independent from processes involved in conflict due to response-selection itself, and that while the former uniquely recruits the left-IFG, the latter recruits the anterior cingulate in response to conflict. Thus, the authors proposed that the best account for interference resolution mechanisms involves a competition between internal representations, and that the left-IFG is involved in the selection between these representations in accordance to task goals. This account is further consistent with the working memory account by Cowan (1999), which would suggest that an attentional orienting response allows for information in long-term memory (features without context) to enter the focus of attention when features of the contents in the focus physically match those in long-term memory. Finally, J. Jonides and Nee (2006) proposed an 'interference-resolution' network including the intraparietal sulcus, frontopolar cortex, and middle frontal gyrus, along with the left-IFG. Generally, these additional areas are assumed to be differentially involved in the modulation of attention, monitoring, and response-selection, respectively; and the left-IFG is assumed to be involved in the retrieval of contextual information to help counteract the increased familiarity signal when these are in conflict. Thus, proactive interference can be said to represent a conflict between a familiarity signal and recollection processes when these provide incongruous information.

WM Processes and the N-Back Task

The *n*-back task was first described by Kirchner (1958) in order to measure *short-term memory* for rapidly and continuously changing information in young and older adults. Typically, this task involves continuous sequences of stimuli presented one at a time, and participants are instructed to decide whether or not the current stimulus matches the stimulus presented *n* stimuli back in the sequence. Although varying *n* can be thought of as a way to increase load on working memory, some variations may not constitute purely a change in load and it may actually change the cognitive processes involved in performing the task (Szmalec et al., 2010). For example, an $n = 0$ does not involve the same sub-processes as an $n = 1$, given that the former only involves matching the same stimulus throughout the task without changing the target stimulus. In other words, if the target stimulus were a circle, the task would be to decide whether or not every stimulus in the sequence is a circle. In that task, then it is only necessary to remember that the target stimulus is a circle since the target does not change. In contrast to $n = 0$, in $n = 1$ the current stimulus becomes the stimulus to-be-matched and the task becomes one of searching for an immediate repetition. Once n is greater than one, the task changes in that it not only involves the passive maintenance of information, but it also engages the continuous updating of its contents. Similarly, Chen, Mitra, and Schlaghecken (2008) suggested that while the 0-back condition only involves maintenance of the target but not manipulation, the 1-back condition involves both of these processes with manipulation further requiring a simple replacement operation. Furthermore, the authors suggested that the 2-back condition not only involves the maintenance and manipulation of two items, but it also involves a more complex updating process that includes a shift operation along with a replacement operation. The shifting operation, according to the authors, refers to the process of moving the 1-back position to the 2-back position, as well as moving the current item to the 1-back position (order information). Thus, they suggested that while maintenance requirements vary with n, manipulation processes distinguish the 0-back from other n-back conditions. Furthermore, they also suggested that the updating process should differentiate the 2-back condition from both the 0-back and 1-back conditions. This differentiation refers to the 2-back condition having a primarily frontal locus, and the 1-back condition having a more posterior locus when looking at event-related potentials (ERPs). Thus, in order to study the effects of proactive interference within working memory updating, the current study employed a 2-back task with lure trials.

WM and Emotional Content

The current investigation, adopts the view of emotion as reflecting a motivational system as described by Bradley, Codispoti, Cuthbert, et al. (2001). Broadly, their *motivational model* characterizes emotion in terms of two basic parameters; namely, affective *valence* and *arousal*. Specifically, in this view, the evaluation of evocative pictorial stimuli is conceptualized along a pleasant-unpleasant (pleasure/valence) and a calm-aroused (intensity/arousal) dimensional space that is assumed to reflect motivational activation. Accordingly, valence and arousal are respectively associated with the motivational systems (appetitive and defensive) and their intensity of activation, which function to mobilize action and attention (Bradley, Codispoti, Cuthbert, et al., 2001). Furthermore, it is well stablished that emotion facilitates perception and attentional processing and that the amygdala plays a significant role (for review see (Phelps, 2006). Hence, emotion and cognition appear to be interrelated from early perception to action.

Working memory is crucial for our day-to-day lives since it helps us to keep necessary information in mind in order to complete our daily tasks. It is where we put information that must be kept for fast or immediate access and manipulation. Also, control processes in working memory allow us to make choices in a world rich in stimuli and in the midst of external and internal distractors. Although there is a vast amount of research on working memory, there seems to be significantly less research looking into the role of emotional content in working memory. The study of the effects of emotional content on working memory is crucial because as humans we have a tendency to attach meaning to all kinds of stimuli around us, so that even what would be considered a neutral stimulus could be given affective value (Phelps, 2006). This process of attaching affective value to stimuli around us can be very beneficial to us, since as it has been long established that we have an attentional bias toward and remember emotional information better than its neutral counterpart in long-term memory paradigms (Buchanan & Adolphs, 2002; Hamann, 2001). In fact, it may be that we have emotions in order (or because it was adaptive) to prioritize attention to certain stimuli (e.g., things that are dangerous, things that help us survive, etc.). The importance of considering emotional processing within working memory is such that Baddeley has integrated the discussion of emotional processing into the multiple component model of working memory (Baddeley, Banse, Huang, & Page, 2012). In order to adapt his model to account for the flow of emotional information through the working memory system, Baddeley et al. (2012) added a fifth component, namely, the *hedonic detector*. He described this component as a system for the evaluation of valence, which compares and weights the hedonic evidence to aid response choice. Baddeley et al. (2012) further characterized this system as having sensitivity to both positive and negative valences, having access to focusing and scanning processes, having the ability to average information, and having access to storage for outcomes, which can then be compared. This added component seems useful when the emotional information is relevant to the task at hand; however hedonic processing may be detrimental when the emotional information is irrelevant. The added processing may slow and interrupt the processing of the 'relevant' information. Cowan, to my knowledge, has not directly addressed the effects of emotional content of stimuli on working memory, but he has alluded to the inherent significance of certain stimuli as described in the 'attention' literature (Cowan, 1999). Specifically, the embedded-process model postulates that control and regulation of the focus of attention in working memory is not only supported by the executive control system (i.e. voluntary orienting of attention) but also by the attentional orienting system (i.e., involuntary attentional orienting response and habituation of this response). Furthermore, these two systems work conjointly such that attention is optimal when the systems work together. Hence, the allocation of attention can be facilitated toward a target stimulus by its inherent significance (e.g., relevance, physical properties, and affective value). An attentional bias toward the affective significance of information appears to have an inherent saliency factor, such that emotional content can enter consciousness automatically by capturing attentional resources and resulting in enhanced encoding (Anderson, 2005; Anderson & Phelps, 2001). Specifically, the valence of a stimulus seems to be processed automatically, and the arousal level of the stimulus mediates the relatively automatic access to consciousness leading to enhanced perceptual encoding (Anderson, 2005). Thus, affective automaticity seems to parallel the cognitive automaticity of the attentional orienting response described by Cowan (1999). In general, emotional content has the potential to facilitate attention and enhance perceptual encoding, which could further enhance memory by increasing encoding distinctiveness (Ochsner, 2000) and providing relevant contextual detail (Kensiger & Corkin, 2003). Therefore, it is plausible that emotional content could aid in the control of interference, potentially through enhanced encoding of contextual bindings and facilitation of access through attentional orienting mechanisms (Cowan, 1999; Levens & Phelps, 2008, 2010). However, given that working memory is limited in capacity and requires the inhibition of irrelevant information, an attentional bias toward emotional information may also be detrimental when such information is not relevant to the cognitive task at hand. According to the embedded-process model by Cowan (1999), the executive control system and the attentional orienting system may come into conflict when the physical properties of stimuli detract attention away from the relevant target. Thus, emotional content could either help or hinder performance depending on whether it is a target stimulus (or property of the stimulus) or not.

In general, given the complexity of the working memory construct and its different components and mechanisms (e.g., maintenance, manipulation, and updating processes), it is difficult to predict the outcomes of processing affective information through the system. Not surprisingly, paradigms focusing on different aspects of working memory likely yield varying results. Investigations on the effects of emotional content on working memory performance have generally shown inconsistent results when using paradigms focusing on maintenance and capacity components. For example, an investigation by Fairfield, Mammarella, Domenico, and Palumbo (2015) used a *running working memory task* with neutral and affective (negative and positive) words, and they found that affective content showed hindering effects on performance (i.e., accuracy). These results appear to indicate that emotional information adds to the working memory load with detrimental effects on capacity. Conversely, a study by Lindstrom and Bohlin (2011) used a modified 2-back dual (go/no-go) task with neutral and high arousal emotional (negative and positive) pictures, and they found that emotional content facilitated performance. Thus, the latter results appear to suggest that emotional content can have facilitating effects in working memory components related to executive control. Furthermore, Kensiger and Corkin (2003) investigated the effects of emotional content on performance using several different working memory tasks. Emotional content had no effect on accuracy on a working memory task requiring updating and monitoring of visual images (*self-ordered pointing task*) or a task involving the maintenance and manipulation of words (*backward and alphabetical word span*). The *pointing task* involved presenting a grid comprised of 15 pictures (five columns by three rows) for 15 times (pictures presented in random order within the grid each time), and participants were required to point to a different picture each time. The grids were comprised of neutral, negative, or positive pictures of animals or people resulting in six different grids. The *word span tasks* involved repeating series of words in the backward order (backward word span condition) or in alphabetical order (alphabetical order word span condition). The series of words were comprised of either all emotional or all neutral words (Experiment 2), or they were comprised of emotional and neutral words intermixed together (Experiment 3). Thus, the authors suggested that emotional content might not have a robust effect on accuracy indexes of tasks involving monitoring and updating or maintenance and manipulation. Then in two last experiments, Kensiger and Corkin (2003) employed an *n*-back task with faces and words that were either emotional or neutral. They used blocked (Experiment 4) and intermixed trials (Experiment 5), and they measured both accuracy and reaction time. The two versions of the task differed also in that in the latter task, participants made motor responses to both indicate a match and non-match (rather than just responding to matches), both speed and accuracy were emphasized (rather than just emphasizing accuracy), and performance was examined for the 2-back condition only (as opposed to the former experiment in which data involved performances in trials from different *n*-back conditions involving an increasing *n*).

Again, the authors found no effects of emotional content on accuracy across these two experiments. However, the latter task did yield an effect of emotional content on reaction time. This effect was specific to the face stimuli (there were no effects on the word version of the task), such that emotional faces slowed down participant's responses compared to neutral faces. Interestingly, in looking at the valance of the stimuli that preceded target stimuli, the authors found that performance was slowest for trials were an emotional face was preceded by another emotional face and fastest when a neutral face was preceded by another neutral face. Finally, all these tasks were followed by long-delay free recall tests, which showed emotional content enhanced memory performance across all these tests. Thus, the authors suggested that the effects of emotional content on working memory are variable and range from no effect to hindering of performance. According to the authors, the latter effect can be the result of inhibitory processes (e.g., inhibiting the emotional orienting response) that must take place when processing emotional content, in order to be able to stay on task. While these extra inhibitory processes may actually be beneficial for long-term encoding and retrieval, they likely hinder processing in working memory. In that study, though the *n*-back is an updating task, the reaction time to identify the target can be said to be a measure of processing efficiency as a function of maintenance and load characteristics since it does not involve lure trials to measure interference in working memory. Thus, the reaction times in such task may rather represent the fact that emotional faces are not only encoded in more detail than neutral faces, but the match process may also involve the recollection of more information. Thus, while the trials involving neutral faces may be performed on the basis of a fast familiarity matching likely without the recollection of details, the recollection of details for the emotional faces may take place more automatically but it may slow down performance. In that case, however, both strategies may have led to equal levels of accuracy indicating that a familiarity matching may be enough to accurately perform such task. Similarly, Grimm, Weigand, Kazzer, Jacobs, and Bajbouj (2012) investigated the effects of emotional content on working memory performance using a 2-back task with blocks of emotional or neutral words. Participants were instructed to respond only when a word was presented that matched the word two trials back. Accuracy (percent) represented correct responses to targets and non-targets (i.e., correct absence of response), and reaction times represented correct responses to targets. Similar to Kensiger and Corkin (2003), results showed no significant effect of emotional content on accuracy, and also no significant differences between emotional and neutral words on reaction time. However, a trend toward faster reaction times for positive compared to negative words was observed, and participant's ratings showed that they perceived the positive words as significantly more arousing than negative words. This would suggest that in this task emotional arousal modulated processing time such that higher arousal facilitated processing. Though this seems to contradict the results by Kensiger and Corkin (2003), it is important to note that the stimulus materials that yielded a reaction time difference in that study were negative and neutral faces rather than words. In general, the effects of emotional content on working memory updating seem to be inconsistent at best when the focus is on the maintenance and capacity characteristics.

In a study by Levens and Phelps (2008), the authors examined the effects of emotion on executive processes involved in interference resolution within working memory. The authors used a *recency probes paradigm*, which creates proactive interference. The authors proposed that in this paradigm, proactive interference arises from a conflict between source recognition and familiarity within working memory. The task involved the presentation of three target items (words or pictures) for study. After a brief delay, a probe was presented, and the participants had to decide if the probe matched any of the target items. Interference was believed to occur when the probe did not match any of the targets in a set, but it matched an item from a previous target set presented in one of the preceding two trials. Participants made responses to both matches and non-matches. There were four types of trials reflecting the combination of match and non-match trials for non-recent or recent (interfering) probes. Furthermore, two valence conditions (neutral and emotion) were distinguished by the type of material used in the trials. While the neutral condition included only neutral stimuli, the emotion condition included both neutral and emotional stimuli. The emotion condition was further subdivided according to the type of probe (neutral or emotional), such that an emotion probe condition and an emotion distractor condition were formed. Both of these conditions involved target sets that included both neutral and emotional words, but the probes were emotional or neutral for the emotion and distractor conditions, respectively. The reasoning being that using an emotional probe would represent a situation where emotional content is task-relevant, while using a neutral probe would represent a situation where emotional content is not task-relevant. Reaction times (as well as accuracy) for the different types of trials were compared in each condition. Proactive interference was defined as the difference between recent and non-recent non-match trials, which were compared across conditions. Across three experiments (Experiment 1 and 3 used words; Experiment 2 used pictures), the authors found that the reaction times differences between recent and non-recent trials were reduced for the emotion probe condition. Thus, the authors showed that task-relevant emotional stimuli (words or pictures) facilitated interference resolution in working memory. Furthermore, the authors found that arousal contributed to the facilitation effect on interference resolution in working memory regardless of valence. However, positive words also facilitated interference resolution regardless of arousal level in Experiment 3. In addition to the main results, negative pictures were found to impair reaction times for non-match trials (though the interference difference was reduced compared to neutral and distractor trials). The latter results further seem consistent with the findings by Kensiger and Corkin (2003). However, the authors suggested that this finding likely reflects the nature of the images (i.e., graphic and highly arousing) rather than working memory processing. Thus, the mere fact that a probe is a highly arousing negative image increases reaction times, but this is independent from any processing in working memory. Overall, the authors proposed two explanations for the facilitation of interference resolution in working memory. One hypothesis was that interference resolution is facilitated by emotional stimuli through the reduction of the strength of a familiarity-based signal. The second hypothesis was that the strength of the correct source response signal is increased due to an enhanced encoding of emotional stimuli. However, the authors noted that it is likely that both of these mechanisms may work together to reduce interference for emotional information. Interestingly, the authors mentioned that while past literature has failed to establish any consistent effects of emotion on working memory's maintenance process and capacity, emotion consistently affects working memory's processes involved in conflict resolution. Therefore, the various components of working memory seem to interact with emotion independently; such that emotional content only inconsistently shows an effect on maintenance and capacity components, but consistently affect the executive components involved in interference resolution in working memory. Lastly, though Levens and Phelps (2008) also aimed to study the effects of 'irrelevant' emotional content on interference resolution within their working memory updating paradigm through inclusion of an 'emotional distractor' condition, the results did not clearly show whether this manipulation had a consistent effect on performance other than not showing the same facilitation effect as the 'emotional probe' condition. In principle, the two conditions only differed in that the probe was either emotional or neutral, but the target set contained both emotional and neutral items. Thus, it could be argued that the nature of 'distraction' (emotional words embedded with neutral words in a set) was the same for both conditions, and the emotion is still task-relevant in that it provides relevant context to the target set items. Thus, this condition was like another neutral counterpart to the emotion condition, rather than a 'distractor' condition.

In general, it seems that tasks of working memory updating with no specific induction of interference are not sensitive to the effects of emotional content because they may not involve the type or degree of conflict that calls for resolution processes that are sensitive to the affective properties of stimuli. In fact, in the study by Levens and Phelps (2008) it was suggested that the effects of emotion were specific to the interference manipulation in this paradigm. Furthermore, reaction time but not accuracy data shows more sensitivity to the effects of emotional content of stimuli on working memory across studies. In a way, the systematic introduction of interference could parallel how the working memory system is affected by emotional content when it is 'impaired'. Thus, it provides a superficial opportunity to study the effects of emotional content on interference resolution within working memory when the system becomes vulnerable to interference due to impairing conditions (e.g., schizophrenia, mild cognitive impairment).

Becerril and Barch (2011) examined the effects of emotional content on working memory in individuals with schizophrenia and healthy control participants. The authors suggested that since individuals with schizophrenia present with a more vulnerable cognitive system, then emotion might have a greater influence on performance. Participants performed a 2-back task with blocks of neutral and emotional (negative or positive) faces, which were intermixed within each block as both targets and non-targets. Participants were asked to respond whether or not a current stimulus matched the one seen two trials before by pressing the corresponding button. Overall, control participants were more accurate and had a tendency to respond faster than individuals with schizophrenia. Both groups showed a tendency to be more accurate for emotional compared to neutral stimuli in negative blocks, and to be less accurate for emotional compared to neutral stimuli on positive blocks. However, within-group contrasts showed that while the former difference was only significant for the individuals with schizophrenia alone, the latter difference was only significant for control individuals alone. Likewise, both groups showed a tendency to be faster for emotional compared to neutral stimuli in negative blocks, and slower for emotional compared to neutral stimuli on positive blocks. Again, within-group contrasts showed that the former difference was only significant for the individuals with schizophrenia alone, but the latter difference was not significant for either group alone. Thus, this study showed facilitation of performance by negative content in both accuracy and reaction time, but this effect seemed to be somewhat stronger for individuals with schizophrenia. Furthermore, similar to previous studies using the *n*-back task without interfering trials, when examining the performance of control participants alone, no significant effects of negative emotional content compared to neutral content were observed. Hence, it seems that when the cognitive system is more vulnerable, the effects of emotional content on performance become apparent. Perhaps the introduction of interference trials in working memory updating tasks simulates such vulnerability. Furthermore, Döhnel et al. (2008) investigated the effects of emotional content on working memory in patients with amnestic mild cognitive impairment (aMCI) using an *n*-back paradigm. This study used neutral and emotional (positive and negative) picture stimuli from the IAPS randomly intermixed in a 2-back task, and participants were instructed to respond to both targets and non-targets accordingly. Stimuli were presented for 2700 ms with an inter-stimulus interval varying between 1000 ms and 5000 ms. This study also focused on target processing to measure performance. Results showed overall higher accuracy for negative targets compared to neutral and positive targets. However, while within group comparisons showed no significant effect of emotion on accuracy for the control group, the patient group showed higher accuracy for negative targets compared to neutral and positive targets. There were no significant effects of emotion on reaction time data. Group comparisons showed that while patients performed slightly worse for neutral and positive targets, their performance for negative targets was comparable to controls. Thus, it appears that negative emotional material facilitated working memory performance for patients, such that it compensated for their reduced working memory performance when compared to healthy aged controls. The facilitation by negative stimuli was suggested to arise from the arousal properties of this material. It is possible that the performance by the patient populations represented facilitation effects of highly arousing negative content on working memory in the context of a dysexecutive syndrome, which could be broadly similar to the introduction of proactive interference through the inclusion of lure trials in working memory tasks (J. Jonides & Nee, 2006).

With regard to the hypothesis that task-irrelevant emotional content would likely impair conflict resolution in working memory, the literature is even less clear. The hindering effects of emotion on working memory, as the facilitation effects, seem to be highly dependent on the specific task and stimulus characteristics. However, it has been suggested that emotional processing may inhibit or interrupt task-relevant cognitive processes (Yamasaki, LaBar, & McCarthy, 2002). In general, resolving emotional interference is proposed to require cognitive control mechanisms to prioritize processing for task-relevant information and to simultaneously inhibit processing of task-irrelevant emotional information which may or may not affect performance (Erk, Kleczar, & Walter, 2007). In a study by Melcher, Born, and Gruber (2011), the authors investigated the effects of negative affect on interference processing. They used pictures from the IAPS pictures to modulate affective states in a procedure combining a *Stroop* and an *oddball task*. In general, participants had to respond by pressing a button to the print color (blue and yellow print) of word stimuli (‘blue’ and ‘yellow’). Thus, trials in which the print did not match the word (e.g., the word blue/yellow printed in yellow/blue color) created *Stroop interference*. The *oddball task* embedded in this procedure consisted in the occasional presentation of different words with no semantic relation to color. Prior to each trial, a picture depicting negative or neutral content was presented to systematically manipulate the participant's affective state. The results showed that negative affective priming increased error rates for interference trials, but it had either no effect or an inverse effect on non-interference trials (affect induction had no significant effect on oddball interference). Also, reaction times were slower for interference trials in the negative affect condition compared to the neutral affect condition. The authors interpreted these results as evidence of impaired interference processing by emotional processing. Thus, the results of this study support the hypothesis that emotional content could hinder interference resolution when it is not task-relevant. The previously discussed investigation by Melcher et al. (2011) used emotional pictures to elicit an emotional state that affected performance on a task that required responding to a target stimulus while filtering out irrelevant perceptual information (Stroop task). This task then involved interference trials that required resistance to perceptual distractors (Bissett et al., 2009). More relevant to the current investigation, Erk et al. (2007) examined the effects of emotional context (task-irrelevant emotional content) on working memory using a *delayed-match-to-sample* task (modified Stenberg item recognition paradigm). In this task, trials were composed of six capital letters that appeared on a screen for 1500 ms, and either one or all ,the six letters appeared in white ink (when only one letter was white, the rest were gray). Participants were asked to remember the white letters only. During a delay (4000 ms) period, participants saw either a blank screen or a picture (i.e., neutral, positive, or negative picture from the IAPS). Then, after the delay, a probe consisting of one lower case letter was presented on the screen for 1500 ms, and participants were instructed to indicate whether it was one of the letters in the target set. The results showed that when participants had to remember only one letter (low load condition), their responses to the probe were slower after seeing an emotional picture (negative or positive) compared to the no picture condition. Emotional context did not have an effect on reaction time data for the high load condition (remembering six letters). Contrary to response times, emotional context was shown to affect performance for the high load condition but not the low load condition, such that accuracy was higher for the emotional (and no picture) conditions compared to the neutral condition. Thus, under low cognitive load, emotional context slowed performance, which may indicate difficulty disengaging from the preceding emotional picture. However, under high cognitive load, it appears that participants were able to resist or inhibit interference from the emotional pictures and their performance was equivalent to the no interference condition. The finding that performance was less accurate on the neutral condition compared to the no interference condition, may further indicated that resistance to interference from emotional context was facilitated compared to neutral context. The authors suggested that interference by emotional context is lessened when the cognitive effort is higher. In a more recent study by Bergmann, Rijpkema, Fernández, and Kessels (2012), the authors found that highly arousing or negative stimuli impaired working memory performance when using pairs of items to be associated as stimuli. The authors used neutral and emotional pictures from the IAPS in a *delayed-matched-to-sample* task. They used pairs of pictures composed of one neutral and one emotional picture. Trials were composed of five picture pairs, each presented for 2000 ms and separated from each other by an inter-stimulus-interval (ISI) of 500 ms, and participants were asked to remember the pairs. Then, a probe set composed of five picture pairs presented consecutively followed each trial after a ten second delay, and participants were instructed to indicate whether each pair matched one of the five pairs they were asked to remember. Both speed and accuracy were emphasized. These probe pairs involved matches and non-matches, and the later were composed of rearranged pairings from the pictures presented in the target set. In general, the results showed that pairing a neutral picture to a high arousal emotional picture reduced recognition accuracy for the pair compared to pairs involving a neutral and a low-arousal emotional picture. Thus, these results support the idea that highly arousing emotional content attracts attention automatically, while peripheral information presented close in space and time (even when this information is task-relevant) is 'ignored' (they may be allotted less processing resources do to difficulty disengaging from highly arousing stimuli). The studies described above mainly examined the effects of emotional context on working memory maintenance and capacity (Erk et al., 2007) or binding (Bergmann et al., 2012). Therefore, the effects of irrelevant emotional content/context on interference resolution remain relatively unexplored.

Neural Correlates of the Interaction between WM and Emotional Content

Emotion has been said to modulate perceptual processing via the amygdala and its connectivity with sensory cortex (Phelps, 2006). Working memory performance has been associated with prefrontal and parietal cortex functioning (Döhnel et al., 2008; J. Jonides & Nee, 2006). Emotional content, when compared to neutral, has been found to exhibit differential involvement of regions in the prefrontal cortex in working memory tasks even in the absence of differences in performance (Grimm et al., 2012). While emotional content has been found to be related to increased activation in 'cognition-related' dorsolateral prefrontal cortex (DLPFC) regions, cognitive effort has been proposed to be related to higher deactivation in ‘emotion-related’ cortical midline regions (Grimm et al., 2012). Findings of increased activation in working memory related areas for emotional stimuli has been interpreted as to reflect compensatory mechanisms (e.g., higher cognitive effort involved in counteracting arousal-based interference) or inefficient use of mental effort (Becerril & Barch, 2011; Döhnel et al., 2008; Grimm et al., 2012). Alternatively, increased activity during negative content has also been interpreted to possibly reflect better active maintenance and enhanced encoding (Becerril & Barch, 2011). In either case, increased activation in cognitive-related areas (i.e., precuneus, hippocampus and middle frontal gyrus including the DLPFC) has been shown to be present in cognitively vulnerable individuals (Becerril & Barch, 2011; Döhnel et al., 2008). It is then possible that when highly arousing emotional content is detected by the system, this information is preferentially processed and recruits increased activation. Such increased activation in the absence of interference may prove inefficient, but it is easily counteracted and not reflected in performance by healthy individuals with relatively intact global cognitive systems. However, the preferential processing and enhanced activity can be beneficial in the presence of interference or cognitive vulnerability in cognitively healthy and disordered individuals respectively. In examining the neural correlates of the facilitation effects of emotional content on interference resolution in working memory, Levens and Phelps (2010) identified interference resolution related regions (i.e., differential bilateral IFG activation for interference and noninterference trials), regions related to processing of emotional information (i.e., left amygdala), and additional regions differentially involved in working memory interference resolution as a function of emotional content. Thus, the authors proposed an ‘emotional interference resolution network’ comprised by regions in the anterior insula, amygdala, and right orbitofrontal cortex (OFC) for negative content. Furthermore, Melcher et al. (2011) investigated the neural correlates of interference resolution when emotional content is not task-relevant and also showed that negative affect enhanced and recruited additional activation of the brain correlates (involving fronto-parietal brain regions) believed to support control mechanisms. These enhanced and additional activations were interpreted to underlie enhanced control efforts in attempts to compensate for the interference created by the negative affect manipulation. In order to further understand these results, the authors looked at the effects of emotional stimuli on sensory processing and attentional mechanism. According to the authors, their imaging data showed enhanced activation of sensory processing regions for emotional stimuli. The authors explained this increased activation as evidence that the neural system automatically uses attentional mechanisms to prioritize the processing of emotional over non-emotional information. The authors called this effect an amygdala-based ‘emotion-related attentional selection mechanism’, which they believed to differ from what they called a fronto-parietal-based ‘goal-directed attentional selection mechanism’. The latter was described as a mechanism that prioritizes the processing of information that is goal-directed and task-relevant and protects from distraction. Thus, the authors concluded that these different top-down attentional mechanisms (one for emotion-related attention and the other for goal-directed attention) could either work together in an additive fashion when directed toward an emotional target or interfere with each other when the emotional stimulus is not task-relevant.

CHAPTER THREE

THE PRESENT STUDY

The current investigation aims at examining the effects of emotional content on interference resolution in working memory using an updating paradigm (i.e., *n*-back task) with lure trials where the emotional stimuli are either task-relevant (Experiment 1) or task-irrelevant (Experiment 2). This paradigm allows for a more direct manipulation and examination of interference effects. Thus, the specific goals are to further examine the effects of emotional content on proactive interference and resolution in working memory. In general, it was hypothesized that while task-relevant emotional content would facilitate proactive interference resolution, task-irrelevant emotional content would show hindering effects. The *n*-back task with lure trials closely resembled that of Szmalec et al. (2010), but the current study differed in that pictorial stimuli from the IAPS was used to compare between a highly arousing emotional condition and a low-arousal neutral condition. The focus of the analyses was on behavioral performance (accuracy and reaction time) for the lure trials in order to examine the interference effects under the emotional and neutral conditions. This is different from previous studies that have tended to focus on analyses of correct match trials (i.e., does a current stimulus match what was previously viewed) when investigating the effects of emotion on working memory. As mentioned before, previous investigations on the effects of emotional content on working memory have been equivocal; however, such studies often used paradigms that focused on working memory maintenance and capacity components rather than executive control processes. It is assumed that control of interference is supported by the modulation of the allocation of attentional resources by both voluntary (i.e., executive control) and involuntary (i.e., automatic orienting response) mechanisms (Cowan, 1999); and whether emotional content impairs or facilitates performance on interference resolution, at least in part, likely mirrors the effects of emotion on attention. In general, emotion has been shown to impair attention when emotion represents an irrelevant dimension to task requirements, and to facilitate attention and recognition when emotion is relevant to the task (Anderson, 2005; Anderson & Phelps, 2001). Furthermore, it has been suggested that the effects of emotion on executive control components (i.e., interference resolution) in working memory are more consistently observed upon examination of performance efficiency (i.e., reaction times) during interference trials (Levens & Phelps, 2008). Thus, the current investigation also aims at replicating the facilitation effects of emotional content on interference resolution in working memory using a different interference resolution task, as it has been suggested that the effects may be task specific. As in the Levens and Phelps (2008) paradigm, the current task involves the constant 'updating' of contents in working memory (*n*-back task), and interference trials are included to create proactive interference from previous stimuli that are no-longer relevant and stimuli that are not-yet relevant. Overall, the current study investigated the effects of emotional content on interference resolution in working memory. A *2*-back working memory task with standardized emotional pictures from the IAPS (Lang et al., 2005) was used. Stimuli were composed of neutral and negative valence pictures. Specifically, a 2-back task was used with two types of lures (i.e., non-match trials in which the probe matches the item seen in either the 1-back position or the 3-back position) in order to compare the degree of interference caused by 'not-yet relevant' and 'no-longer relevant' memory representations. In general, while in Experiment 1 the emotional content was task-relevant and hypothesized to facilitate interference resolution, in Experiment 2 the emotional content was task-irrelevant and hypothesized to hinder interference resolution.

Experiment 1

The embedded-process model by Cowan (1999) postulates that control and regulation of the focus of attention in working memory is supported conjointly by the executive control system (i.e. voluntary orienting of attention) and the attentional orienting system (i.e., involuntary attentional orienting response and habituation of this response). Attention is then optimal when these two systems work together, such that the allocation of attention is facilitated toward a target stimulus by its inherent significance (e.g., relevance, physical properties). However, these processes may also come into conflict when the physical properties of stimuli attract attention away from the relevant target. With regard to emotional material, a stimulus could attract the focus of attention automatically because of its affective value, and either help or hinder performance depending on whether it is a target stimulus or not. However, emotional content has not consistently been shown to have an effect on working memory performance when using paradigms that focus on maintenance components (Kensiger & Corkin, 2003). Moreover, recent investigations have begun to look at the effects of emotional content on executive components such as the updating process of working memory; however, these also have not yielded reliable results, with either null findings (Grimm et al., 2012) or enhancing effects (Levens & Phelps, 2008, 2010). Levens and Phelps (2008) examined the effects of emotional content on a measure of working memory updating when proactive interference was systematically induced, and it was suggested that the effects of emotion were specific to the interference manipulation in this paradigm. Furthermore, in that study, the interference effect was only reliably observed for reaction times but not for accuracy data, suggesting that the former index of performance may be more sensitive to the effects of emotional content of stimuli on working memory. In general, it is possible that tasks of working memory updating with no specific induction of interference are not sensitive to the effects of emotional content. Such tasks may not involve the type or degree of conflict that calls for resolution processes that are sensitive to the affective properties of stimuli. The type of interference introduced in the current paradigm is further suggested to be similar to the type of conflict in individuals with dysexecutive syndrome (J. Jonides & Nee, 2006), and effects of emotional content on working memory updating have been more reliably captured in individuals with executive problems (Becerril & Barch, 2011; Döhnel et al., 2008; Hanseeuw, Seron, & Ivanoiu, 2012). The current experiment used a 2-back task with interference (*lure*) trials to measure proactive interference resolution in working memory updating (Szmalec et al., 2010). With regard to the embedded-process model, proactive interference in this task can be considered another situation where the physical properties of a stimulus (i.e., a probe in a non-matching trial that matches a non-target in a neighboring position to the *n* position in the *n*-back) attracts the focus of attention because of its significance as either matching the identity of a representation in memory of a previous relevant set (n+1/1-back item in a 2-back task) or a current set where the item in memory also needs to be remembered for future processing (n-1/3-back item in a 2-back task). Thus, interference resolution could be hypothesized to be mediated by voluntary control of attentional focus and habituation/inhibition of the orienting response. In further specifying more explicit processes involved in this model, retrieval dynamics in recognition memory as postulated by dual-process theories of working memory would predict that both familiarity and recollection processes underlie proactive interference resolution. Accordingly, when memory is probed (by a lure) in a recognition situation, like the current paradigm, a fast familiarity signal arises when the features (i.e., identity) of the probe activate representations of similar features in long-term memory or from shared features with the contents currently in the focus of attention (i.e., the region of direct access). At the same time, a parallel but slower process of recollection takes place to retrieve representations of the contents and their associated contextual information (e.g., serial order) in working memory, but these associations may be weak given the inherent nature of the updating process that requires rapid and constant binding and unbinding of information. Similarly, previous research with the current paradigm has successfully introduced proactive interference, which was suggested to arise from competition between a familiarity assessment and recollection processes, and that prioritizing recollection can aid in the control of interference (Szmalec et al., 2010). However, given that the current task is believed to lead to weak bindings given its demand for rapid updating of a large string of continuous information, it is assumed that performance must highly rely on familiarity matching, which leads to detrimental results in the face of interference (Szmalec et al., 2010). While the current experiment does not allow for the direct dissociation of these two processes, it allows for the examination of how emotional content interacts with interference resolution arising from information at different stages of accessibility; namely—interference from information in the region of direct access (i.e., n - 1) and information in activated long-term memory (i.e. *n* +1) (Oberauer, 2002; Szmalec et al., 2010). Therefore, these two types of lures are hypothesized to represent different degrees of familiarity, such that the items that are kept in the region of direct access produce greater familiarity compared to items that have been discarded and can only be indirectly retrieved from long-term memory. The goal of Experiment 1 was to examine the effects of emotional content of information that is task-relevant since it employed emotional (i.e., negative) pictures as the task stimuli to be operated on. Emotional content has been shown to facilitate attention processing (Anderson & Phelps, 2001) and provide relevant contextual detail (Kensinger & Corkin, 2003). Increased attention to, and processing of, emotional stimuli could then enhance memory for them by increasing encoding distinctiveness (Ochsner, 2000). It is assumed that introducing emotional contents could aid in the control of interference potentially through enhancement of encoding of contextual bindings and facilitation of access through attentional orienting mechanisms (Cowan, 1999; Levens & Phelps, 2008, 2010). Thus, the current experiment had two aims: (a) test the hypothesis that task-relevant emotional content (i.e., task materials included negative pictures) facilitates interference resolution in working memory updating; and (b) compare these effects in two different kinds of interfering memory representations introduced by not-yet relevant lures (i.e. this item is next for processing in the *n* position) and no-longer relevant lures (i.e. this item has been removed from the relevant serial string).

Experiment 1 Method

Participants

Participants were 59 (41 female) students (mean age = 21 years) volunteering for participation at Loma Linda University (12 graduate students) and La Sierra University (47 college students). Given the nature of the task and materials, participants were excluded if they reported any learning disabilities, neuropsychological dysfunction, clinical levels of depression, use of centrally active medications, visual impairments, or hand-motor impairments. The investigation was conducted under approval of the Loma Linda University's and La Sierra University's Institutional Review Board (IRB) for protection of human subjects. Participants provided informed consent prior to participation in accordance with the IRB guidelines.

Stimuli

Pictures from the International Affective Picture System (IAPS) developed by Lang et al. (1997) served as stimuli. A total of 320 pictures were used to represent emotional (160) and neutral (160) content based on normative ratings from the IAPS technical manual. Given that emotional arousal (i.e., high-arousal), regardless of its associated valence (negative or positive), is assumed to be the more significant factor in the facilitation of proactive interference resolution in working memory updating (Levens & Phelps, 2008), only negative pictures were chosen to represent the *emotion* variable in the current study. Exclusion of positive valence pictures in the current investigation was also based on the notion that including positive pictures with similar arousal levels as those found in their negative valence counterparts would include pictures portraying sexual content; which has been suggested to potentially introduce gender differences in that women may respond with "mixed motivation" (appetitive/defensive) to erotic stimuli (Bradley, Codispoti, Sabatinelli, & Lang, 2001). Attempts were made to match scene complexity and the presence of people between emotional and neutral pictures sets. Negative pictures included mutilated bodies, dead animals, car and plane accidents, guns, and animals that are commonly the source of phobias (snakes and insects). Neutral pictures included objects, animals, individuals and groups of individuals engaging in everyday activities. The *n*-back lists were constructed by drawing randomly from these sets. Participants were alerted during the informed consent process that they may find some of the negative valence materials to be disturbing, and a sample picture was shown to represent the most disturbing content. In the cases in which a participant found the images too upsetting, he or she was allowed to discontinue participation without any penalty or loss of benefits.

Design and Procedures

A 4 (trial type: match, mismatch, *n*+1 lure, and *n*-1 lure) X 2 (valence: negative and neutral) within-subjects design was employed. The procedures included performing a 2-back task that closely resembled those of Szmalec et al. (2010). In fact, the specific lists used were borrowed from Szmalec et al. (2010) to determine the order presentation of stimuli. For each valence condition, four different 2-back lists of the four trial types were used for a total of eight lists presented across two blocks separated by a short break. Lists were presented in an alternating manner in order to prevent habituation to a valence condition. The list that came first (negative or neutral) within a block was counterbalanced within participants (e.g., if in the first block a participant was shown a neutral list first, then a negative list was presented first in the second block) and such order was also counterbalanced across participants. The negative-valence lists included negative-high arousal pictures randomly drawn from the corresponding set. Likewise, the neutral-valence lists included neutral-low arousal pictures drawn from the corresponding set. Each list consisted of 47 pictures of which 15 were match trials (i.e., the current picture matches the picture presented 2 positions back) and 30 were mismatch trials (i.e., the current picture does not match the picture presented 2 positions back). From the 30 mismatch trials on each list, six were lure trials (i.e. the current picture matches the picture on either the n + 1 or n - 1 position). Three lures were in the n + 1 position and three lures were in the n - 1 position. See Figures 1 and 2 for procedure.

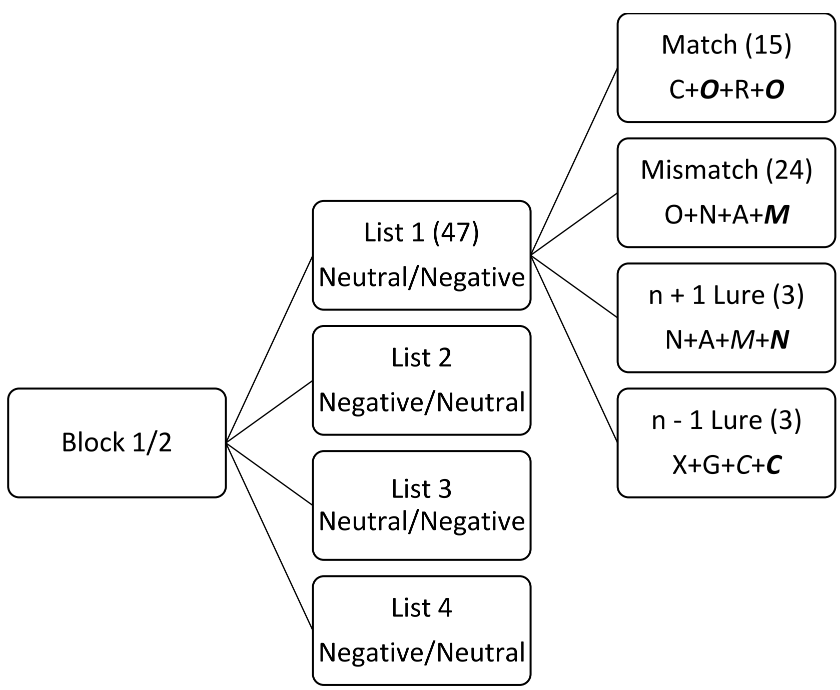

Figure 1. List construction diagram for Experiment 1. Two blocks comprised of four lists each. Each list included 47 trials which included 15 *match*, 24 *mismatch*, and 6 *lure* trials.

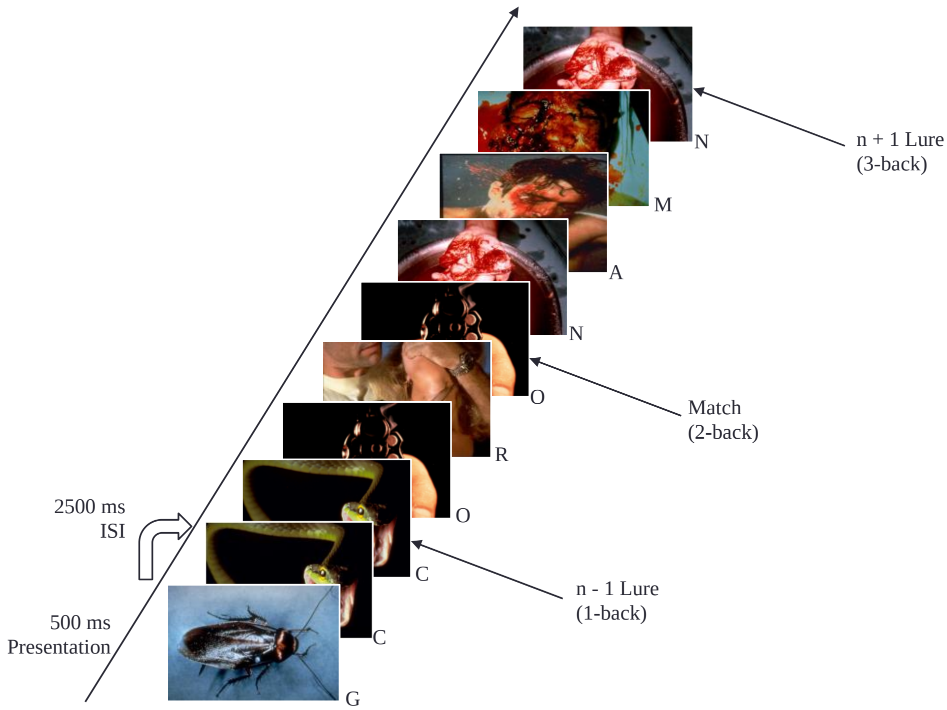

Figure 2. *2*-back task for Experiment 1. Each picture was presented for 500 ms with a 2 sec inter-stimulus-interval (ISI).

The experiment was programmed in MATLAB_R2016B and run on a computer with a 15-in. monitor. Participants were seated approximately 40 cm from the screen. Each image was presented individually on the center of the screen. Pictures remained on the screen for 500 ms, followed by an inter-stimulus interval (2,500 ms) during which a fixation cross stayed centered on the screen. Participants were instructed to indicate as fast and accurately as possible whether a presented item matched the one presented two positions back by pressing the number "1" or "2" key (i.e., match or mismatch respectively) on the computer key board using their preferred hand. Participants were not informed about the occurrence of lures. Participants were given a practice session of trials (one block of 20 trials) prior to starting the experimental condition, and each participant performed the practice task (with no lure trials) until achieving an accuracy level of at least 80%. Materials for the practice session included neutral pictures not included in the experimental picture set.

Experiment 1 Results

Given that Experiment 1 and Experiment 2 were conducted at the same time, most participants completed both experiments with some exceptions. (1) The first nine participants were only administered Experiment 1, and Experiment 2 was added after that point. (2) Of the subsequent 50 participants, 33 participants were administered Experiment 1 before Experiment 2, three of whom declined to continue their participation onto Experiment 2 either because of the nature of the negative pictures (two participants) or time constraints (one participant). (3) In order to examine potential order effects, 17 participants were administered Experiment 2 before Experiment 1; five of whom declined to continue their participation onto Experiment 1 because of the nature of the negative pictures.

The overall data was analyzed by means of a 4 (trial type: match, mismatch, *n* + 1lure, and *n* – 1 lure) X 2 (valence: negative and neutral) repeated measures MANOVA with reaction times (correct trials only) and accuracy as dependent measures. All comparisons between trial types were independent such that "mismatch" trials did not include any lure trials. The data was examined for missing values, outliers, and for the assumptions of multivariate analysis prior to running the main analyses. Missing values were replaced by the corresponding means for all cases, with no particular cells missing values on more than 3% of the cases. Cases found to be univariate outliers (*z*-score greater than 3.29) were replaced by the corresponding raw score of the next most extreme score in the particular distribution, with no more that 2% of cases being replaced in any particular cell. One case was identified through Mahalanobis distance as a multivariate outlier with $p < .001$, and it was deleted. After dealing with univariate and multivariate outliers and missing data, the assumptions of multivariate analysis were met.

First, the data was analyzed including all participants who completed Experiment 1 regardless of whether or not they also completed Experiment 2 (58 participants after removal of the multivariate outlier case). Table 1 shows mean accuracies as a function of the different trial types and emotional valence. Figure 3 shows mean reaction times, as function of the different trial types and emotional valence. There was a significant main effect of trial type, F (6, 342) = 34.01, $\eta_p^2 = .37$, $p < .001$. For the trial type effect, follow up contrasts revealed that mismatch trials were performed faster (F (1, 57) = 25.50, $\eta_p^2 = .31$, $p < .001$) and more accurately (F (1, 57) = 109.22, $\eta_p^2 = .66$, $p < .001$) than match trials. Also, while n + 1 lures produced lower accuracy than n – 1 lures (F (1, 57) = 120.58, $\eta_p^2 = .68$, $p < .001$), no significant difference in reaction times was observed between the two types of lures ($F = 3.64$, $p = .061$). No significant overall main effects of emotional valence were observed, $F = 1.16$, $p > .05$. Finally, there was a significant interaction of trial type by emotion, F (6, 342) = 3.06, $\eta_p^2 = .05$, $p < .01$. Follow up contrasts revealed that the pattern of performance on the n + 1 lures versus n – 1 lures comparison was different under the negative and neutral conditions for reaction times (F (1, 57) = 6.81, $\eta_p^2 = .11$, $p = .012$), but not accuracy ($F < 1$, $p > .05$).

Table 1. Mean accuracy and standard deviation for the different types of trials in the neutral and negative valence conditions of the *2*-back task, Experiment 1.

Valence	Match	Mismatch	*n* + 1 lure	*n* - 1 lure
Negative	.81 (.14)	.98 (.02)	.52 (.24)	.84 (.19)
Neutral	.82 (.13)	.99 (.02)	.50 (.24)	.80 (.20)

Note. Accuracy scores are percentages; standard deviations appear within parentheses.

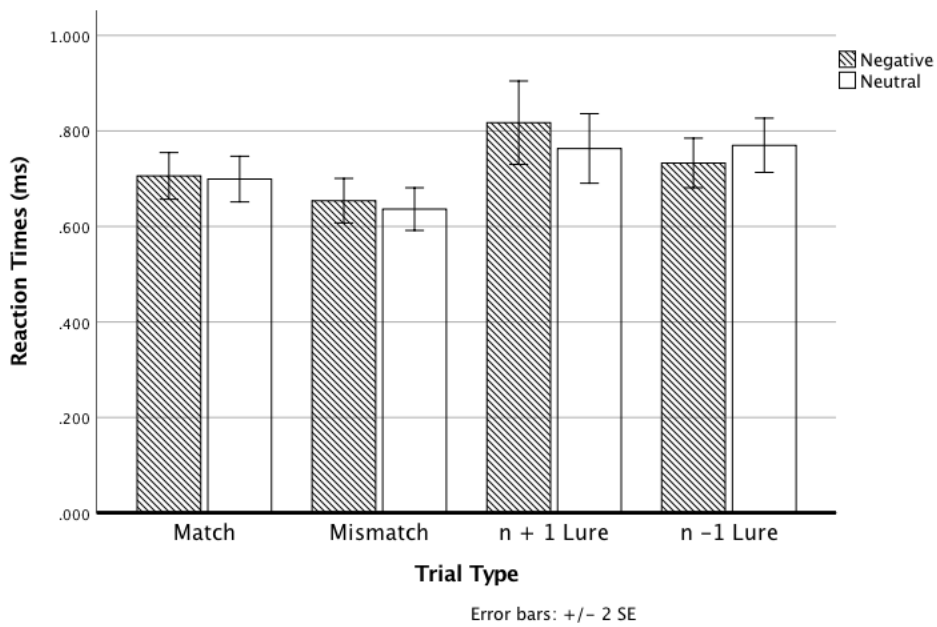

Figure 3. Mean reaction times for the different trial types in the negative and neutral valence conditions in Experiment 1. Vertical bars denote standard errors.

Planned comparisons of interference effects (mismatch trials versus each of the different lure trials) were analyzed by means of 2 (trial type: mismatch and *n* + 1lure or *n* – 1 lure) X 2 (valence: negative and neutral) repeated measures MANOVA with reaction times (correct trials only) and accuracy as dependent measures. Again, all comparisons between trial types were independent such that "mismatch" trials do not include any lure trials. The overall main effect test for the n + 1 interference effect (mismatch vs. n + 1 lures) was significant, F (2, 56) = 155.70, η_p^2 = .85, p < .001. Follow up contrasts revealed that the n + 1 interference effect was significant for both reaction time (F (1, 57) = 32.90, η_p^2 = .37, p < .001) and accuracy (F (1, 57) = 265.29, η_p^2 = .82, p < .001). The overall main effect of emotional valence was not significant, F = 2.47, p = .09. However, follow up contrasts revealed that when averaged across all trial types, reaction times were slower for the negative valence compared to neutral valence condition (F (1, 57) = 4.81, η_p^2 = .08, p = .031); but no significant difference was observed for accuracy (F < 0, p > .05). No significant interaction effects were observed for trial type by emotional valence, F < 0, p > .05. Thus, although the n + 1 interference effect appears to be similar under the two conditions, it seems to be more pronounced for the negative valence condition.

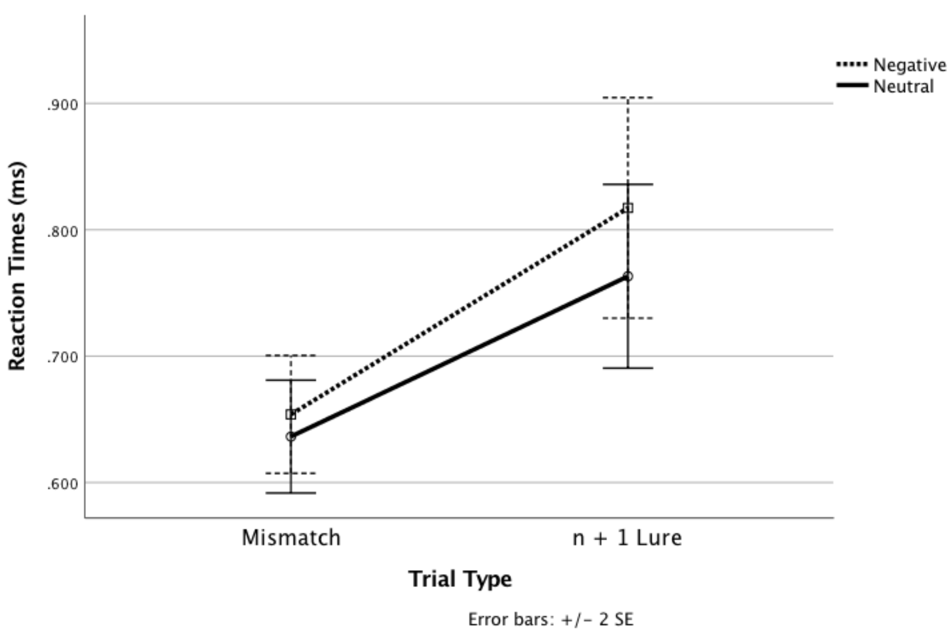

Figure 4. Mean reaction times for the mismatch and n + 1 lure trial types (n + 1 interference effect) in the negative and neutral valence conditions in Experiment 1. Vertical bars denote standard errors.

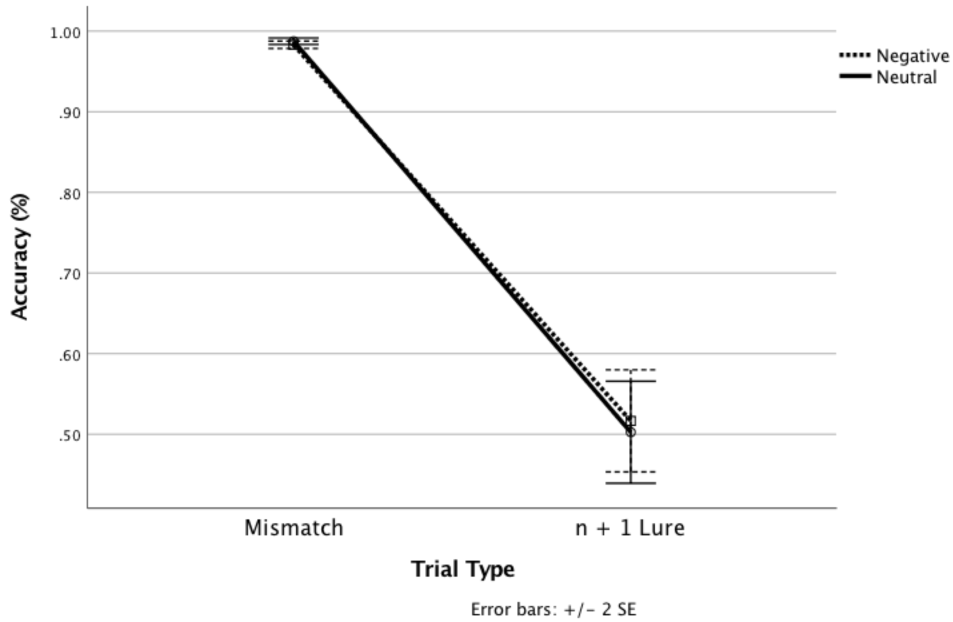

Figure 5. Mean accuracy for the mismatch and n + 1 lure trial types (n + 1 interference effect) in the negative and neutral valence conditions in Experiment 1. Vertical bars denote standard errors.

The overall test for the n - 1 interference effect (mismatch vs. n - 1 lures) was significant, F (2, 56) = 66.95, η_p^2 = .71, p < .001. Follow up contrasts revealed that the n - 1 interference effect was significant for both reaction time (F (1, 57) = 64.77, η_p^2 = .53, p < .001) and accuracy (F (1, 57) = 47.86, η_p^2 = .46, p < .001). There was no overall significant main effect of emotional valence, F = 1.00, p > .05. There was an overall significant interaction of trial type by emotional valence, (F (2, 56) = 10.52, η_p^2 = .27, p < .001). Follow up contrasts revealed that the n – 1 interference effect was different across the negative and neutral valence conditions for both reaction times (F (1, 57) = 13.81, η_p^2 = .20, p = .001), but not reliably for accuracy (F (1, 57) = 4.18, η_p^2 = .07, p = .045). Namely, the n – 1 interference effect for the negative valence condition appears to be reduced compared to n – 1 interference effect for the neutral condition at least in terms of processing efficiency, and a trend in the similar direction was observed for reaction times.

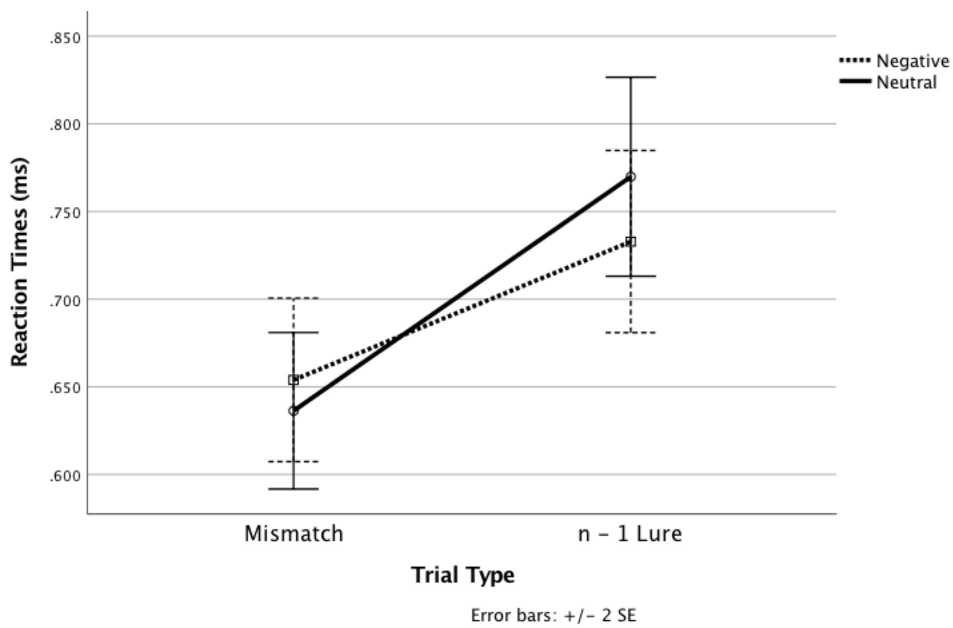

Figure 6. Mean reaction times for the mismatch and n - 1 lure trial types (n - 1 interference effect) in the negative and neutral valence conditions in Experiment 1. Vertical bars denote standard errors.

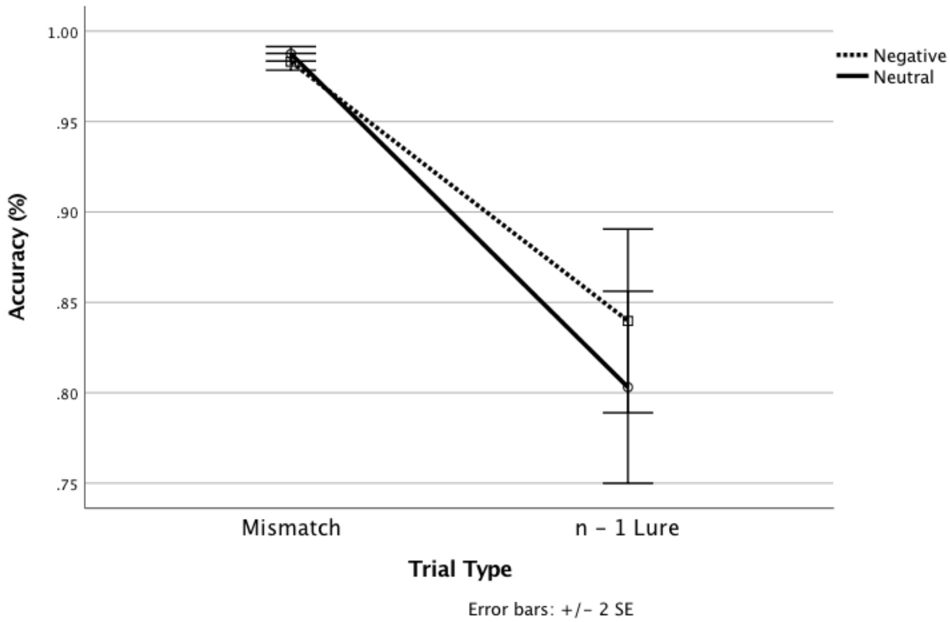

Figure 7. Mean accuracy for the mismatch and n - 1 lure trial types (n - 1 interference effect) in the negative and neutral valence conditions in Experiment 1. Vertical bars denote standard errors.

Furthermore, performance for the n + 1 and n - 1 lures was compared. The overall test for the main effect of trial type was significant, F (2, 56) = 59.48, $\eta_p^2 = .68$, $p < .001$. Follow up contrasts revealed that the difference was significant for accuracy (F (1, 57) = 120.58, $\eta_p^2 = .68$, $p < .001$), but it did not reach significance for reaction times ($F = 3.64$, $p = .06$). The overall main effect of emotional valence was not significant, $F < 1$, $p > .05$. A significant interaction of trial type by emotional valence was observed, F (2, 56) = 3.69, $\eta_p^2 = .12$, $p = .03$. Follow up contrasts revealed the interaction was significant for reaction times (F (1, 57) = 6.81, $\eta_p^2 = .11$, $p = .012$), but not for accuracy ($F < 1$, $p > .05$). In general n + 1 lures were less accurate than n – 1 lures for both negative and neutral valence equally. However, while n + 1 lures were performed less efficiently (slower) that n – 1 lures for the negative valence condition, the two types of lures produced similar reaction times for the neutral valence condition. Interestingly, when compared to their corresponding neutral counterparts, while negative high arousal content appears to hinder response efficiency for n + 1 lures, it appears to facilitate response efficiency for n – 1 lures.

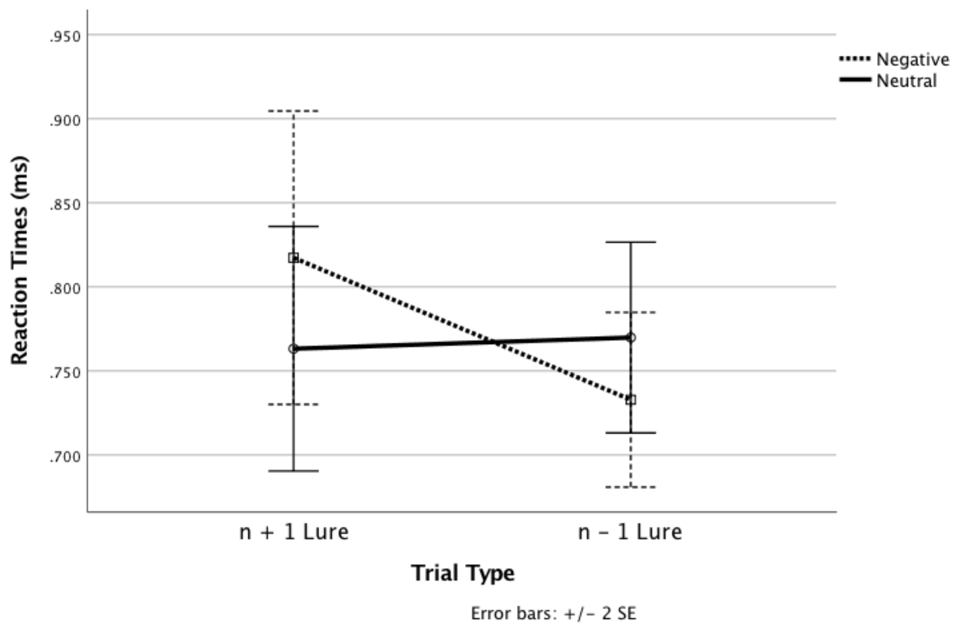

Figure 8. Mean reaction times for the n + 1 and n - 1 lure trial types in the negative and neutral valence conditions in Experiment 1. Vertical bars denote standard errors.

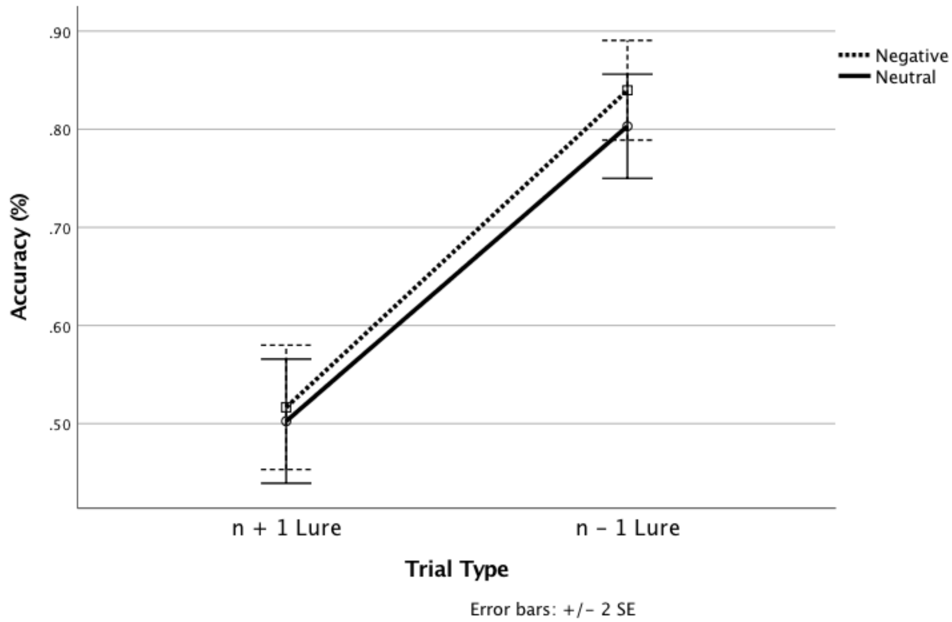

Figure 9. Mean accuracy for the n + 1 and n - 1 lure trial types in the negative and neutral valence conditions in Experiment 1. Vertical bars denote standard errors.

Additionally, the data was analyzed including only those participants who completed both Experiment 1 and Experiment 2 (46 participants) in order to rule out potential selection confounds. Overall, the results remained the same. There was a significant main effect of trial type, F (6, 270) = 28.82, $\eta_p^2 = .39$, $p < .001$. For the trial type effect, follow up contrasts revealed that mismatch trials were performed faster (F (1, 45) = 21.32, $\eta_p^2 = .32$, $p < .001$) and more accurately (F (1, 45) = 102.53 $\eta_p^2 = .70$, $p < .001$) than match trials. Also, while n + 1 lures produced lower accuracy than n – 1 lures (F (1, 45) = 112.62, $\eta_p^2 = .71$, $p < .001$), no significant difference in reaction times was observed between the two types of lures ($F = 1.08$, $p > .05$). No significant overall main effects of emotional valence were observed, $F < 1$, $p > .05$. Finally, there was a significant interaction of trial type by emotion, F (6, 270) = 2.67, $\eta_p^2 = .06$, $p = .016$. Follow up contrasts revealed that the pattern of performance on the n + 1 lures versus n –

1 lures comparison was different under the negative and neutral conditions for reaction times (F (1, 45) = 5.94, η_p^2 = .12, p = .019), but not accuracy (F < 1, p > .05).

Planned comparisons of interference effects (mismatch trials versus each of the different lure trials) were analyzed by means of 2 (trial type: mismatch and n + 1lure or n – 1 lure) X 2 (valence: negative and neutral) repeated measures MANOVA with reaction times (correct trials only) and accuracy as dependent measures. The overall main effect test for the n + 1 interference effect (mismatch vs. n + 1 lures) was significant, F (2, 44) = 151.72, η_p^2 = .87, p < .001. Follow up contrasts revealed that the n + 1 interference effect was significant for both reaction time (F (1, 45) = 21.32, η_p^2 = .32, p < .001) and accuracy (F (1, 45) = 253.79, η_p^2 = .85, p < .001). The overall main effect of emotional valence was not significant, F = 2.48, p = .096. However, follow up contrasts revealed that when averaged across all trial types, reaction times were slower for the negative valence compared to neutral valence condition (F (1, 45) = 4.34, η_p^2 = .09, p = .043); but no significant difference was observed for accuracy (F < 0, p > .05). No significant interaction effects were observed for trial type by emotional valence, F = 1.15, p > .05. Overall, the results remained unchanged; thus, although the n + 1 interference effect appears to be similar under the two conditions, it seems to be more pronounced for the negative valence condition.

The overall test for the n - 1 interference effect (mismatch vs. n - 1 lures) was significant, F (2, 44) = 55.17, η_p^2 = .72, p < .001. Follow up contrasts revealed that the n - 1 interference effect was significant for both reaction time (F (1, 45) = 49.55, η_p^2 = .52, p < .001) and accuracy (F (1, 45) = 41.57, η_p^2 = .48, p < .001). There was no overall significant main effect of emotional valence, F = 1.24, p > .05. There was an overall significant interaction of trial type by emotional valence, (F (2, 44) = 7.54, η_p^2 = .26, p = .002). Follow up contrasts revealed that the n – 1 interference effect was different across the negative and neutral valence conditions for reaction times (F (1, 45) = 10.99, η_p^2 = .20, p = .002), but not for accuracy (F = 2.09, p > .05). Thus, the n – 1 interference effect for the negative valence condition appears to be reduced compared to n – 1 interference effect for the neutral condition at least in terms of processing efficiency. Overall, these results remained relatively similar to the previous analyses, and further demonstrate that the accuracy results for the interaction effect can be unreliable.

Furthermore, performance for the n + 1 and n - 1 lures was compared. The overall test for the main effect of trial type was significant, F (2, 44) = 56.19, η_p^2 = .72, p < .001. Follow up contrasts revealed that the difference was significant for accuracy (F (1, 45) = 112.62, η_p^2 = .71, p < .001), but it did not reach significance for reaction times (F = 1.08, p > .05). The overall main effect of emotional valence was not significant, F = 1.14, p > .05. A significant interaction of trial type by emotional valence did not reach significance, F (2, 44) = 2.91, p = .065. However, follow up contrasts revealed a significant interaction for reaction times (F (1, 45) = 5.94, η_p^2 = .12, p = .019), but not for accuracy (F < 1, p > .05). In general n + 1 lures were less accurate than n – 1 lures for both negative and neutral valence equally. However, while n + 1 lures were performed less efficiently (slower) that n – 1 lures for the negative valence condition, the two types of lures produced similar reaction times for the neutral valence condition. Interestingly, when compared to their corresponding neutral counterparts, while negative high arousal content appears to hinder response efficiency for n + 1 lures, it appears to facilitate response efficiency for n – 1 lures. Considering the fact that this second run of analysis included a smaller sample, but the overall results remained broadly similar to the previous analyses, they appear to be robust and not due to potential selection biases.

Additionally, the data was analyzed including only those participants who completed both Experiment 1 and Experiment 2 (46 participants), and the file was split between those administered Experiment 1 first (n = 34; order 1) and those administered Experiment 2 (n = 12 order 2) first in order to rule out potential order confounds. Only the overall analysis was performed. There was a significant main effect of trial type for both order 1 *(F* (6, 198) = 22.63, η_p^2 = .41, *p* < .001) and order 2 *(F* (6, 66) = 6.21, η_p^2 = .36, *p* < .001). While n + 1 lures produced lower accuracy than n – 1 lures (order 1: *F* (1, 33) = 76.70, η_p^2 = .70, *p* < .001; order 2: *F* (1, 11) = 44.10, η_p^2 = .80, *p* < .001), no significant difference in reaction times was observed between the two types of lures (*F* < 1, *p* > .05 for both orders). No significant overall main effects of emotional valence were observed (*F* < 1, *p* > .05 for both orders). Finally, although the overall test for the interaction of trial type by emotion did not reach significance (order 1: *F* = 1.82, *p* = .097; order 2: *F* = 1.28, *p* > .05), there was a pattern of performance on the n + 1 lures versus n – 1 lures comparison toward being different under the negative and neutral conditions for reaction times (order 1: *F* (1, 33) = 4.32, η_p^2 = .12, *p* = .046; order 2: *F* (1, 11) = 5.39, η_p^2 = .33, *p* = .041), but not accuracy (*F* < 1, *p* > .05 for both orders). Considering the fact that this run of analyses included a smaller sample, but the overall results were in similar direction to each other and to the results from the main analyses, order was not considered to have had a significant impact on the overall results.

Experiment 1 Discussion

This study was designed to explore the effects of emotional content on interference resolution in working memory. The emotional content is said to be task-relevant in Experiment 1, because the emotional pictures are the stimuli to-be-processed and attended to. Two types of interference effects were introduced to examine the interaction between emotion and interference from information at different stages of processing in working memory. Namely, the n + 1 interference effect (mismatch vs. n + 1 lure) represents interference from information that is no longer relevant and is to be discarded. The n – 1 interference effect (mismatch vs. n – 1 lure) represents interference from information that is not-yet relevant, but it is next in line to be processed. In general, the reaction times data differentiated between trial types, and showed significant interference effects. Critically, Experiment 1 revealed significant effects of emotional content on interference resolution in working memory. Specifically, while there was a larger n + 1 interference effect for the negative valence compared to the neutral valence condition, there was a smaller n – 1 interference effect (mismatch vs. n – 1 lure) for the negative valence compared to the neutral valence condition. Thus, while highly arousing emotional content was processed less efficiently (i.e., slowed response times) when interference was produced by no-longer relevant (n + 1 lures) information (hindering effect on interference resolution), it was processed more efficiently when interference was produced by not-yet relevant (n – 1 lures) information (facilitating effect on interference resolution). Overall, when the affective information is task-relevant as in Experiment 1, it appears to have both facilitating and hindering effects on interference resolution depending on the stage of processing of such representations in working memory.

The accuracy data generally followed the reaction times data in differentiating between trial types. It also differentiated between information in different stages of processing, such that no-longer relevant (n + 1 lures) information produced lower accuracy than not-yet relevant (n – 1 lures) information. Interference effects were also significant for the accuracy data. However, emotional content does not appear to have consistent effects on accuracy. A significant effect of emotional content on accuracy was only observed during planned comparisons and only for the n - 1 interference effect, such that performance was facilitated for highly arousing negative information compared to its neutral counterpart. Overall, when the emotional content is task-relevant, it can facilitate interference resolution when interference is produced by not-yet relevant (n – 1 lures) information resulting in both higher processing efficiency and accuracy, but it can hinder processing efficiency when produced by no-longer relevant (n + 1 lures) information.

Experiment 2

Experiment two was designed to test the hypothesis that when the emotional content of stimuli is not task-relevant, the content would hinder interference resolution in working memory updating. Again, the embedded-process model by Cowan (1999) postulates that control and regulation of the focus of attention in working memory is supported conjointly by the executive control system (i.e. voluntary orienting of attention) and the attentional orienting system (i.e., involuntary attentional orienting response and habituation of this response). However, these two systems may come into conflict when the physical properties of stimuli attract attention away from the relevant target. With regard to emotional material, a stimulus could attract the focus of attention automatically because of its affective value, and either help or hinder performance depending on whether it is a target stimulus or not. In Experiment 2, the *n*-back paradigm with interference trials was again used to measure proactive interference in working memory updating as in the previous experiment. However, in the current experiment the emotional content was presented as a contextual feature not relevant to the task, and though the participant was given explicit instructions to ignore this information, it was assumed that attention would be captured automatically by highly arousing negative background scenes. The attentional 'trade-off' hypothesis assumes that negative arousal causes a narrowing of attention, such that details spatially and temporally associated with the emotional item are attended to and later remembered, while information peripheral to that item is likely to be forgotten (Easterbrook, 1959; Kensiger, Garoff-Eaton, & Schacter, 2007). In experiment 2, the materials to-be-remembered were all neutral objects, but these objects were presented in the context of a scene that was either neutral or negative. Then, according to the attentional 'trade-off' hypothesis, a highly arousing negative scene would attract attention away from the neutral object presented close in space and time. In the study by Levens and Phelps (2008), emotional content facilitated interference resolution on a working memory updating paradigm when the focus was on the emotional contents and thus relevant to the task at hand. Though, in that paradigm an 'emotional distractor' condition was included, the results did not clearly show whether this manipulation had a consistent effect on performance other than not showing the same facilitation effect as the 'emotional probe' condition. The two conditions only differed in that the probe was either emotional or neutral, but the target set contained both emotional and neutral items. Thus, it could be argued that the nature of ‘distraction’ (emotional words embedded among neutral words in a set) was the same for both conditions, and the emotion was still task-relevant in that it provided relevant context to the target set items. In Experiment 2, pictorial material was used to pair emotional scenes serving as backgrounds with neutral objects serving as to-be-remembered stimuli. Thus, the background contexts were irrelevant to the task. It was hypothesized that the highly arousing contexts would attract attention away from the neutral objects hindering proactive interference resolution, such that the interference effect would be highest for the emotional context condition.

Experiment 2 Method

Participants

Participants were 52 (35 female) students (mean age = 20 years) that also participated in Experiment 1 (see corresponding section in Experiment 1).

Stimuli

Stimulus materials consisted of two picture components, a smaller picture of a single everyday object (e.g., chair, spoon, camera, etc.) superimposed on a biger background context (i.e., IAPS). In order to demarcate the separation of objects against the backgrounds, objects were presented within a white box. The backgrounds were drawn from a set of 188 IAPS (94 negative and 94 neutral) pictures not included in Experiment 1 but chosen to match the characteristics of the Experiment 1 sets (see description on Experiment 1 method). A set of another 180 neutral valence pictures of everyday objects served as the to-be-remembered stimuli which were superimposed on the background pictures. The later pictures were of objects comprising a wide range of semantic categories (e.g., tools, furniture, clothing, machinery, domestic objects, etc.) drawn from the internet. Materials for list construction were drawn randomly from these sets, and the pairing of each background and target object was random for each trial.

Design and Procedures

The procedures followed those in Experiment 1 unless specified below. Stimuli were presented on the center of the screen. For each valence condition, two different 2-back lists of the four trial types were used for a total of four lists. Lists were presented in an alternating manner in order to prevent habituation to a valence condition, and such order was also counterbalanced across participants. The negative-valence lists included negative-high arousal pictures randomly drawn from the corresponding set. Likewise, the neutral-valence lists included neutral-low arousal pictures drawn from the corresponding set. Each list consisted of 47 pictures of which 15 were match trials (i.e., the current picture matches the picture presented 2 positions back) and 30 were mismatch trials (i.e., the current picture does not match the picture presented 2 positions back). From the 30 mismatch trials on each list, six were lure trials (i.e. the current picture matches the picture on either the n + 1 or n - 1 position). Three lures were in the n + 1 position and three lures were in the n - 1 position.

A background was initially presented alone on the screen for 250 ms, and then the critical object was superimposed centrally upon the background. The background-object pair remained on the screen for 500 ms, followed by an inter-stimulus interval (2,500 ms) during which a fixation cross stayed centered on the screen. Participants were instructed to ignore the background pictures, as they were irrelevant to the task. Participants were instructed to indicate as fast and accurately as possible whether a presented critical object (i.e., not the background) matched the object presented two positions before by pressing the number “1” or “2” key (i.e., match or mismatch respectively) on the computer key board using their preferred hand.

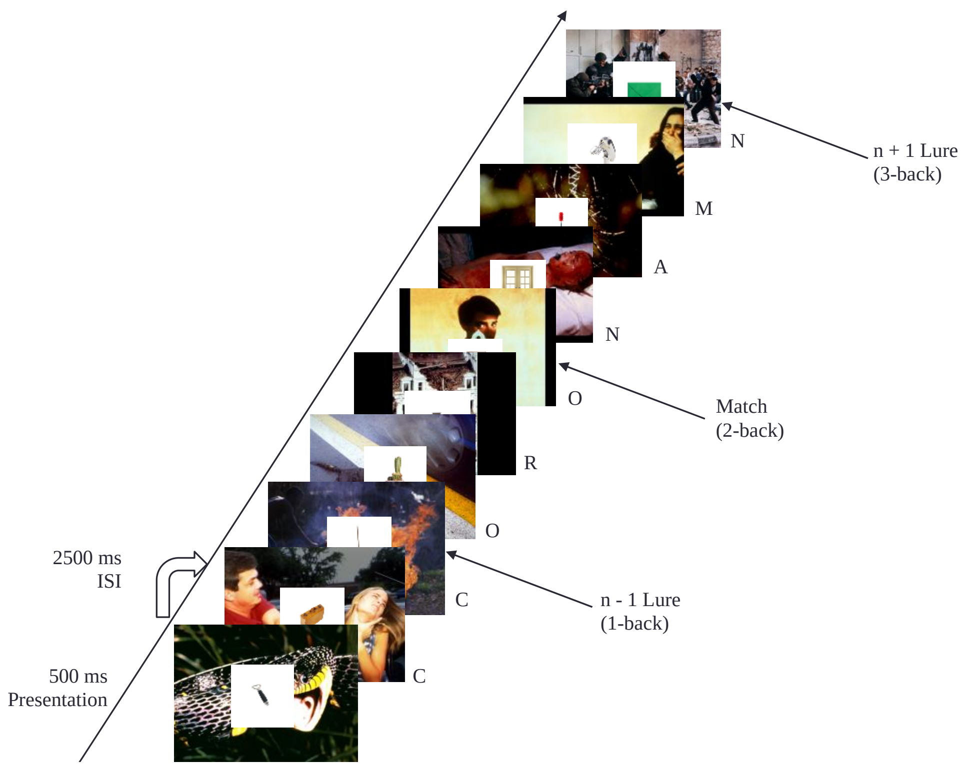

Figure 10. 2-back task for Experiment 2. Each picture pair was presented for 500 ms (after a 250 ms presentation of the background by itself) with a 2 sec inter-stimulus-interval (ISI).

Experiment 2 Results

As noted before, Experiment 1 and Experiment 2 were conducted at the same time, and most participants completed both experiments with some exceptions (see beginning of results section in Experiment 1). The overall data was analyzed by means of a 4 (trial type: match, mismatch, *n* + 1lure, and *n* – 1 lure) X 2 (valence: negative and neutral) repeated measures MANOVA with reaction times (correct trials only) and accuracy as dependent measures. All comparisons between trial types were independent such that “mismatch” trials do not include any lure trials. The data was examined for missing values, outliers, and for the assumptions of multivariate analysis prior to running the main analyses. Missing values were replaced by the corresponding means for all cases (missing values only on reaction times data: 4% negative n + 1 lures, 6% negative n - 1 lures, 12% neutral n + 1 lures, 4% negative n - 1 lures). Cases found to be univariate outliers (*z*-score greater than 3.29) were replaced by the corresponding raw score of the next most extreme score in the particular distribution (accuracy data: 6% negative mismatches, 4% neutral mismatches; reaction times data: no more that 2% of cases being replaced in any particular cell). One case (same individual as in Experiment 1) was identified through Mahalanobis distance as a multivariate outlier with $p < .001$, and it was deleted. After dealing with univariate and multivariate outliers and missing data, the assumptions of multivariate analysis were met. A total of 51 (after removal of a multivariate outlier case) individuals participated in Experiment 2.

Table 2 shows mean accuracies as a function of the different trial types and emotional valence. Figure 11 shows mean reaction times, as a function of the different trial types and emotional valence. Like in Experiment 1, there was a significant main effect of trial type, F (6, 300) = 25.36, $\eta_p^2 = .34$, $p < .001$. For the trial type effect, follow up contrasts revealed that mismatch trials were performed faster (F (1, 50) = 27.78, $\eta_p^2 = .36$, $p < .001$) and more accurately (F (1, 57) = 90.88, $\eta_p^2 = .65$, $p < .001$)

than match trials. Also, while n + 1 lures produced lower accuracy than n – 1 lures (F (1, 50) = 21.43, η_p^2 = .30, p < .001), no significant difference in reaction times was observed between the two types of lures (F = 2.62, p > .05). No significant overall main effects of emotional valence were observed, F < 1, p > .05. Finally, there was no overall significant interaction effects of trial type by emotion, F (6, 300) < 1, p > .05. Thus, the interference effects did not appear to differ across the two valence conditions. Incidentally, follow up contrast did reveal a marginally significant interaction effect, such that the match versus mismatch trials comparison was different across the negative and neutral conditions for the accuracy data, F (1, 50) = 3.91, η_p^2 = .07, p = .05. Namely, it appears that the difference between match and mismatch trials is larger for the negative condition compared to the neutral condition.

Table 2. Mean accuracy and standard deviation for the different types of trials in the neutral and negative valence conditions of the 2-back task, Experiment 2.

Valence	Match	Mismatch	*n* + 1 lure	*n* - 1 lure
Negative	.75 (.20)	.98 (.03)	.56 (.25)	.72 (.28)
Neutral	.79 (.15)	.98 (.02)	.56 (.27)	.69 (.25)

Note. Accuracy scores are percentages; standard deviations appear within parentheses.

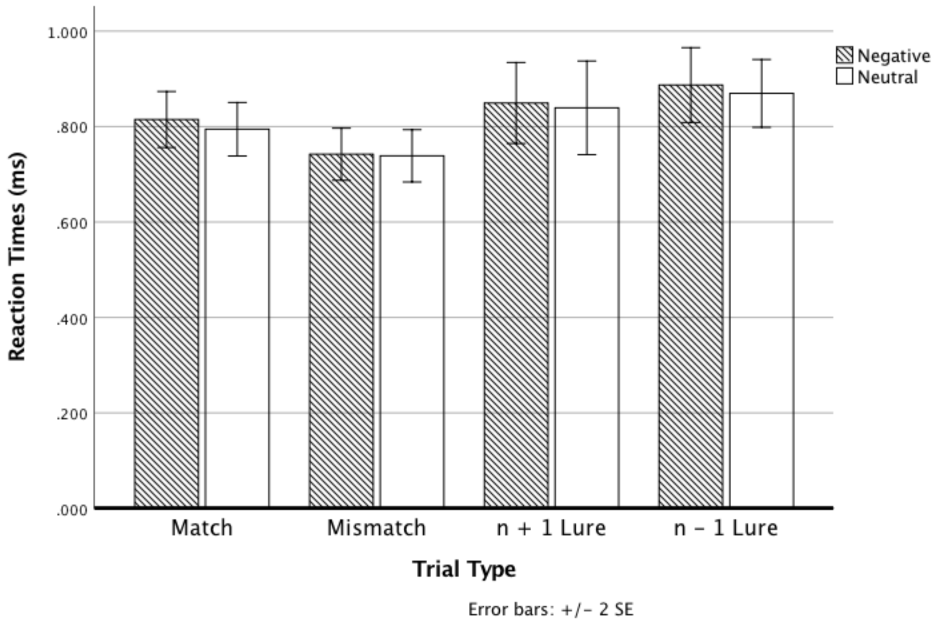

Figure 11. Mean reaction times for the different trial types in the negative and neutral valence conditions in Experiment 2. Vertical bars denote standard errors.

Planned comparisons of interference effects (mismatch trials versus each of the different lure trials) were analyzed by means of 2 (trial type: mismatch and *n* + 1lure or *n* – 1 lure) X 2 (valence: negative and neutral) repeated measures MANOVA with reaction times (correct trials only) and accuracy as dependent measures. Again, all comparisons between trial types were independent such that "mismatch" trials do not include any lure trials. The overall main effect test for the n + 1 interference effect (mismatch vs. n + 1 lures) was significant, F (2, 49) = 144.67, $\eta_p^2 = .86$, $p < .001$. Follow up contrasts revealed that the n + 1 interference effect was significant for both reaction time (F (1, 50) = 16.60, $\eta_p^2 = .25$, $p < .001$) and accuracy (F (1, 50) = 207.09, $\eta_p^2 = .81$, $p < .001$). The overall main effect of emotional valence was not significant, $F < 1$, $p > .05$. Also, no significant interaction effects were observed for trial type by emotional valence ($F < 0$, p

> .05). Thus, the n + 1 interference effect appears to be similar under the negative and neutral valence conditions.

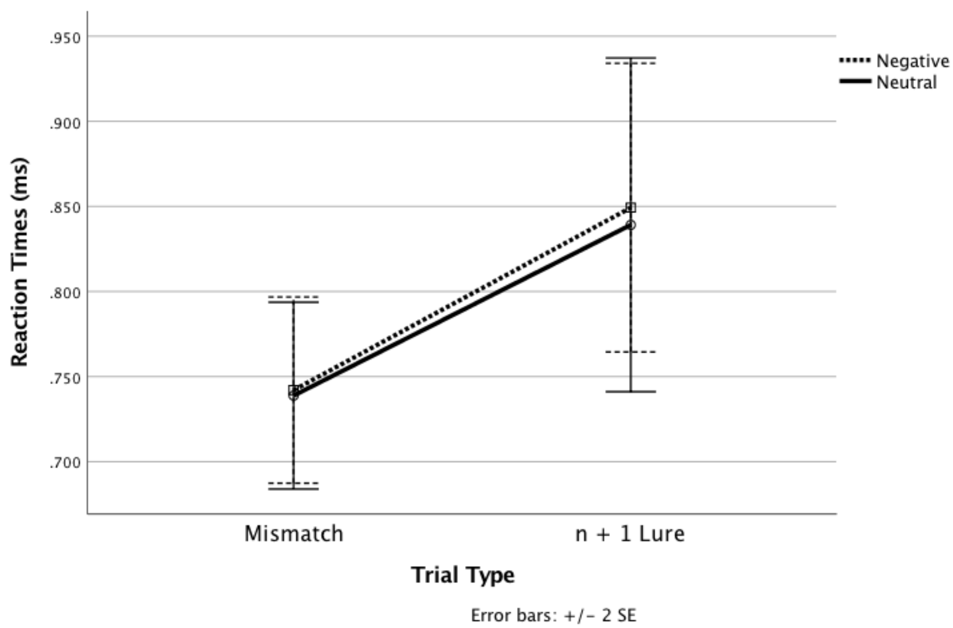

Figure 12. Mean reaction times for the mismatch and n + 1 lure trial types (n + 1 interference effect) in the negative and neutral valence conditions in Experiment 2. Vertical bars denote standard errors.

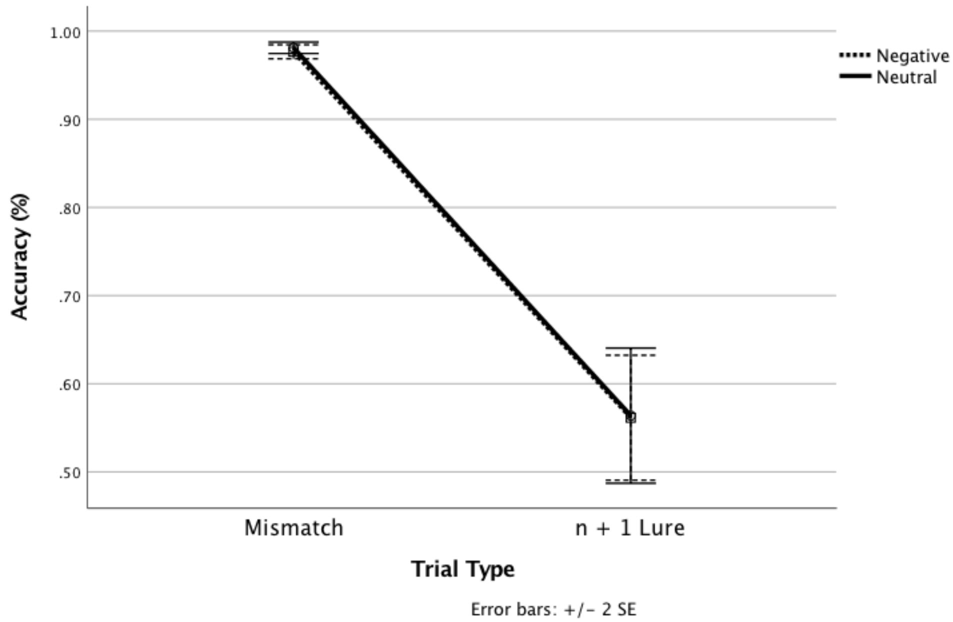

Figure 13. Mean accuracy for the mismatch and n + 1 lure trial types (n + 1 interference effect) in the negative and neutral valence conditions in Experiment 2. Vertical bars denote standard errors.

The overall test for the n - 1 interference effect (mismatch vs. n - 1 lures) was significant, F (2, 49) = 77.74, $\eta_p^2 = .76$, $p < .001$. Follow up contrasts revealed that the n - 1 interference effect was significant for both reaction time (F (1, 50) = 43.93, $\eta_p^2 = .47$, $p < .001$) and accuracy (F (1, 50) = 72.95, $\eta_p^2 = .59$, $p < .001$). There was no overall significant main effect of emotional valence, $F < 1$, $p > .05$. Also, no significant interaction effects were observed for trial type by emotional valence, $F < 0$, $p > .05$. Thus, the n - 1 interference effect appears not to differ between the negative and neutral valence conditions.

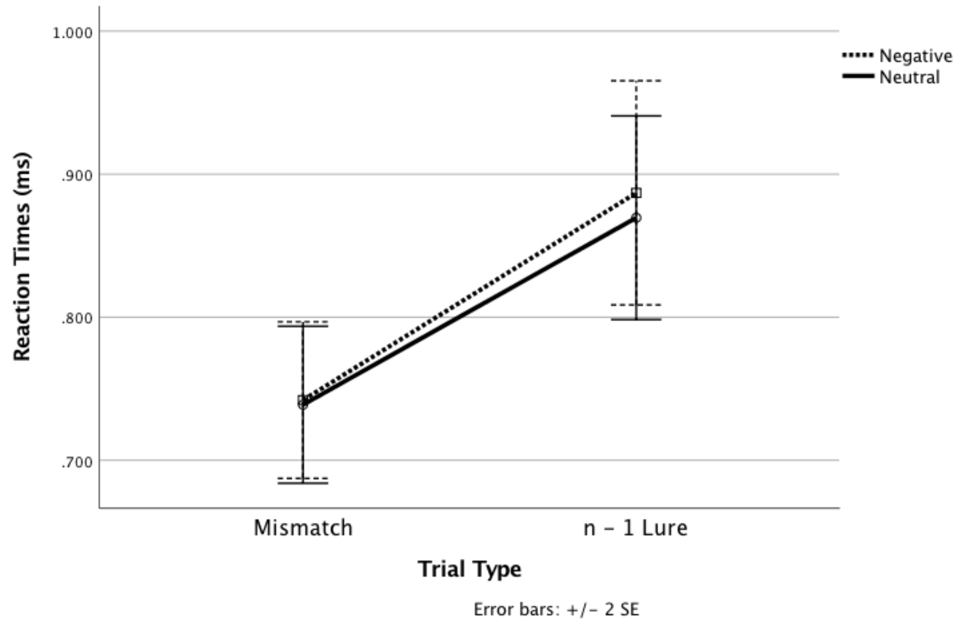

Figure 14. Mean reaction times for the mismatch and n - 1 lure trial types (n - 1 interference effect) in the negative and neutral valence conditions in Experiment 2. Vertical bars denote standard errors.

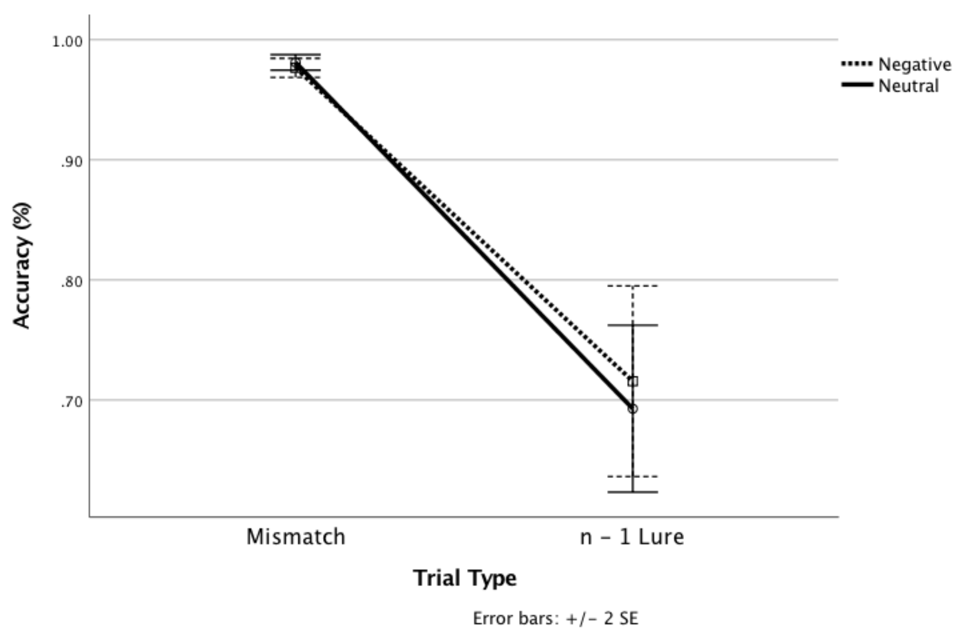

Figure 15. Mean accuracy for the mismatch and n - 1 lure trial types (n - 1 interference effect) in the negative and neutral valence conditions in Experiment 2. Vertical bars denote standard errors.

Furthermore, performance for the n + 1 and n - 1 lures was compared. The overall test for the main effect of trial type was significant, F (2, 49) = 11.51, $\eta_p^2 = .32$, $p < .001$. Follow up contrasts revealed that the difference was significant for accuracy (F (1, 50) = 21.43, $\eta_p^2 = .30$, $p < .001$), but not for reaction times ($F = 2.62$, $p > .05$). The overall main effect of emotional valence was not significant, $F < 1$, $p > .05$. Also, no significant interaction effects of trial type by emotional valence were observed, $F < 1$, $p > .05$. Thus, performance between the two types of lures does not appear to differ between the negative and neutral valence conditions.

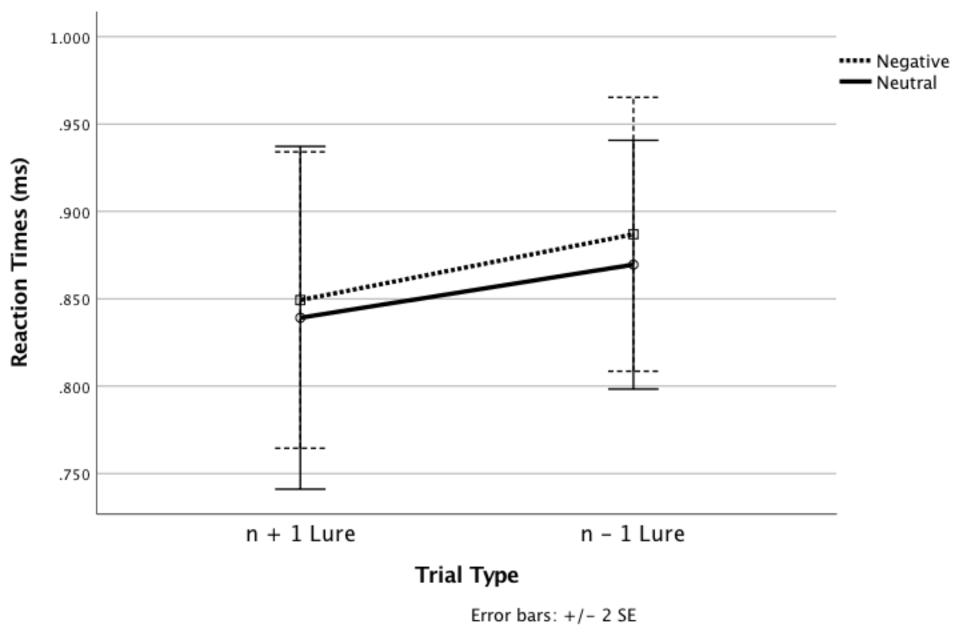

Figure 16. Mean reaction times for the n + 1 and n - 1 lure trial types in the negative and neutral valence conditions in Experiment 2. Vertical bars denote standard errors.

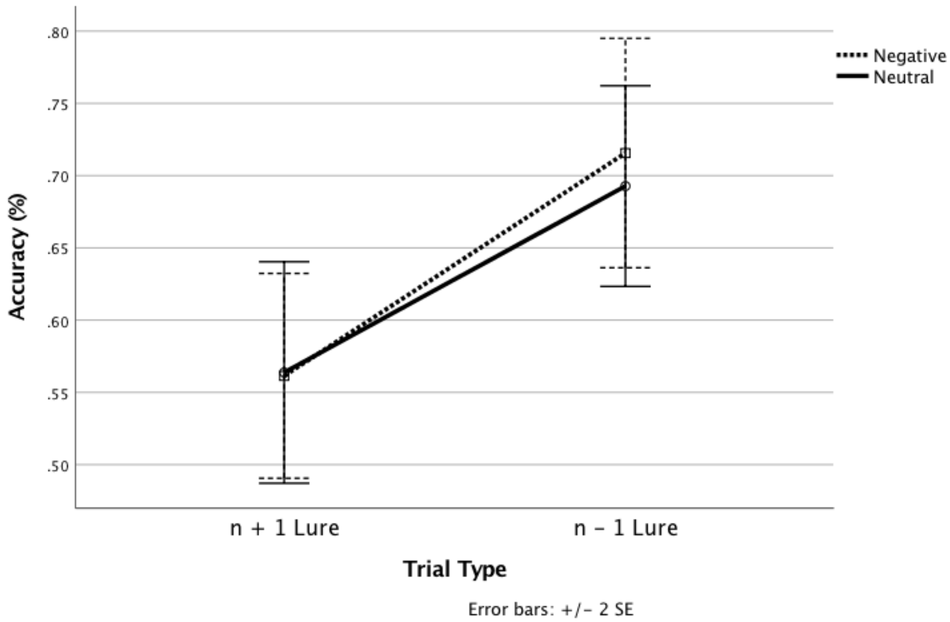

Figure 17. Mean accuracy for the n + 1 and n - 1 lure trial types in the negative and neutral valence conditions in Experiment 2. Vertical bars denote standard errors.

Experiment 2 Discussion

This study was designed to explore the effects of task-irrelevant emotional content on interference resolution in working memory. The emotional content is said to be task-irrelevant in Experiment 2, because the emotional pictures were used as backgrounds (peripheral) to the stimuli to-be-remembered and attended to. Again, two types of interference effects were introduced to examine the interaction between emotion and interference from information at different stages of processing in working memory. The n + 1 interference effect (mismatch vs. n + 1 lure) represents interference from information that is no-longer relevant and is to be discarded. The n – 1 interference effect (mismatch vs. n – 1 lure) represents interference from information that is not-yet relevant but is next in line to be processed. In general, both the reaction times and accuracy data differentiated between trial types and followed a similar pattern to

Experiment 1. Also similar to Experiment 1, Experiment 2 results differentiated between information at different stages of processing, such that no-longer relevant (n + 1 lures) information produced lower accuracy than not-yet relevant (n – 1 lures) information. Interference effects were also significant for both reaction times and accuracy data. However, in Experiment 2, the emotional and neutral conditions produced similar interference effects from both types of irrelevant representations in working memory. Thus, when the affective information is not task-relevant as in Experiment 2, it does not appear to have significant effects on interference resolution.

CHAPTER FOUR

GENERAL DISCUSSION

The experiments presented above were designed to investigate the effects of emotional content on interference resolution within working memory, either when the affective content was task-relevant (Experiment 1) or when it was peripheral to the task itself (Experiment 2). Two types of interference effects were introduced. The n – 1 interference effect (mismatch vs. n – 1 lure) represented interference from activations of not-yet relevant representations within the region of direct access. The n + 1 interference effect (mismatch vs. n + 1 lure) represented interference from activations of no-longer relevant representations within the region of activated long-term memory. Overall, the results showed reliable interference effects in both Experiment 1 and 2, with lure trials producing lower accuracy and slower reaction times compared to pure mismatch trials. In principle, pure mismatch trials did not produce interference because the cues likely elicited a weak familiarity signal and were not remembered to have been in the target position, thus response selection was made relatively fast. This is in line with the account by Oberauer (2001), suggesting that when the evidence provided by a familiarity signal and a recollection process coincide, no decision conflict needs to be resolved. Also, in line with such account, the familiarity signal was likely high for lure trials, and the recollection process was not consistent with the familiarity signal (i.e., the cue did not match the target), producing a decision conflict. Hence, performance was less accurate, and in resolving such decision conflict, reaction times were slowed to allow recollection to override the high familiarity signal (Oberauer, 2001). Furthermore, the overall difference in performance between the two types of lures discriminated between representations within different stages of processing in working memory. Specifically, while n - 1 lures were performed more accurately than n + 1 lures, no significant differences in reaction times were observed between the two types of lures. This likely represents differences in accessibility of information interacting with retrieval dynamics of a decision conflict. Namely, although both types of representations likely produced a high familiarity signal, while the contents of the region of direct access are more accessible for a more exhaustive recollection process, the activated long-term memory region is less accessible in such regard. Thus, although individuals responded with similar speed to both types of lures, while the responses to the n -1 lures were likely based on higher levels of recollection, the responses to the n -1 lures were likely based on higher levels of familiarity. This is consistent with the assumption by Oberauer (2001) that familiarity and recollection processes work in parallel in the service of task performance, and the different regions within the working memory system also differentially represent different levels of accessibility to such processes.

In addition, while in Experiment 1 there was an interaction between interference effects and emotional valence, Experiment 2 failed to show a significant relationship. Specifically, Experiment 1 showed that while there was a larger n + 1 interference effect (i.e., slowed response times) for the negative valence compared to the neutral valence condition, there was a smaller n – 1 interference effect (i.e., faster reaction times and higher accuracy) for the negative valence compared to the neutral valence condition. Broadly, it appears that while negative valence hindered interference resolution when interference was produced by no-longer relevant (n + 1 lures) information, it facilitated interference resolution when interference was produced by not-yet relevant (n – 1) information. Therefore, when the emotional content is task-relevant, it can facilitate interference resolution when interference is produced by not-yet relevant (n – 1 lures) information, resulting in both faster processing efficiency and higher accuracy. These results from Experiment 1 are very interesting in that they speak to the inconsistencies in the literature on the hindering and facilitating effects of emotional content on working memory. Nonetheless, the current results seem consistent with perceptual processing and attentional modulation by emotion, which could further be explained in terms of recognition dynamics (i.e. familiarity and recollection). In principle, the interference produced by not-yet relevant information can be resolved through facilitating access to, or activation of, contents and contextual bindings stored in the region of direct access (or focus of attention) through attention orienting mechanisms. This is in accordance with the assumption postulated by Cowan (1999) of a cognitive automaticity of the attentional orienting response when processing relevant or salient information, such that emotional content has the potential to facilitate attention and enhance perceptual encoding (Ochsner, 2000). Given that the specific representation (i.e. n – 1 stimulus) is next in line to be processed, it is likely given a higher degree of relevance; and when coupled with an affective attentional bias (i.e., emotional content), it results in enhanced perceptual encoding and contextual binding. Furthermore, such biasing of attentional resources by emotional content also likely increases a familiarity signal of having seen the particular stimulus, and given that information in the region of direct access is readily accessible, a recollection process can more quickly and accurately retrieve information on contextual bindings (e.g., specific representations along with information on their time sequence and particular order in the chain). In other words, the cue produces a strong familiarity signal of having been encountered recently, then the recollection process supports the retrieval of the specific representation as having been seen in the position *1*-back. In general, these results appear to suggest that when emotional content is both task-relevant and interference is produced by information in the region of direct access, then control of the focused of attention is facilitated conjointly by involuntary and voluntary processes (i.e., automatic attentional orienting and central executive control), and familiarity and recollection work in parallel to achieve task goals.

Conversely, the interference produced by no-longer relevant (n + 1 lures) information requires accessing memory representations stored in the activated region of long-term memory, which would require more involvement of executive control mechanisms to attenuate the attentional orienting response and to trigger inhibitory processes. In essence, such representations (i.e., n + 1 lures) have been recently discarded and updated in the processing chain but are activated by the attentional orienting response given their recency and similarity (they match) to the stimulus cue currently in the focus of attention. In addition, when such stimuli also produce high emotional arousal, the attentional orienting response is likely higher and produces a higher familiarity signal. Thus, a recollection process must overcome the familiarity signal in order to retrieve contextual information from long-term memory (e.g., remembering that the stimulus was previously seen, but is not in the target position). In other words, the affective value likely captures attention automatically, which increases the level of interference from no-longer relevant information, and in turn overloads processing capacity. The recollection process then likely takes longer to occur and may be less likely to overcome the high familiarity signal resulting in longer reaction times. In sum, the latter results are in line with the assumption described by Oberauer (2001) about proactive interference arising from activated representations in long-term memory, which generates a fast familiarity signal that conflicts with the evidence from a more reliable (though slower) process of recollection; and although accurate performance can be achieved if recollection overrides the misleading familiarity signal, such process likely yields longer response times. Thus, this is further in accordance with the idea suggested by Kensiger and Corkin (2003) that the hindering effects of emotional content on working memory likely result from processing emotional content that requires recruitment of inhibitory processes (e.g., inhibiting the 'emotional orienting' response); which appears to be the case for interference from information that is no-longer relevant, but is in the activated long-term memory region.

In general, Experiment 2 suggest that when emotional content is presented as peripheral information and not relevant to the task, then it may not consistently show significant effects on interference resolution within working memory. In Experiment 2, the negative and neutral scenes (i.e., pictures from the IAPS) were used as backgrounds to the task stimuli (i.e., pictures of single everyday objects). Therefore, in principle, the task could be successfully performed without having to pay any attention to the background scenes. In fact, participants were explicitly instructed to ignore the backgrounds. As noted before, interference effects were successfully introduced as portrayed by the difference between pure mismatch trials and the lure trials, with the latter producing worse performance overall. However, the interference effects were similar and did not significantly differed between the negative and neutral valence conditions. Thus, it seems that participants were be able to successfully ignore or counteract any potential distraction from highly arousing emotional content when resolving a decision conflict.

Conclusion and Future Directions

Overall, when the affective information is task-relevant (Experiment 1), it appears to have both facilitating and hindering effects on interference resolution depending on the stage of processing of such representations within working memory. However, when the affective information is peripheral to the task at hand (Experiment 2), it does not appear to have observable effects on interference resolution. In sum, when emotional content is both central to the task and interference is produced by information in the region of direct access, then interference resolution is facilitated by emotional content likely through interacting with attentional control and recognition dynamics, such that the parallel processes of familiarity and recollection are more likely to work conjointly to achieve task goals. Finally, when interference arises from activated representations in long-term memory, then interference resolution is hindered by emotional content, as it likely requires more effort for a recollection process to override a misleading familiarity signal.

Furthermore, although the current investigation focused on behavioral performance, a speculation about the potential neural mechanism underlying the effects of emotional content on interference resolution in the current investigation can be hypothesized based on what is known from relevant literature. Levens and Phelps (2008) found that emotional content facilitated (i.e., faster response time) interference resolution in a recency-probes paradigm, and the authors suggested their results likely represented enhanced contextual encoding for emotional information that further facilitates source recognition. In a subsequent study, Levens and Phelps (2010) replicated their previous results and used event-related fMRI to investigate the corresponding neural circuitry. The authors proposed an emotional interference resolution network. In general, they noted that activation of the inferior frontal gyrus (bilateral IFG) was related to interference resolution of both neutral and emotional information (i.e., verbal). In addition, interference resolution of emotional information specifically also differentially engaged the anterior insula and the orbital frontal cortex (right OFC). The authors speculated that while the activation in the anterior insula was likely related to the development of a specific strategy for interference resolution, activation in the OFC was likely related to monitoring of temporal and contextual information for emotional content. Also, in a subsequent study on lesion patients, Levens, Devinsky, and Phelps (2011) concluded that the (left) amygdala was also a critical component of the emotional interference resolution network related to the emotion facilitation effect, and its role was likely related to producing a saliency and arousal signals differentiating emotional from neutral information. Furthermore, in this later study, the authors also conjectured about the role of specific brain regions in the recognition processes (i.e., familiarity and recollection) involved in interference resolution within working memory. Broadly, in resolving interference from emotional content, the authors proposed that the amygdala is involved in the processing of a salience/arousal signal contributing to an increased familiarity signal that differentiates emotional from neutral stimuli. Given that the amygdala and the OFC are highly interconnected, the OFC in parallel produces an enhanced source signal for emotional content (e.g., additional temporal context) in response to the familiarity signal produced by the amygdala. Then, the anterior insula integrates the familiarity and source recollection signals produced by the amygdala and OFC, in order to enact a specific strategy for interference resolution of emotional content. Additionally, the middle frontal gyrus (left MFG) was said to mediate the interaction of emotion processing and attention to task demands, such that it can be said to mediate aspects of control of the focus of attention. Such model of interference resolution for emotional content in working memory is helpful in hypothesizing neural networks supporting the interference resolution facilitation effect for task-relevant emotional content. However, such model was based on verbal stimuli and performance of a different paradigm from the current study. Becerril and Barch (2011) conducted a study using a 2-back task with pictorial stimuli (i.e., faces) comparing patients with schizophrenia and healthy control participants. The 2-back task did not include interference trials and was based on overall performance (accuracy and reaction times) to targets and non-targets. Thus, it is assumed that no significant levels of conflict were introduced to engage interference resolution processes at least in the healthy control participants. However, if we assume an inherent vulnerability to proactive interference in patients with schizophrenia, then they would be expected to experience higher levels of conflict even in such task. Thus, in order to maintain performance, they would need to engage interference resolution processes. In fact, the patient group demonstrated worst performance compared to the control group, which make such assumptions plausible. Furthermore, while the patient group demonstrated a facilitation of performance by negative content, the control group did not. Such results are in line with the current results of a facilitation of interference resolution for emotional content. In addition, neuroimaging (fMRI) findings in this study, can be said to further support such interpretation. Broadly, greater amygdala activity was observed for negative content compared to neutral for both groups. However, while the control group showed decreased activity in bilateral hippocampal regions and MFG for negative as compared to neutral content, the opposite was observed for the patient group. This would be consistent with the proposed function of the MFG by Levens et al. (2011), such that it mediates the interaction of emotion processing and attention to task demands for negative content, and it would be expected to show higher activation with higher levels of conflict. Overall, based on the above findings, it is speculated that the effects of emotional content on interference resolution in the current investigation involve the amygdala producing a saliency/arousal signal contributing to higher levels of familiarity for negative information, and the MFG mediating the interaction between processing and attention to task demands for negative content. In a general sense, the proposed function for the MFG resembles aspects involved in the mediation of the attentional orienting system as postulated by Cowan (1999), such that it supports the regulation of an involuntary attentional orienting response and its habituation. It is difficult to speculate about any specific neural correlates involved in the effects of emotional content on interference resolution that differentiates between the two types of interference effects examined in the current investigation, since no specific studies related to such examination were found in the reviewed literature. However, it would be interesting to investigate if the OFC and anterior insula also play a role when employing a paradigm like the one in the current study, and if they show differential activation for interference resolution when interference is produced by the two types of lures examined in the current investigation.

Since the activation in the OFC is suggested to be related to monitoring of temporal and contextual information for emotional content, then it would be hypothesized to show greater activation for interference resolution when interference is produced by not-yet relevant negative information given the state of accessibility of such representation in the region of direct access. It is unclear if there would be any differences in activation of the anterior insula between the two types of negative lures. However, assuming that interference resolution of information produced by no-longer relevant negative representations involves less access to contextual information and bindings, then a source recollection signals produced by the OFC would be weaker and contribute less to the integration process mediated by the anterior insula in supporting a specific strategy for interference resolution of emotional content.

Clinical implications of the current results can be considered in the context of findings from previous literature. In general, individuals afflicted with cognitive vulnerabilities can be expected to be particularly susceptible to proactive interference. Moreover, individuals with certain impairments in cognition, also often present with emotional disturbances. Given the current results, coupled with previous findings on the effects of emotional content on interference resolution, it would be reasonable to suspect that susceptibility to proactive interference may be related to emotional disturbances in cognitively vulnerable individuals. Although individuals with vulnerable brains have been found to demonstrate facilitating effects of emotional content on working memory performance (Becerril & Barch, 2011; Döhnel et al., 2008), such findings have been based on paradigms in which emotional stimuli is task-relevant and cognitive conflict is relatively low (i.e., no interference trials). It would be interesting to investigate the effects of emotional content on interference resolution from the different interference effects in the present study. Would the facilitating effects of emotional content on working memory be observed in cognitively vulnerable individuals even when using an interference paradigm with high cognitive conflict such as the one in the current study? Or would the added cognitive interference prove detrimental to their brain's ability to use emotional content to compensate for their vulnerability and aid in interference resolution, and therefore override or reverse the facilitating effects? Also, in the case of the observed hindering effects of emotional content on interference resolution for interference produced by no-longer relevant information, it is likely that cognitively vulnerable individuals would show augmented disturbances in interference resolution given their apparently higher sensitivity to emotion effects. Also, it is important to note that the facilitating effects of emotional content on working memory performance are more often seen with negative stimuli. Therefore, when examining the effects of irrelevant emotional content on interference resolution such as in Experiment 2, it is possible that the predicted hindering effects of emotional content would be more obvious in cognitively vulnerable individuals. Overall, the study of the effects of emotion on interference resolution can provide insight into how emotion and executive control might interact to produce certain emotional disturbances in clinical populations with cognitive vulnerabilities.

There were some limitations to the findings of the current investigation. First, there were several factors that differed between Experiment 1 and Experiment 2, which could have had an impact, at least in part, into the lack of significant effects of emotional content on interference resolution in the latter experiment. The two-picture component in

Experiment 2 may have added to the overall task difficulty, such that participants perceived this experiment as more difficult than Experiment 1. In such case, task difficulty could have interacted with top-down control of attention to minimize attentional interference of emotional stimuli and maximize prioritizing of task demands. This would be in line with previous results suggesting that high working memory load can help emphasize top-down control of attention, resulting in the attenuation of attentional interference of negative information (Van Dillen & Koole, 2009). Furthermore, in Experiment 2, explicit instructions were given to ignore the background scenes, thus the task could be successfully performed without having to process/encode the background scenes. Thus, the results of no observable effects of emotion on performance could potentially be due to successfully overcoming an attentional bias toward highly arousing peripheral information given an initial readiness or active removal process due to the experimental instructions. This in in line with results from studies using directed forgetting instructions, which show that a removal process completely eliminates proactive interference (Ecker et al., 2014). This interpretation is also in line with previous results demonstrating that encoding instructions have an effect on 'emotion-related memory trade-offs' (Kensiger, Gutchess, & Schacter, 2007), thus it is possible that a "central/peripheral trade-off" could be reduced with explicit instructions to ignore peripheral information.

In addition, Experiment 2 only included four lists of trials presented in a single block. Adding a second block would have added significant time to the study session, which was avoided in order to minimize effects of fatigue. Thus, there were less trials to contribute to the overall analyses of this experiment. Also, because the two experiments were administered during one study session, possible order effects would be a concern. However, such hypothesis was explored, and the results indicated that order effects were unlikely to have had a significant impact on the overall findings. Interestingly, as it can be observed from Table 2, there was a tendency for match trials in the negative valence condition to produce lower accuracy compared to their neutral counterparts. Hence, it is possible that when the emotional content is peripheral to the task, then maintenance components are more sensitive to the hindering effects of emotion. Such interpretation would be in line with studies using paradigms focusing on maintenance and capacity components that show that affective content can have hindering effects on performance as it adds to the working memory load leading to detrimental effects on capacity (Erk et al., 2007). Therefore, in the future, it would be important to replicate the current findings and continue to optimize experimental conditions for presenting negative content as peripheral to task goals. This is important as it would add to the understanding of how the working memory system deals with distracting emotional information or intrusive thoughts, which is further important in the understanding of the psychopathology of disorder such as anxiety and depression.

Furthermore, the current investigation focused on behavioral performance; however, emotional content has been found to yield differences in the level of activation of ‘cognition-related’ regions (e.g., increased lateral prefrontal activation) when compared to its neutral counterparts even in the absence of corresponding differences in behavioral performance on a verbal *n*-back task (Grimm et al., 2012). However, the *n*-back task used in that study did not include interference trials, and only responses to match trials were recorded and analyzed. Thus, the results were interpreted as possibly reflecting added load to working memory capacity by emotional processing. Thus, in order to further investigate the effects of emotional content on interference resolution, more studies are needed to investigate the neural correlates underlying both the facilitating and hindering effects of emotional content on working memory. Given that no such study was found in the reviewed literature, it would be interesting to investigate the specific neural correlates involved in the effects of emotional content on interference resolution that differentiates between the two types of interference effects examined in the current investigation. The task introduced in the current study (i.e., Experiment 1) provides the opportunity to study both facilitating and hindering effects of emotional content on interference resolution, thus such task would be ideal for studying the particular neural correlates. Furthermore, this task allows for the investigation of executive control aspects within working memory, which adds to the more well researched literature on maintenance and capacity components. Hence, using neuroimaging techniques with the current protocol would allow for the investigation of how affective information is selected from working memory and the effects on interference resolution.

In general, the current results appear to support the conceptualization of working memory as a system that processes information via the allocation of attention to internal representation at different states of activation, which has become a more prominent view in more recent investigations given that it aligns with findings within the cognitive neuroscience literature on working memory (D'Esposito & Postle, 2015). Thus, in order to better understand the facilitating and hindering effects of emotional content on working memory, more studies are needed to continue to elucidate the effects of emotional content and interference resolution as it pertains to the different states of representations within the working memory system. Additionally, only negative pictures were employed in the current study to represent the emotional condition. It would be interesting to look at any possible differences between the effects of negative and positive content on interference resolution; however, including both types of pictures in the same experiment produces challenges when attempting to match the intensity of emotional arousal.

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APPENDIX A

PARTICIPANT CHARACTERISTICS

Table 3. Participant characteristics.

	Experiment 1	Experiment 2
Mean Age (SD)	21 (3.27)	20 (2.27)
# Female/Male	41/18	35/17
Race-Ethnicity		
Asian	16	12
Black	3	3
Hispanic	21	21
White	9	6
Multiracial	10	10
Bilingual	38	33

Participant characteristics including mean age (standard deviation), number of female/male participants, ethnicity, and number of bilingual participants Experiment 1 and Experiment 2.

APPENDIX B

STIMULI CHARACTERISTICS

Table 4. Stimuli characteristics.

	Experiment 1	Experiment 2
Negative IAPS		
Valence (SD)	2.96 (.82)	2.97 (.74)
Arousal (SD)	5.51 (.87)	5.54 (.89)
Neutral IAPS		
Valence (SD)	5.44 (.67)	5.45 (.67)
Arousal (SD)	3.89 (1.05)	3.87 (.98)
# of Pictures	160	94

Stimuli characteristics including mean valence and arousal (standard deviation) for negative and neutral IAPS sets, and number of pictures for Experiment 1 and Experiment 2.