We Are What We Attend To: Individual Differences in Attention and Personality

by

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Abstract

As the gatekeeper of conscious awareness, visual attention plays a formative role in how and what we experience. Visual attention is influenced by a cluster of exogenous (e.g., visual onsets and motion) and endogenous factors (e.g., goals, desires), which work in tandem to influence how visual attention is calibrated in terms of spatial scope (spatial spread) and selectivity (biased enhancement of relevant and suppression of irrelevant information). While the influence of exogenous factors on visual attention has been studied widely, the relationship between endogenous factors, such as personality, and visual attention is less clear. There has been some work exploring the relationship between attention and personality, but this field of interdisciplinary work lacks a unifying theory that operationalizes these relationships. The aim of this thesis is to propose such a guiding framework, the Attention and Personality Framework, and demonstrate how this framework can provide insight into individual differences in visual processing. This framework suggests visual attention is related to specific personality traits. Specifically, Conscientiousness is related to the selectivity of attention, while Openness is related to the spatial scope of attention. The experiments in this thesis provide evidence supporting this hypothesis and demonstrate the utility of this guiding framework. In particular, performance on a task probing the spatial scope of visual attention is predicted by Openness (Inhibition of Return, Chapter 2), while performance on a task probing the selectivity of attention is predicted by Conscientiousness (Localized Attentional Interference, Chapter 3). Further, these relationships are evident in other forms of visual processing that rely on visual attention, such as iconic memory (Chapter 4) and visual working memory (Chapter 5). Taken together, this thesis provides a framework that refines our understanding of individual differences in visual cognition and personality and demonstrates its utility in visual cognition and personality research.
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Chapter 1
Introduction

1 Introduction

“Tell me what you pay attention to and I will tell you who you are.”

- Spanish philosopher Jose Ortega y Gasset

1.1 Aim of Thesis

This quote, by famous Spanish philosopher Jose Ortega y Gasset suggests that attention and personality are intimately related, such that knowledge of one enables an understanding of the other. The scientific exploration of visual attention, however, has developed rather independently from personality research. For instance, the study of visual attention has focused primarily on how attention modulates our perceptual experience, conscious awareness and memory, rather than how attention may interact with more global traits such as personality or temperament. Given that visual attention plays a central role in determining what we experience and learn, might individual differences in how we attend to the world influence or interact with who we are or in other words, our personality?

Our personality, as a complex cluster of behavioural, emotional, and cognitive attributes (Zillig, Hemenover, & Dienstbier, 2002), impacts our preferences and goals and there is abundant evidence that these top-down factors influence how attention is deployed and controlled (some examples: Adamo, Pun, & Ferber, 2010; Adamo, Pun, Pratt, & Ferber, 2008; Folk, Remington, & Johnston, 1992; Hopfinger, Buonocore, & Mangun, 2000). Failing to acknowledge the degree to which differences in how attention may be differentially deployed by individuals during experiments may contribute to inconsistent results in the literature and failed replication. The purpose of this thesis is not to challenge existing models of attention or propose a new theory of attention. Rather,
the aim of this thesis is to address two key questions. First, is there a relationship between individual differences in attentional function and specific personality traits and second, is there some practical utility to understanding how attention and personality may be related?

In response to the first question above I argue that yes, there is a relationship between the tuning of attention and personality, as measured by the Big Five Personality Traits. Further, because of this relationship between personality and visual attention, personality may also predict variance in visual processing that is reliant upon visual attention. Throughout this thesis I will refer to this proposed relationship between visual attention and personality as the Attention and Personality Framework. More precisely, this framework posits that attention and personality are intimately related, as attention plays a guiding role in cognition, as will be outlined in the follow section (1.2), acting on and modifying other cognitive processes altering our experience of the world in fundamental ways. Attentional modulation of core cognitive faculties likely impacts the particular cluster of behaviours, cognitions, and motivations that comprise who we are. That is not to say, however, that the causal relationship between personality and attention is necessarily unidirectional, with attention simply determining our personality. Attention may modulate other cognitive processes, but is itself tuned by what an individual deems to be relevant, which is influenced by task demands, but also by an individual’s particular cluster of psychological attributes, goals and desires. Thus, individual differences in how one attends to the world and personality are likely intimately entwined.

As mentioned above, the second aim of this thesis is to demonstrate the practical utility of the Attention and Personality Framework. If personality and attention are shown to be related, then there should be utility in terms of explaining variance in data that would otherwise remain unexplained. This may help to reconcile some conflicting and/or non-replicable research and lead to some novel insights into individual differences in attention and how they play out in the visual processing stream.

2
Which personality traits are most likely to be related specifically to attention? The most prudent place to start to explore this question is with personality traits that have been highly validated, are operationalized by cognitive characteristics, and for which there is a precedent in the literature suggesting a relationship between these traits and cognition. In particular, we are looking for traits related to cognitive outcomes known to depend on attention. Two of the Big Five personality traits (a widely used and well-validated taxonomy of personality) fit this description, namely Conscientiousness and Openness. Based on previous research and how these two personality traits have been operationalized, the Attention and Personality Framework specifically predicts that Conscientiousness is related to the selectivity of visual attention, while Openness is related to the spatial scope of visual attention. These two aspects of attention – selectivity and scope – will be explained in section 1.3. Further, if this framework is accurate, it would be reasonable to expect these personality traits to also be associated with other cognitive processes, such as iconic memory and visual working memory. Attention is intimately related to these cognitive processes, which will be outlined in section 1.4.

1.2 General Principles of Attention

*The Gatekeeper of Cognition: Deciding Who/What is Important*

Our sensory system receives a plethora of input, exceeding the processing capacity-limited capabilities of our cognitive faculties. The primary function of attention is to help organize and prioritize incoming information. Thus, the term attention refers broadly to an internal mechanism that controls the amount of information processing in a cognitive system. When processing is directed at or guided by the external world, this is referred to as exogenous or perceptual attention; when processing is directed towards or guided by internal mental states and personal goals, this is referred to as endogenous or executive attention (Chun, Golomb, & Turk-Browne, 2011).
Attention has been operationalized through the ways in which it impacts or acts upon other forms of cognitive processing, selecting and modulating the processing of information deemed ‘important’. There are two primary ways in which importance is characterized in terms of attention. Attention can be exogenously directed by saliency, which typically is triggered by or attracted to stimuli that are biologically determined to be important and have a rather automatic influence on directing attention. For instance, loud noises, quick movement, or flashing, and bright lights or colours attract attention (Theeuwes, 1991; Theeuwes & Burger, 1998; Yantis & Jonides, 1984; Yantis, 1996). Attention can also be endogenously directed by relevance, which is characterized by personally relevant goals, such as abiding by task demands, and is largely under an individual’s control (Hopfinger et al., 2000; Posner & Petersen, 1989). Interestingly, a stimulus that may not be particularly salient, in the biologically important sense mentioned above, may actually attract exogenous attention, depending on transient states of the individual, which is discussed further in section 1.6. As such, attention is guided by information deemed salient or relevant in a given moment and in the next section I will look at the influence attention has on information processing.

**What Attention Does: Attentional Modulation & Selection**

Attention is characterized by its effects on other cognitive processes and behavioural outcomes and it acts through the mechanisms of modulating processes (facilitating, up-regulating) and selective processing (inhibiting, biasing) (Chun et al., 2011). The effect of modulated processing is demonstrated in a prototypical attention task, the Posner Cueing paradigm. In these paradigms, individuals' attention is directed by an exogenous spatial cue (pre-cue appearing less than 200ms prior to the target), pointing at or highlighting a location where a target will appear. The cue spatially guides the focusing of resources on the expected location of the target and performance is enhanced (increased accuracy and decrease in reaction times) relative to when a target appears at an un-cued location (Posner, 1980; Posner & Boies, 1971; Posner & Cohen, 1984; Posner & Petersen, 1989).
Attention does not always speed up responses to cued locations, however, as demonstrated by the phenomenon of Inhibition of Return (IOR). IOR paradigms are quite similar to Posner Cuing paradigms, with the exception that the target appears at a longer latency following a spatial cue and the cues are irrelevant and non-predictive of where the target will actually appear. It is believed that IOR reflects a bias towards novel locations over previously attended ones, by temporarily inhibiting the return to already searched locations, which facilitates search efficiency (Klein & MacInnes, 1999). For instance, if I am looking for my dog’s green leash, my ability to search efficiently depends on my capacity to remember the places I have already looked. Thus, IOR can be thought of as an attentional bias away from already attended locations, a process that is mediated by the storage of these locations in visual working memory (Castel, Pratt, & Craik, 2003).

Thus a processing ‘enhancement’ does not always reflect a speeding up, as in the case of IOR, where search efficiency is enhanced, while target responses at cued locations is actually inhibited. Not all attention effects, however, are based on spatial constraints. Attention is also guided by objects, showing enhanced processing when targets appear within an attended object compared to another equidistant location (Egly, Driver, & Rafal, 1994) and features within a given area (e.g., colour, orientation, motion direction) (Folk et al., 1992).

A defining characteristic of attention is its selectivity, operationalized as the selective enhancement of important (i.e. relevant or salient) information. What differentiates this mechanism from a general modulatory effect – as observed in the classic Posner Cuing paradigm – is that selectivity occurs in the face of irrelevant or distracting stimuli. Selectivity thus involves a critical inhibitory mechanism that suppresses irrelevant stimuli and information processing. When searching a crowded restaurant for a friend or focusing on a friend’s speech amidst noise, selectivity suppresses the processing of visual and auditory distractions.
The two mechanisms of attention noted above – modulation and selection – act on information processing across visual, auditory, tactile, perceptual, emotional, social, or internally represented (e.g., thoughts and memories) faculties. Given the vast domain over which attention operates there is a necessity to focus the present thesis in one area. Given the large body of work in the area of visual processing, the present thesis focuses on the domain of visual attention and its operation within the visual processing stream, from perception to iconic memory to visual working memory (VWM).

1.3 Visual Attention: Selectivity & Scope

Mechanisms of Selective Visual Attention

In visual processing, attention tunes the ability to select important information (target item/feature) among other items that compete for representation. Competition often arises from objects that are featurally similar and/or are close in physical proximity to target/important items. The selectivity of visual attention ‘chooses’ a relatively narrow range of visual inputs for additional processing and transfer in visual memory (Moore & Egeth, 1997). While selective attention is restricted by capacity limitations (Jonides, 1980; Yantis & Jonides, 1984), it does confer an enormous computational advantage and is essential for cognition. For example, consider the task of looking up a phone number online. Without selective attention we would not be able to focus on the relevant numbers on the computer screen or inhibit the other numbers and visual information on the screen that compete for representation. Selective attention is also critical to more complex forms of cognition, such as the ability to fixate on relevant information when solving a complex arithmetic problem (Wiley & Jarosz, 2012) or engage in rule-based learning (DeCaro, Thomas, & Beilock, 2008).

The Biased Competition Model of attention (Desimone & Duncan, 1995) can account for a broad range of the effects on visual processing exerted by selective attention. For example, when
multiple stimuli are presented within the same receptive field of a visual neuron, activation of that neuron is reduced or inhibited as a result of competition between stimuli (Kastner, De Weerd, Desimone, & Ungerleider, 1998). However, if one selectively attends to one area of space or one type of stimuli, neural activation is enhanced for the attended stimuli, thus attention acts to bias a neural signal in favour of an attended stimuli (e.g., Moran & Desimone, 1985; Spitzer, Desimone, & Moran, 1988).

There is also ample behavioural and electrophysiological evidence that attention functions as a mechanism of biasing processing in the face of competition or interference through a process of selection (e.g., Luck, Girelli, McDermott, & Ford, 1997). For instance, a common way in which the selectivity of attention is challenged by interference is exemplified by a Localized Attentional Interference (LAI) paradigm. In a typical LAI experiment individuals are shown a circular array composed of placeholders and a single target (the letter ‘T’) and single distractor (the letter ‘L’) appear on the screen (random orientation, right side up or up-side down). Participants are simply required to report the orientation of the “T” (right side up or up-side down), however, the challenge here is that the distractor ‘L’ shares featural similarities to the target ‘T’. The task requires selective attention to inhibit further processing of the distractor. The degree of interference is manipulated through the spatial proximity of the distractor to the target. The closer the target and distractor are to each other, the more distractor related interference arises as the distractor competes for representation and target discrimination is consequently impaired (Hilimire, Mounts, Parks, & Corballis, 2009, 2010; McCarley, Anderson, & Kramer, 2007; McCarley & Mounts, 2008).

In humans, these effects of selective visual attention can be seen behaviourally and electrophysiologically as early as 100 milliseconds (ms) into processing, as reflected by the event-related potential (ERP) P1 component (Mangun, Buonocore, Girelli, & Jha, 1998). In LAI paradigms these attention affects can be observed as they cascade into modulating effects in later
ERPs, such as the N2pc (200ms), and the Pte, (300ms) (Hilimire et al., 2009, 2010). Interestingly, individuals differ in terms of their selective visual attention, as selectivity (ability to overcome interference) on the LAI task declines with age (McCarley, Mounts, & Kramer, 2004). Further, this selectivity mechanism of visual attention is particularly important for gating VWM, which will be discussed in more detail in section 1.4 and 1.5. The LAI paradigm illustrates how the selectivity of attention can be challenged, but it also highlights the important role that space plays in visual attention.

*The Scope of Visual Attention*

Visual attention is not only characterized by and vary in terms of selectivity, but it also can be characterized by and vary in terms of spatial scope. Visual attention typically has a spatial component to it, as exogenous visual selection occurs within space and changing the scope or spatial spread of attention impacts selective attention (Belopolsky, Zwaan, Theeuwes, & Kramer, 2007). The Zoom Lens Model of attention draws the analogy of spatial distribution of attention being akin to the lens of a camera (Eriksen & St. James, 1986; Eriksen & Yeh, 1985). This spatial model of attention is based on the observation that the spatial distribution and degree of selectivity of attention seem to vary flexibly based on transient external factors, such as task demands (Eriksen & St. James, 1986; Posner & Petersen, 1989). Attentional selectivity and scope, however, are somewhat interdependent, just as a camera lens when zoomed out may capture a vast landscape, but with lower resolution on particular features of that landscape. This pattern of behaviour is evidenced by studies of visual attention, where participants are asked to attend to and detect targets in cued regions of space, which are varied in size. When a larger region of space is cued the spatial scope of attention spreads around that cued region. Consequently, attentional resources spread more diffusely and there is a cost, in terms of accuracy and reaction time, in discriminating target items, relative to conditions where the cued region is smaller and the attentional scope is more narrow (Eriksen & St. James,
The experiments mentioned thus far demonstrate how the scope of visual attention can be cued and controlled, but there is also evidence in favour of a natural or endogenous scope or spread to attention. In other words, when a particular item is visually selected there is a degree to which attention spatially spreads around that selected item.

An endogenous spatial spread to visual attention has been insightfully demonstrated using IOR paradigms. Research shows that the inhibitory mechanism that prevents people from re-attending to a previously attended location (IOR), is not restricted to precisely the cued location, but spreads within the cued hemifield (Collie, Maruff, Yucel, Danckert, & Currie, 2000). In a modified version of an IOR task, Bennett and Pratt (2001) systematically varied the distance between cue and target over many locations, which revealed, with a high degree of resolution, the spatial distribution to IOR (RTs decrease with distance from cue). Given that IOR is driven by where attention has been, this task provides an index of the inherent spatial scope or spread of attention around a cued item/location.

When the scope of visual attention is spread more broadly there may be a cost in terms of the degree of selectivity, however, there may be advantages to this more diffuse tuning of attention. For instance, a broader scope of attention likely facilitates efficient computation of spatial ensemble statistics (Alvarez, 2011) and discovering connections between remote associations (Rowe, Hirsh, & Anderson, 2007), presumably by pooling information across a greater range of environmental stimuli. A greater spatial spread of attention may also be advantageous in some forms of search (Smilek, Dixon, & Merkle, 2006; Smilek, Enns, Eastwood, & Merkle, 2006), information-integration learning (DeCaro et al., 2008) and creative or insightful problem-solving (Wiley & Jarosz, 2012).
A Combined Model of Selectivity and Scope of Visual Attention

The Zoom Lens Model and Biased Competition Model can work together, as the Zoom Lens Model provides a conceptual framework that captures the spatial movement of attention and the impact of spreading limited visual resources, while the Biased Competition Model provides a neural mechanistic description of how attention does what it does. A study by Müller, Bartelt, Donner, Villringer, & Brandt, (2003) demonstrates how these two models work in tandem in the visual system. In this fMRI study, participants were pre-cued to attend to regions of space that varied in size and were asked to detect whether a target item was present on a given trial (present 50% of the time). The results showed a spatial spread of activation in retinotopic visual areas that corresponded with the size of the cued region, such that a larger cued region was associated with a diffusion of activation across retinotopic regions, however, the magnitude of activation in any particular region was lower (Müller et al., 2003). The spatial spread of attention in retinotopic regions also corresponded with behaviour, specifically a decrease in target accuracy. Thus, the spatial spread of attention in the visual system appears to result in a trade-off between spatial spread and the extent to which a single item can be selected and represented via biased competition. The Biased Competition Model and Zoom Lens Model are not antithetical, but rather when combined offer a more complete theory of visual attention, accounting for both selectivity and scope. Though selectivity and scope influence each other, it is unclear the degree to which the calibration of these two features of attention may differ between individuals (i.e., the degree of spatial scope relative to selectivity).

Capacity Limitations and the Tuning of Selectivity and Scope in Visual Attention

Visual attention is a capacity-restricted resource, with limitations on the region of space that can be attended (Eriksen & St. James, 1986) and the number of objects that can be selected and
enhanced at once (Intriligator & Cavanagh, 2001). There is also ample evidence of individual differences in visual attention (discussed in Sections 1.5 - 1.7). The spatial spread of visual attention can have an effect of reducing the degree of selectivity (Eriksen & St. James, 1986), however, there may be individual differences in how these two aspects of attention are tuned. For instance, some individuals may naturally distribute their attention more broadly. For some of these individuals, this broad scope of attention may impact selectivity, while for others selectivity may be relatively preserved. Others may prioritize selectivity and this may be associated with a concomitant narrowing of scope where the degree to which attention is narrowed varies between individuals.

The degree to which there is a trade-off between breadth of scope and selectivity likely depends upon individual differences in the amount and control one has over their attentional resources or in other words, one’s attentional capacity. Individual differences in attentional capacity are closely linked to other forms of visual cognition and some argue that attentional capacity is actually what determines the capacity limitations of other cognitive faculties such as VWM (Cowan, 2001; Cowan & Morey, 2006). It is possible that individuals have an endogenous propensity to preference visual attentional scope over selectivity or vice versa. There may also be individual differences in the extent to which one can distribute the scope of attention while maintaining a functional amount of selectivity (e.g., how much attentional resource is required to bias the system or select sufficiently to meet task demands). Arguably, differences in the utilization and capacity of attentional resources may interact with more stable aspects of who we are. In other words, we may each have an attentional style that is linked to more stable traits that may predict or explain variance in other forms of visual cognition, such as iconic memory and VWM, where the calibration of visual attention has great influence.
1.4 Attention in the Visual Processing Stream

Visual attention plays a critical role in the visual processing stream, from perception to visual memory. The first few sections have focused on the role of attention primarily in perceptual tasks or the first phase in the visual processing stream. Figure 1 provides a pictorial representation of visual selective attention in a typical attentional cuing paradigm, where attention is guided by a cue that arrives prior to (pre-cue) or simultaneously (simu-cue) with visual information. The ‘pre-cue’ guides selection of a particular region within the attentional scope, concentrating resources on that location and affording transfer of that information into VWM with a relatively high degree of resolution or precision. This graphic also provides a representation of the visual processing stream when visual information has been removed and information must be selected and stored in visual memory. This figure illustrates the critical role attention plays for visual processing, from perceptual processing to broad but fleeting storage in iconic memory, to capacity-limited durable storage in VWM. In this section I will briefly review the two forms of visual memory that follow perception and the role visual attention plays in these stages of visual processing.

Iconic Memory

After the initial perceptual processing stage, visual information can be held briefly in a relatively large (75% of the content of visual perception), but fragile (rapidly decaying, within 300-500ms), visual memory store known as iconic memory (Gegenfurtner & Sperling, 1993). Here, attention is used to select a subset of the rapidly decaying information for transfer and further processing in visual short-term or working memory. Information that has not been selected fades from awareness faster than it can be reported, thus partial report methods have been used to estimate iconic memory capacity, where a subset or single item in the array is cued. This method has revealed that individuals can report the identity of just about any item in an array, where arrays are typically around 8-12 items, if the cue arrives quickly (within 50ms) after the stimulus is removed.
and the cue is relatively specific (cuing a single item or a few items in a small region of space). Given that participants do not know where the cue will appear, this cued or partial report method provides evidence that all items are initially represented equally in iconic memory. This partial report procedure is in contrast with whole report procedures that require individuals to report all items in a display and do not involve cuing of any specific items or regions of space. Whole reports typically result in the accurate report of about 4 items, which reflects the temporal rate of decay in iconic memory and the capacity limit of VWM (Sperling, 1960). On a typical iconic memory task, performance decays exponentially as a function of time, however, performance asymptotes at an individuals' VWM item capacity (Dick, 1974; Gegenfurtner & Sperling, 1993; Sperling, 1960). Attention, however, plays two important functions in iconic memory, in terms of determining what enters iconic memory and selective transfer into VWM.

The initial spatial scope of attention plays a central role in determining what enters iconic memory (see Figure 1), as the spatial allocation of attention and iconic memory share largely overlapping neural resources (Ruff, Kristjánsson, & Driver, 2007). Once information is encoded in iconic memory, selective visual attention then selects a few elements of this iconic representation for further consolidation and maintenance in a more durable format, in VWM (Gegenfurtner & Sperling, 1993; Sperling, 1960). As can be seen in Figure 1, there are two phases of selection in iconic memory, pre-cued or un-cued selection, which occurs when the temporal delay between the memory array (or the perceptual experience itself) and the probed item (the item that is to be recalled or reported) is long enough that the memory representation starts to fade. Items are then selectively transferred to VWM, before the probe item arrives. When the probe item arrives, and if there is still room in VWM, that item is transferred to VWM and reported (Gegenfurtner & Sperling, 1993). As information moves through the processing stream, from veridical to mnemonic representation, the amount of information that can be represented in mind is dramatically restricted.
from about 75% of the perceptual input down to about 3-4 items. There is also evidence of a shift from parallel processing, which occurs initially in iconic memory to more serial and selective processing (Dick, 1974). The central point here is that visual attention is paramount to how information is represented in iconic memory and what information is chosen for further processing in the visual stream. Therefore, variance in how the scope of visual attention is distributed and the selectivity of visual attention is deployed are likely to have important consequences for visual memory.

*Visual Working Memory*

Visual working memory is a more robust form of visual memory than iconic memory, yet there are greater capacity restrictions on this critical cognitive function, which enables us to hold and manipulate information in mind. VWM studies reveal that VWM has a behavioural capacity of about 3-4 items on average in healthy young adults. This behavioural VWM item capacity is also reflected in the brain, as revealed in both electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) studies. The contralateral delay activity (CDA) is a widely used electrophysiological measure of an individual’s item capacity, as the amplitude of this event-related potential (ERP) increases with each additional item added to a memory array and encoded in VWM, but does not continue to increase once the memory array reaches an individual’s behavioural capacity (Vogel, McCollough, & Machizawa, 2005). This electrical activity at the scalp likely originates in the parietal lobe, as activity in this region shows a similar increase with memory load and also asymptotes at one’s behavioural capacity (Todd & Marois, 2004). Selective attention, however, plays an important role in determining what enters VWM, which is reflected in frontal activity that precedes this scaling activity in the parietal lobe (McNab & Klingberg, 2007).
Unsurprisingly, the average item capacity limit derived from many VWM studies is consistent with the early findings in the iconic memory literature, where whole report methods consistently resulted in participants only being able to reliably report on 3-4 items (Coltheart, 1980; Dick, 1974; Gegenfurtner & Sperling, 1993; Sperling, 1960). However, VWM capacity may not be best conceptualized as simply holding any 3-4 items, regardless of what those items are. The number of items that can be stored appears to be impacted by the complexity of those items (Alvarez & Cavanagh, 2004; Wilson, Adamo, Barense, & Ferber, 2012) and there appears to be a trade-off in the precision of memories as more items are added to a display (Bays, Catalao, & Husain, 2009; Bays & Husain, 2008). Taken together, there is good evidence suggesting that VWM is best described by a continuous resource model. There is consistent research showing that individual differences in VWM item capacity are the result of inefficient or ineffective selective attention, however, there has been less work exploring how information may be differentially represented within VWM.

Figure 1. The Visual Processing Stream: The amount of information that can fall within the scope of attention is limited, relative to the amount of information that enters as visual perceptual processing. When the visual input is removed, information that was within the scope of attention is transferred into iconic memory, where the iconic
representation quickly fades. During this time, if no cue has appeared the fading representations trigger pre-cued or uncued selective attentional transfer of items into VWM. Once a cue appears, a particular item may then be transferred to VWM for report, if VWM is not already at capacity from the un-cued selectively transferred items.

1.5 Individual Differences in VWM and Selective Visual Attention

There are individual differences in VWM item capacity or the amount of information that an individual can store (Vogel et al., 2005). A large body of research suggests these differences are largely driven not by VWM storage capacity per se, but rather by individual differences in the filtering efficiency of selective attention (Awh & Vogel, 2008; Awh, Vogel, & Oh, 2006; McNab & Klingberg, 2007; Todd & Marois, 2004; Vogel et al., 2005). When low VWM capacity individuals are presented with displays containing task-irrelevant items they exhibit an increase in the amplitude of an electrophysiological correlate of VWM, the CDA. This increase is taken to indicate that individuals with low VWM capacity do not sufficiently engage the selectivity of attention, allowing irrelevant information to consume VWM resources (Vogel et al., 2005). High VWM capacity individuals, on the other hand, do not show an increase in the CDA when task irrelevant items are in a memory display, suggesting that they are able to ignore irrelevant information, selecting only relevant items. These results suggest that variance in VWM may not be the result of differences in memory item capacity (storage space) per se, but rather, may arise from individual differences in how this resource is utilized.

Visual selective attention, as the executive control mechanisms of VWM (Baddeley, 1996; Baddeley & Hitch, 1974), determines how resources in VWM are organized and distributed and it has been argued that the capacity limit of VWM in fact reflects an attentional capacity (Cowan, 2001). Thus the interaction between attention and VWM likely extends beyond the ability to select items prior to encoding in VWM, as Vogel et al., (2005) suggest. There may be individual differences in the way information is stored (e.g., precision), bound (e.g., stability of feature and location
binding), or selected within VWM (e.g., selective forgetting or dropping items after initial storage). It is unclear where these individual differences in attention arise from or how to predict them. There is evidence, however, that the scope and selectivity of visual attention may be differentially tipped by internal transient states such as mood or emotion (Rowe et al., 2007; Schmitz, De Rosa, & Anderson, 2009). Visual attentional scope and selectivity may also be influenced by more stable traits, such as temperament, which predict individual differences in selective attention (Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005).

1.6 Transient States of the Observer Modulate Visual Attention

As mentioned earlier, attention is guided by what is deemed ‘important’ in a given moment, which can be driven by salience or relevance. This distinction between salience and relevance or endogenous and exogenous attention is not as clear cut in practice, as something that might typically be enhanced by endogenous attention in one situation or in one moment may capture attention more exogenously in another (Folk et al., 1992; Folk, Remington, & Wright, 1994) and this shift has much to do with the particular task and shifting goals of the individual. To illustrate the dynamic and somewhat transient interplay between exogenous and endogenous attention I will use an example of how holding the endogenous goal of finding an object can impact how things in the environment may capture one’s attention. Returning to the example of what happens when I am searching for my dog’s green leash, my attention is tuned to enhance my response to and awareness of other green items, which is referred to as an attentional set (Adamo et al., 2010, 2008, Folk et al., 1992, 1994). This research on attentional sets shows that when I hold the goal of finding an item with a particular feature (e.g., green leash) my attention is more likely to be drawn to or captured by other items around my house and out in the world that are green and suddenly my experience of the world becomes a little greener. Thus my particular goals have a way of directing or calibrating attentional selection in a way that can influence my perceptual experience of the world, in order to
potentiate the likelihood of goal achievement (e.g., homing in on green things to find the green leash).

Attention is not only influenced by cognitive goals and perceptual or sensory properties, but also by internal transient states of the individual, such as emotions. Positive emotions, like joy, seem to broaden attention, while negative emotions, like fear, can narrow or constrict attention (Fredrickson, 2001; Fredrickson & Branigan, 2005; Lundqvist & Ohman, 2005; Schmitz et al., 2009). This emotional tuning of attention helps explain why problems that require more open, creative problem-solving are improved by the attention-broadening effect of positive mood (Rowe et al., 2007; Subramaniam, Kounios, Parrish, & Jung-Beeman, 2009), while performance on problems that rely on a higher degree of focus and selectivity may benefit from the focusing of attention related to some negative emotions (Becker, 2009). Thus, the tuning of visual attentional selectivity and scope varies based on transient states of the individual, such as goals, task demands, and emotional state, which impacts other forms of cognitive processing (e.g., search and problem-solving). When various transient states are more stable or predictable within an individual, these persistent states are classified as traits. For instance, if someone experiences frequent states of anxiety or negative thoughts that individual may be characterized as having trait anxiety or trait neuroticism. Given that attention is influenced by these transient states or how an individual’s attention changes across task conditions or time, the question follows: might attention be tuned by more stable aspects of who we are, those traits that vary between individuals but are more stable over time?

1.7 Evidence of Individual Differences in Visual Attention

The capacity of visual attention, as mentioned earlier, is often referred to in terms of the number of items that can be individuated and identified within a given region of space. However, attention is also restricted in terms of time, the rate at which items can be attended and identified when presented in serial sequence. There is evidence of individual differences in this temporal...
capacity of attention. The temporal limitation of attention is defined by the rate at which rapidly presented items can be differentiated and identified. Temporal restrictions on attention, however, seem to arise from the ability to control the allocation of attentional resources, rather than absolute temporal thresholds per se. The phenomenon known as the *Attentional Blink* (AB) can be used to explore the temporal dynamics/thresholds of attention (Raymond, Shapiro, & Arnell, 1992; Shapiro, Raymond, & Arnell, 1997). AB is characterized by a reduction in accurate identification of the second of two stimuli that appear in a rapid serial visual processing (RSVP) stream (within 500ms). In terms of sensory stimulation, both items are ‘seen,’ as individuals can report the second target (T2) if instructed to ignore the first target (T1). The phenomenon of missing T2 only emerges when T1 is attended and appears to result from an over-investment of attentional resources allocated to T1, leaving too few resources for the processing of T2. In effect, the insufficient dedication of attentional resources to T2 often results in a failure of T2 to reach conscious awareness. In accordance with this notion, reducing attentional engagement to T1, for instance by introducing a secondary task, reduces the AB, preserving T2 accuracy (Olivers & Nieuwenhuis, 2005, 2006). Interestingly, there appears to be a relationship between this temporal aspect of attention and the spatial scope of attention (Arend, Johnston, & Shapiro, 2006) and important to the present thesis, individual differences in how an individuals distributes their attention impacts the AB (Dale & Arnell, 2010).

An experiment by Arend et al. (2006) provides evidence that manipulating the attentional scope in individuals alters the AB. Arend et al. (2006) used a central RSVP AB task, but surrounded the display with motion either expanding outwards, which exogenously broadens attention or contracting inwards towards the central AB task to exogenously narrow attention. The expansive motion and broader attention had an effect of reducing the AB, suggesting that the diffusion of the spatial scope of attention can alter temporal boundaries or limitations to attention. One of the key
mechanisms here is that the broader attentional scope likely results in a reduction in the selective overinvestment of resources in any one item (e.g., T1), thus preserving resources for T2 processing. This provides an example of how differences in attentional scope may impact the way attention is deployed can alter typical attentional processes.

Research shows that the AB is not only altered by changing task demands or properties of a stimulus, but it is also predicted by more stable trait-based individual differences, as well as transient shifts in one’s state. For instance, the size of one’s AB can be predicted by a task that measures the degree to which one endogenously gravitates towards diffuse/global processing or more narrow/local processing, as measured by a Navon task (endogenous global vs. local bias). This research reveals that individuals that show an endogenous global bias (more broad attention) have a smaller AB and those with more of a local bias (narrow focus of attention) have a larger AB (Dale & Arnell, 2010). Further, transient shifts in an individual’s state, such as emotion, also impact attentional scope and the AB. For instance, it has been shown that positive affect, which has an effect of broadening attention, reduces the attentional blink, while negative emotion narrows attention increasing the attentional blink (Ashby, Isen, & others, 1999; Jefferies, Smilek, Eich, & Enns, 2008; Olivers & Nieuwenhuis, 2006). Taken together, these studies provide evidence that both stable traits and transient states modulate the scope of visual attention, impacting the temporal dynamics of attention and what individuals perceive. The degree to which performance on the Navon task, the measure of global or local bias, is stable or trait-based is a bit unclear form the research mentioned here. There is, however, evidence of that stable traits/attributes, such as personality, predict global/local processing biases and individual differences in the scope and selectivity of attention.
1.8 The Big Five Personality Traits and Visual Attention

The Big Five is a well-validated personality model that posits Openness, Conscientiousness, Extroversion, Agreeableness, Neuroticism as primary personality traits. Each of these five traits are largely independent and remain stable over the lifespan (Costa & McCrae, 1992; Soldz & Vaillant, 1999). Two of the Big Five traits appear to be particularly closely related to cognitive factors: Conscientiousness (characterized by being competent, orderly, dutiful, achievement/goal oriented, self-disciplined, and deliberative) and Openness (characterized by being imaginative, creative, emotionally aware, adventurous, intelligent, and liberal). These traits are operationalized by or are composed of more cognitive attributes (based on personality scales) than the other five personality traits (Zillig et al., 2002). One of the ways the validity of a scale and a latent variable like personality is operationalized is by looking at behavioural outcomes that those traits predict. There is good consistency here, as Openness and Conscientiousness are predictive of many cognitive outcomes in life and in the lab. Further, many of these outcomes are arguably reliant on attention. For example, Openness and Conscientiousness are predictive of academic success (Furnham, Chamorro-Premuzic, & McDougall, 2002; O'Connor & Paunonen, 2007), career success (Judge, Higgins, Thoresen, & Barrick, 1999), as well as specific cognitive processes, such as latent inhibition (Peterson, Smith, & Carson, 2002), decision making, degree of cognitive flexibility (LePine, Colquitt, & Erez, 2000) and learning styles (Komaraju, Karau, Schmeck, & Avdic, 2011). Thus there is some evidence that an underlying cognitive style is tied to these two personality attributes, with Openness being characterized by a generally more ‘open’ and flexible cognitive style. Conscientiousness is characterized by a more ‘focused’ and diligent cognitive style. An overarching theory of how attention and these personality traits relate may help to explain some of these relationships between personality and cognitive outcomes.
1.9 Visual Attention, Openness and Conscientiousness

The inferential connection between Openness and the spread or spatial scope of attention in part emerges from the fact that Openness is largely operationalized by cognitive factors (Goldberg, 1992). Zillig et al., (2002) explored the extent to which each of the Big Five personality traits are operationalized by cognitive, affective, or behavioural characteristics. In this study many different raters were used (3 groups, ranging from highly experienced clinical psychologists to psychology graduate students, to undergraduate students) to assess each item on various Big Five inventories. These raters characterized the items in these inventories in terms of whether each item probed cognitive, affective or behavioural attributes. The results showed good consistency between raters and importantly, Openness was characterized more heavily by cognitive attributes. The other factor for this proposed connection between Openness and attentional scope is that several behavioural studies suggest Openness may be associated with a greater breadth of processing, which is consistent with a broader scope of attention.

If Openness is operationalized as a personality trait tied to cognitive outcomes, then Openness should be a reliable predictor of cognitive performance in the lab. Further, if Openness is associated with a broader spatial scope of attention, then Openness should be predictive of cognitive performance that arguably relies on or reflects a broader scope of attention. There is research that does in fact support this connection. For instance, Openness is associated with reduced latent inhibition and greater distractor processing (Peterson et al., 2002), which according to the Zoom Lens Model is an expected consequence of a broader scope of attention. A broader attentional scope may also explain the type of divergent, creative and flexible cognitive style those high in Openness demonstrate (McCrae, 1987). A greater spread of attention, as revealed by the foundational work of Eriksen & St. James and later neuroimaging evidence of Müller et al., 2003, is associated with a decrease in one’s ability to ignore distractors (inhibitory control), however, it is precisely this broader
scope that may facilitate the broad or divergent flexibility that Open individuals show as they adapt to novel rules and changes in task context, resulting in better decision making (LePine et al., 2000).

Recently, researchers have begun to explore the relationship between personality and some forms of attention. For instance, Wu, Bischof, Anderson, Jakobsen & Kingston (2014) have shown that attention deployed in a search task with social scenes varies with personality. These researchers measured eye movements, commonly used as an index of the direction and movement of attention, during scene viewing. Individuals were shown images of scenes of humans interacting, fractals, and landscapes and were free to visually explore the images. Wu et al., (2014) predicted that Open individuals would show greater fixations and more attention to the faces and eyes in the scenes with humans, given that this trait is associated with emotional intelligence. Interestingly, the authors found that Openness actually predicted fewer fixations on the eyes and faces and more diffuse fixations across the display in general. The movement of attention towards faces and eyes was predicted by Extroversion and Agreeableness, suggesting that attention may be guided more by social factors in individuals that are higher in these traits. The authors suggest that perhaps viewing images of people is not sufficiently socially engaging to motivate social attention in Open individuals. They go on to suggest that the diffuse eye movements of Open individuals may serve to help them extract meaning and/or create a narrative about the scene, as these individuals tend to be creative and apt at generating narratives (McAdams et al., 2004). Without asking the participants what they are actually doing, however, it is difficult to say whether they are constructing a narrative. The Attention and Personality Framework may offer a more parsimonious interpretation of these data. The more broadly distributed fixations observed in Open individuals may simply reflect a more diffuse attentional style inherent to trait Openness, which drives their looking behaviour and how they visually traverse a scene. This more diffuse attentional style may drive a broader scope of attention as well.
Consistent with this inference, that Open individuals have more diffuse eye movements, there is some evidence that a quality that is characteristic of Open individuals is associated with more diffuse eye movements. Trait Curiosity, which is closely related to Openness (Kashdan et al., 2009) as they both load onto the same factor and appear to measure a single latent variable (Silvia, 2008), is linked to more diffuse eye fixations when viewing natural scenes (Risko, Anderson, Lanthier, & Kingstone, 2012). Open and curious individuals may have a novelty seeking drive that motivates a more diffuse attentional style. More recent evidence further corroborates these findings, showing Openness is related to a decreased susceptibility to inattentional blindness, which is the failure to notice unexpected changes in a scene when attention is narrowly focused (Kreitz, Schnuerch, Gibbons, & Memmert, 2014). Open individuals’ broader spatial scope of attention (e.g., casting a broader attentional net when searching a scene) may be the mechanism that underlies this resistance to inattentional blindness.

A study by MacLean and Arnell (2010) provides further evidence in support of this relationship between Openness and a broader scope of visual attention. The authors explored whether personality is related to the AB. As outlined in the section above (1.7), AB is decreased by the diffusion of attention and increased by the narrowing of attention. Conscientiousness has been associated with more cognitive perseveration and fixation and Openness with more cognitive flexibility (LePine et al., 2000), thus these researchers hypothesized an increase in AB with Conscientiousness and decrease with Openness. More specifically, Openness should be associated with a smaller AB (better processing of T2), while Conscientiousness should be linked to greater attentional investment/perseveration on T1, impairing T2 processing. The results showed that Openness was associated with a greater accuracy for T2 overall and reduction in AB magnitude (T2 at Lag8 minus Lag3), while Conscientiousness was associated with lower T1 and T2 accuracy. The authors concluded these findings are due to differences in cognitive control and flexibility. This
explanation however, does not explain or address the question of why these individuals have more cognitive control/flexibility or what the underlying mechanism is. The Attention and Personality Framework may offer additional explanatory utility here.

The effects observed by MacLean & Arnell (2010), along with the results showing variance in AB magnitude with attentional scope/focus (section 1.7), are better explained by one unifying theory. The Attention and Personality Framework offers the interpretation that these findings are related to an underlying attentional disposition inherent to Openness (broad spatial scope) and Conscientiousness (narrowly focused selective attention). As attention responds to one’s goals and motivations, attention is differentially tuned with resultant changes in visual and perceptual processing. This provides an explanation as to why we might expect these results and what mechanisms may underlie the finding. Taken together, this research showing greater cognitive flexibility, susceptibility to distractors, and enhanced T2 processing in AB in Open individuals provides good reason to suspect that Openness may be associated with a broader distribution and spatial scope of visual attention. Given that selectivity and scope are linked, to a certain extent, the broader scope in Open individuals may or may not result in selectivity impairments. It is possible Open individuals have a greater range over which they can spread visual attention, while maintaining selectivity.

This work on the AB provides some evidence that Conscientiousness is also related to visual attention, however MacLean and Arnell (2010) do not provide a clear account of why these individuals seem to have difficulty processing both T1 and T2. This may indicate more rigid selective attentional engagement and a difficulty flexibly and quickly shifting attention across items in the visual stream. There is some evidence suggesting that the selectivity of visual attention and Conscientiousness may be linked.
Conscientiousness and Selectivity

The hypothesized relationship between the selectivity of attention and Conscientiousness arises from the fact that this personality trait is also operationalized as a more cognitive personality trait (Zillig et al., 2002). The diligent, focused, but more rigid cognitive style of Conscientious individuals corresponds with greater difficulty integrating novel rules/contexts, resulting in weaker decision making in some contexts in a lab-based decision making task (LePine et al., 2000). This is the type of behaviour one might expect of an individual that had a highly focused and selective attentional style. Thus, selectively focusing attention may be intimately related to Conscientiousness. The controlled ability to selectively focus attention is also referred to as executive control or executive attention (Petersen & Posner, 2012; Posner & Petersen, 1989) and it has been argued elsewhere that Conscientiousness is specifically related to executive control (Williams, Suchy, & Rau, 2009). Performance on a classic executive control task is a go-no-go task, which requires individuals to inhibit a proponent response, is predicted by trait Conscientiousness (Rodrigo et al., 2016; Sosic-Vasic, Ulrich, Ruchsow, Vasic, & Grön, 2012). Further, neuroimaging research shows that Conscientious individuals show greater activation in the lateral PFC on this task, an area of the brain that plays a key role in the control of attention (Asplund, Todd, Snyder, & Marois, 2010).

There is limited research showing direct evidence of a relationship between Conscientiousness and visual attention and one reason may be due to the absence of a unifying theory that highlights the nature of this relationship, leaving a dearth of directed research in this area. If Conscientiousness is specifically related to the selectivity of visual attention, a relationship between this personality trait and tasks in the lab would likely only emerge if the selectivity of attention is directly challenged. There are however, some consistent relationships between Conscientiousness and other cognitive/psychological outcomes that are related to attention, which are consistent with the Attention and Personality Framework. For instance, workaholism,
specifically ‘the drive to work’, correlates with Conscientiousness (Burke, Matthiesen, & Pallesen, 2006) and workaholism has previously been associated with a more selective and narrow distribution of attention (Yovel, Revelle, & Mineka, 2005). Yovel, Revelle & Mineka (2005) find that those individuals prone to workaholic tendencies show evidence of a focused, narrowed and local processing biases on a Navon Hierarchical Letters Task. These Navon tasks are typically used as an index of attentional tuning, broad/global versus narrow/local, however, there is some debate as to whether these tasks measure attentional tuning opposed to a more general perceptual processing bias. What is required here is a research program that is able to explain and operationalize the relationship between personality and these various cognitive measures and outcomes. This program should probe the specific facets of attention, namely scope and selectivity, more directly to reveal the nature of individual differences in attention and whether endogenous attentional styles are linked to personality.

1.10 Thesis overview and predictions

Personality measurements predict cognitive performance, across several different tasks, which arguably rely on, are closely related to, or directly probe attention. The aim of this thesis is twofold. The first broad goal is to address the question of how attention and personality are related, a question that is answered by the Attention and Personality Framework. This framework suggests that: 1.) Openness is related specifically to the spatial scope of visual attention; 2.) Conscientiousness is specifically related to the selectivity of visual attention; and 3.) given these relationships with attention, these personality traits also relate to visual cognitive processes that rely heavily on visual attention, namely visual memory (iconic memory and VWM). The second aim of this thesis is to demonstrate the utility of the Attention and Personality Framework in accounting for otherwise unexplained variance, leading to novel insights.
Some of the predictions that follow from the Attention and Personality framework are that tasks that measure or challenge the spatial scope of attention should be associated with Openness, showing a broader spatial scope of attention in those higher in Openness. Tasks that challenge the selectivity of visual attention should be predicted by Conscientiousness, such that visual attention may be more focused, selective and efficient in those higher in Conscientiousness. These attentional affects should impact visual processing that is reliant on visual attention.

Given the close relationship between visual attention and VWM, Conscientiousness and the selectivity of attention should be related to the precision or accuracy of representations in VWM, particularly when individuals are required to select or filter a subset of stimuli. Conscientiousness, however, is not expected to be specifically associated with differences in item capacity or the amount of attentional resources in general. Rather, Conscientiousness is expected to be related to how information is selected (narrowly) and represented (precisely) in VWM. There is less research exploring the relationship between the spatial scope of attention and VWM, so predictions are a little weaker for Openness. It is possible, however, that Open individuals’ more diffuse attentional style may lead to less precise representations in VWM, due to their broader attentional scope admitting more information into VWM, at a lower resolution. Alternatively, the impact of a broader scope of visual attention may lead to less precise representation of information prior to VWM. Iconic memory lies at the intersection between perception and memory and is arguably impacted by both the initial scope of attention (determines what enters and is briefly maintained in iconic memory) and the selectivity of attention (determines when and what information is transferred to VWM). Open individuals’ broader scope of visual attention may be associated with a greater ability to maintain more information in iconic memory early in processing, while the higher degree of selectivity in Conscientious individuals may result in faster and earlier selective transfer of icons to more stable items in VWM.
Experiments

To test these hypotheses 4 experiments will be employed that probe the scope of visual attention (Experiment 1), the selectivity of attention (Experiment 2), the role of attentional scope and selectivity in iconic memory (Experiment 3) and VWM (Experiment 4). Personality traits will be assessed using a highly validated personality taxonomy (NEO-IPIP) (Goldberg et al., 2006; Johnson, 2014). In addition, other measures of individual differences will be included that provide a measure of general fluid intelligence (the Raven’s Progressive Matrices) and an estimate of VWM item capacity (K-estimate task). These additional measures are included primarily as controls for intelligence and VWM capacity so as to ensure that personality emerges as a unique predictor of variance in visual processing.

Experiment 1 utilizes an IOR task that provides a relatively high-resolution measure of the spread of attention around an irrelevant cue. The main predicted result in Experiment 1, following from the Attention and Personality Framework, is that Openness will correspond with a greater spatial spread of attention and IOR. Experiment 2 includes both a behavioural and electrophysiological exploration of the selectivity of attention in a commonly used Localized Attentional Interference (LAI) paradigm. If Conscientiousness is related to the selectivity of attention, then Conscientiousness should predict performance on this LAI task, particularly when the selectivity of attention is most challenged. Further, there may be evidence of stronger or earlier engagement of attention, as revealed by the electrophysiological event-related potentials. Experiment 3 uses an iconic memory paradigm to explore the early influence of both attentional scope and selectivity on early visual memory and the transfer of information from perceptual to mnemonic representation. This task affords the opportunity to measure individual differences in the initial storage of information, decay, and duration of iconic memory, as well as the amount of information transferred from iconic memory to VWM. If Openness is related to a broader scope of attention,
then we might expect a greater ability to initially represent and maintain items in iconic memory and if Conscientiousness is related to selectivity, then we might expect earlier or faster selective transfer of information to VWM. Finally, Experiment 4 tests VWM performance, making use of a continuous response Colour Wheel task, which includes an attentional manipulation. If the selectivity of attention is related to Conscientiousness, then there is good reason to expect a relationship may be present between VWM and Conscientiousness, given that VWM performance depends on the selectivity of attention, particularly when the selectivity of attention is challenged. If Conscientious individual engage early selective transfer earlier in iconic memory, this may afford a higher degree of precision of representation in VWM. If Open individuals tend to prioritize breadth of processing or representation (scope) over depth or resolution of representation, then Open individuals may demonstrate lower precision in VWM.

The aim of this thesis is to propose an Attention and Personality Framework, which may serve to better operationalize the relationship between visual attention and personality. Second, in the experimental chapters I aim to demonstrate how this framework can be used to guide predictions and analyses in common paradigms in the visual cognition literature, elucidating novel insights, resolving inconsistent results, and explaining variance that otherwise would remain unexplained. Overall, my results support the notion that individual differences in personality are predictive of visual attention and visual memory. Specifically, I find evidence that Openness is associated with a broader spatial scope of attention (Experiment 1), which may contribute to a broader or more robust initial representation of information in iconic memory (Experiment 3). Conscientiousness is associated with a greater degree of selectivity in attention (Experiment 2), which may lead to a faster rate of selective transfer of information from iconic memory to VWM (Experiment 3), consequently impacting the precision of how information is represented in VWM (Experiment 4).
Chapter 2
Individual differences in the scope of visual attention

2 Experiment 1

2.1 The Scope of Visual Attention and Inhibition of Return

Previous work in the attention literature has demonstrated a spatial gradient to attention (Eriksen & St. James, 1986; Eriksen & Yeh, 1985), however, these paradigms have used few and fairly discrete probe locations. Revealing individual differences in the spatial scope of attention requires the use of display configurations with higher spatial resolution. Further, it may take a little time for attention to spread and reach its full spatial scope. Thus an ideal paradigm to capture individual differences in the scope of visual attention would fit the following criteria: a.) is based on a well-established phenomenon in the attention literature; b.) enables a relatively high degree of spatial resolution; c.) provides sufficient time for attention to diffuse around a cued location.

An Inhibition of Return (IOR) paradigm, based on Bennett & Pratt’s 2001 experiment, fits the three parameters listed above. IOR is a well-validated and highly studied attentional effect, which exhibits a clear spatial distribution and emerges a little later in processing, after 200ms, once attention has had time to spread around the cued location. IOR is believed to reflect a mechanism that promotes attentional orienting towards novelty, preventing us from searching previously attended areas (Klein, 2000). This function is critically useful in our everyday search for solutions to ‘problems’, whether those problems are physical in nature (e.g., ‘where are my keys?’) or conceptual (e.g., ‘what career path should I choose?’). Exploring the spatial distribution of attention in this way may help shed light on the mechanism(s) that underlie some of the cognitive outcomes associated with Openness and Conscientiousness. For instance, Open individuals’ adaptability and flexible cognitive style and Conscientious individuals’ propensity to stick with convention and more fixed cognitive style (LePine et al., 2000). The question addressed in Experiment 1 is whether personality predicts the spatial distribution of visual attention. More, specifically,
is the spatial scope of attention more broad or diffuse in Open individuals and more narrow or focused in Conscientious individuals?

2.2 IOR Methods

Participants: All Participants for each experiment in this thesis were compensated for their time by a combination of course credit for the first hour of the experimental session and remuneration at a rate of $10 per hour for the remainder. Each participant gave informed consent and had normal or corrected-to-normal vision. All experimental procedures for all studies were in accordance with the University of Toronto Research Ethics Board. For Experiment 1, 54 University of Toronto undergraduate students (40 female, age: $M = 20.9$, ranging 17-31 years) participated. Eight participants were excluded from analyses due to non-compliance with the task instructions (see exclusions below), leaving 46 participants included in the analyses.

Procedure: Participants completed a personality questionnaire (IPIP-NEO) and several behavioural tasks. All tasks were presented on a 19-inch CRT monitor with a refresh rate of 60 Hz, performed from a distance of 57 cm from the monitor, while participants rested their heads comfortably in a chin rest. There were three behavioural tasks: a behavioural task that correlates well with intelligence (Raven’s Progressive Matrices), a measure of VWM item capacity (K-estimate change detection task) (see Figure 2a and b), and an IOR task (see Figure 3). The personality questionnaire was a 120 item IPIP-NEO questionnaire, a well-validated tool to describe personality traits (Goldberg et al., 2006). The Raven’s Progressive Matrices task, a correlate of fundamental cognitive ability and intelligence (Raven, 2000), presents participants with a visual pattern that is missing one piece and participants have to choose from a selection of 8 sub-patterns the one image that completes the pattern. There were 36 trials and participants had fifteen minutes to complete the task. VWM item capacity was estimated (K-estimate) using a simple colour change detection task, where an array of between 1 and 6 colour squares was presented, followed by a 1000ms delay and then a probe screen with a single item, either in the same or different colour as in the memory array. Participants simply
indicated whether the probe item was the same (index finger) or different (middle finger) with a key press on a keyboard. Participants also completed the primary experimental task, the Inhibition of Return (IOR) task. Participants were asked to respond as quickly as possible by pressing the spacebar as soon as they saw the target appear. They were explicitly informed that an irrelevant cue would be presented before the target on all trials, however this cue was to be ignored, as it was not predictive of target location. Participants completed several practice trials while the experimenter monitored their eye movements to ensure that fixation was maintained. Once participants’ ability to maintain fixation was established (taking the average participant about 3 minutes of practice) the experimenter started the experimental session. The experimenter continued to monitor participants during the experimental session via a video camera.

**Figure 2. Intelligence and VWM Item Capacity Estimate Task Schematics:** a.) Raven’s Progressive Matrices, where the image associated with number 7 is the correct answer. b.) K-estimate task, with example of same (top) and different (bottom) probe screens.

**IOR Stimuli:** The IOR display was composed of an invisible 11 x 11 grid (121 locations), with a center-to-center distance between adjacent locations on that grid of 1° of visual angle. A single irrelevant cue (square outline, 1x1° of visual angle), which was non-predictive of target location, was presented on each trial. This cue appeared for 1000ms at one of four possible locations, centered in one quadrant of the screen. After a delay of 800ms, a single target (solid square, filling one location, 1x1° of visual angle) appeared for 1000ms, at one location on the invisible grid. Targets were never presented at fixation.
Participants maintained fixation at the crosshair at the center of the screen. The task consisted of 1120 trials in two trial types: 960 target-present trials (8 trials per location, 240 per quadrant); and 160 catch trials (40 per quadrant) where no target was presented. Catch trials were included to assess if participants were attending to the task, such that excessive responses on catch trials could be used as a behavioural measure of task compliance. The dependent variable was reaction times (RTs).

**Exclusions:** The key objective of this experiment was to measure the scope of attention, thus it was critical to exclude trials where participants were clearly not attending or responding automatically. There was no measure of accuracy on this IOR task, thus the data were trimmed using RT thresholds. Trials with RTs faster than 100ms (not likely a response related to the task) and slower than 1500ms (clear index of inattention) were excluded from analyses on a trial-by-trial basis. The majority of RTs were quite fast, \( \text{Median} = 310 \text{ms}, \; \text{SD} = 44 \), with a handful that would be well above this 1500ms threshold. Eight participants were excluded from analyses altogether due to at least one of the following reasons, with most meeting two or all of these exclusion criteria: 1.) Percentage of trial-based rejections exceeded the mean rejection rate for the whole group by at least 3 standard deviations; 2.) The trials rejected included those required to calculate IOR (e.g., target appearing at the cued location), precluding our ability to measure IOR in the standard way in that participant; and 3.) The percentage of catch trials a participant responded to exceeded the mean by at least 3 standard deviations. These three measures are indicators that a particular participant was likely not attending consistently throughout the task.
2.3 IOR Results

A clear effect of IOR is observed, such that RTs are slower when the target appears at cued locations ($M = 359$ms) relative to non-cued locations (center of adjacent and opposite quadrants, $M = 336$ms; $t(45) = 2.73$, $M$ difference $= 22.43$, $p = 0.009$). Further, using linear regression analysis, a strong negative relation is found between distance and reaction times across the whole group of 46 participants, such that RTs decrease as a function of distance from the cue ($R = -0.74$, $b = -0.28$, $F(1,39) = 45.9$, $p < 0.001$) – consistent with the Bennett and Pratt findings (Figure 4a & 4b).

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1 These data are published (Wilson, Lowe, Ruppel, Pratt, & Ferber, 2015) and permission to report the results here has been granted.
Figure 4. IOR Results: (a.) This RT plot shows the spatial distribution of IOR, with slower (lighter coloured) RTs for targets appearing close to cued locations and a gradual decrease in RTs with increasing distance, which is reflected in (b.) the significant correlation between target/cue distance and RT. As target locations increase in distance from cued locations, RTs become faster. (c.) Higher Conscientiousness predicted a larger negative slope indicating a more narrow distribution of attention ($r = -0.3$, $p = 0.04$). (d.) Conversely, higher Openness predicted a smaller (shallow) slope indicating a more broad distribution of attention ($r = 0.44$, $p = 0.002$).

To explore the prediction that while Conscientiousness is associated with a more narrow scope of attention and Openness is associated with a broader scope of attention, we calculated regression equations of the spatial distribution of IOR for each individual, plotting RTs as a function of distance (as above). We took the slope of this equation for each individual as an indication of the spatial gradient of IOR/attention. For instance, if someone had a steep or large negative slope this would indicate that they quickly recovered from IOR over cue/target distance, suggesting a narrow distribution of IOR/attention and vice versa for

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2 Permission was granted to use this original figure, published in Wilson et al., 2015.
individuals with a shallow or small negative slope. This measure isolates the rate of change across space within each individual, thus it is a relative measure of the distribution of attention. Examining the relationship between this measure of the scope of IOR or attention and personality using Pearson’s Correlations, we find both Conscientiousness and Openness correlate with the spatial gradient of IOR (Figure 4c & 4d). Conscientiousness is associated with a steep (more negative) RT spatial gradient ($r = -0.3$, $p = 0.04$, $r^2 = -0.1$), such that RTs are finely tuned to cue/target proximity: their narrow focus of attention results in a small area of inhibition around the cued location with an accelerated release from inhibition. Individuals high in Openness, on the other hand, show a shallower RT spatial gradient ($r = 0.44$, $p = 0.002$, $r^2 = 0.19$): their spatially diffuse scope of attention leads to more widespread inhibition.

Though the Big 5 personality traits have canonically been thought to be independent, there is evidence of correlations between these factors, with Conscientiousness and Openness belonging to different latent variables (DeYoung, 2006; Digman, 1997). In addition, given the relationship between these two personality traits and intelligence and academic success, it is possible that an underlying variable, such as intelligence or VWM capacity may account for these relationships. This question was explored by running a multiple regression analysis, which included 8 predictors: intelligence (Raven’s Task), VWM-capacity (K-estimate Task), the five personality traits (Openness, Conscientiousness, Neuroticism, Extroversion, and Agreeableness), and the interaction between Openness and Conscientiousness, regressed on IOR slope ($R = 0.55$, $F(7, 38) = 2.93$, $p = 0.04$) (see Table 1. for regression coefficients and partial correlations). The predictor variables were centered to reduce the influence of collinearity between the interaction variable (Openness x Conscientiousness) and Openness and Conscientiousness. Only Openness accounted for a significant portion of unique variance, over and above the other predictors, ($r = 0.42$, $pr = 0.33$, $p = 0.02$).
Personality Factors | $B$ | $SE$ | $\beta$ | Semi-Partial Correlation
---|---|---|---|---
Openness | 0.046 | 0.019 | .42** | 0.33
Conscientiousness | -0.015 | 0.015 | -0.16 | -0.14
Open x Conscientious | 0.001 | 0.001 | 0.17 | 0.16
Neuroticism | -0.002 | 0.014 | -0.02 | -0.02
Extroversion | -0.008 | 0.019 | -0.07 | -0.06
Agreeableness | -0.028 | 0.016 | -0.26 | -0.24
VWM | 0.116 | 0.189 | 0.10 | 0.08
Intelligence | 0.014 | 0.047 | 0.05 | 0.04

*Single asterisk indicates a trend ($p > 0.05$, $<0.11$) and **double asterisk indicates $p < 0.001$.

**Table 1.** IOR Regression Coefficients: Regression coefficients for the degree to which each of the Big 5 personality traits, interaction between Openness and Conscientiousness, intelligence and VWM capacity predict IOR Slope. All predictors are centered. The slope for Openness was significant, $p = 0.019**$. $B$ is the unstandardized coefficient and $\beta$ is the standardized coefficient.

It is possible that the relationship between RT on this task and personality may be driven by a third variable, such as a difference in processing speed and/or the ability to stay on task (vigilance), rather than the distribution of attention across space per se. I explored these alternative considerations from three angles. First, I examined the relationship between slope and overall average RTs and found little evidence of a relationship ($r = .1, p = .5$), thus individual differences in RT overall does not predict how IOR changes over space (slope) within an individual. Second, I assessed processing speed, as a function of average RT, by running Pearson’s correlations on average RT across all target locations as well as average RT on trials where the target appeared at the cued location (site of peak IOR effect). This approach failed to reveal a significant relationship between personality and average RT (Openness, $r = .08, p = 0.61$; Conscientiousness, $r = -.19, p = 0.23$) and personality and RT at the cued location (Openness, $r = -.01, p = 0.93$; Conscientiousness, $r = -.10, p = 0.51$), providing little support for the processing speed explanation. Lastly, one can hypothesize that personality may modulate how participants respond over the course of a
given experimental session, due to variance in one’s ability to maintain attention to a relatively boring task (i.e., vigilance). Thus the data was binned into four quartiles and for a comparison of RTs in the first and last quartile of the experiment. Slower RTs in the last quartile may be taken as an indication of decrease in attention or vigilance to the task as a function of time. Overall, participants tended to respond faster toward the end of the task, with an average decrease in RT from the first to the last quartile of 22ms. This change over time did not significantly correlate with Conscientiousness \( r = .37, p = 0.71 \) and did not quite reach significance with Openness \( r = .22, p = 0.14 \). Changes in variability across the task were also explored by calculating a difference in standard deviation between the first and second half of the task. This relationship also was not found to be significant with Openness \( r = -.1, p = 0.52 \) or Conscientiousness \( r = -.09, p = 0.57 \). As such, there is little evidence that the findings presented here are driven by differences in processing speed or vigilance, as measured by overall RT or changes in RTs and standard deviation over time.

2.4 IOR Discussion

Experiment 1 provides evidence that stable personality traits, such as Openness and Conscientiousness, are predictive of the spatial scope of attention. The data show the expected negative correlation between proximity and reaction times across the whole group of 46 participants, such that RTs decrease as a function of distance from the cue – consistent with Bennett and Pratt’s (2001) findings. This work is extended by the results showing both Conscientiousness and Openness correlate with the spatial gradient in RTs - an index of the scope of attention. Individuals high in Openness show a shallow (less negative) RT spatial gradient, such that their RTs are more broadly tuned to cue/target proximity: their spatially diffuse scope of attention leads to more widespread inhibition. Individuals high in Conscientiousness, on the other hand, show a steeper (more negative) RT spatial gradient, such that their RTs are more finely tuned to cue/target proximity: their narrow focus of attention results in a small area of inhibition around the cued location with an accelerated release from inhibition.
The relationship between Conscientiousness and a more narrow scope of attention, however, was not robust and did not continue to explain unique variance over and above that captured by Openness. These findings are not easily explained by individual differences in overall processing speed or the ability to sustain attention (vigilance), as average RT and variability in performance over time did not significantly correlate with personality. Openness shows a robust association with the spatial distribution of IOR and the spatial scope of attention, consistent with predictions. Conscientiousness may be associated with a more narrow scope of attention, but the relationship between scope and personality is driven more dominantly by Openness. The Attention and Personality Framework specifically predicts that Conscientiousness, however, is connected to the selectivity of attention, rather than the scope per se. In Experiment 2, this specific prediction is explored.
Chapter 3
Individual Differences in Selective Attention

3 Experiment 2

3.1 The Selectivity of Attention and Localized Attentional Interference

In Experiment 2 the question of whether Conscientiousness predicts behavioural and neural/electrophysiological indices of attentional selectivity is explored using a well-established Localized Attentional Interference (LAI) paradigm. As mentioned in the general introduction, the phenomenon of LAI arises when the spatial proximity between a target and distractor is reduced, increasing competition, and interfering with the ability to ignore the distractor and select the target. In a typical LAI task participants are asked to report the orientation of a single target presented simultaneously with a single distractor (Figure 5). Spatial interference is manipulated by the degree of target-distractor separation, such that the target and distractor are either 5 locations apart (FAR), 3 locations apart (MID), or 1 location apart (NEAR). Accuracy declines for the closest proximities, as the distractor competes with the target for attentional resources (Hilimire et al., 2009, 2010). Competition for representation, which results in interference, can be electrophysiologically de-coded through the N2pc event-related potential (ERP), which appears around 200ms into processing and is attenuated by competition/interference, consistent with the predictions of the Biased Competition Model of attention. The need to call on compensatory attentional resources to later resolve this competition is seen in a later ERP called the Ptc, which appears around 300ms into processing and is enhanced by competition/interference (Hilimire et al., 2009, 2010). An earlier ERP, the P1, also reflects early attentional biasing (Mangun et al., 1998) and may also be modulated by LAI, however, prior studies have not explored or did not find an effect of LAI on this ERP component. This lack of an effect on the P1 in prior research may suggest that the effect of competition simply occurs later in processing. Alternatively, there may be variance in the time-course of selective attention and the effect of competition on the system, such that some individuals may engage the selective mechanism
earlier, while others show later effects. This would likely be occluded by standard analyses that do not consider individual differences.

The question addressed by Experiment 2 is whether Conscientiousness is related to the selectivity of attention. More specifically, is Conscientiousness predictive of performance, particularly when the selectivity of attention is challenged? If there is a relationship with selectivity, might this relationship reflect earlier and more efficient engagement of visual selective attention? Several behavioural and electrophysiological predictions follow from the Personality and Attention Framework. Conscientiousness should be associated with a greater degree of selectivity, reflected in a relationship with accuracy when selectivity is most challenged (NEAR condition). This relationship with accuracy should be attenuated when spatially mediated competition is reduced and selectivity is challenged/recruited less (FAR condition). These behavioural differences should be reflected in the underlying neural/electrophysiological markers of selective attention, namely, the P1, N2pc and Ptc. Specifically, if Conscientious individuals have a more effective or efficient selective mechanism of visual attention, there should be evidence of this attentional engagement perhaps earlier in processing, showing modulation of P1 in high, but not low Conscientious individuals. We might also anticipate a difference in the N2pc amplitude between high and low Conscientious individuals, as this component is believed to be a marker of the selectivity of attention (Eimer, 1996; Luck et al., 1997) and is typically attenuated by spatial interference (Hilimire et al., 2009, 2010). Finally, if high Conscientious individuals engage attentional processing earlier they may not require much compensatory processing later, as reflected in the Ptc. Low conscientious individuals, on the other hand, may engage selectivity later, requiring more secondary processing and thus greater recruitment of the Ptc (Hilimire et al., 2009, 2010).

3.2 LAI Methods

Participants: Sixty-eight undergraduate students (44 females, 52 right-handed; age range: 17-31 years, $M = 21$ years) were recruited from the University of Toronto (see section 2.2 for details on participant
consent, compensation and ethics). Nine participants were excluded due to excessive electrophysiological artifacts (see exclusions), leaving 59 participants for analyses.

**Procedure:** Participants first completed the same computerized IPIP-NEO personality questionnaire as in Experiment 1, followed by the LAI task (Figure 5). The task was presented on a 19-inch CRT monitor with a refresh rate of 60 Hz. Participants performed the task from a distance of 57 cm from the monitor. Participants were instructed to determine the orientation of the target item (either orange or green letter “T”) by using their right hand and pressing the left arrow for right-side up and the down arrow for upside down. They were informed that the colour of the target was irrelevant and would vary between trials, being either green to orange. Similarly, the distractor colour also varied from trial-to-trial, however, the target and distractor were always different in colour from each other on each trial. The stopping rule was set at about 50 participants (after exclusions), as this is the number that has been used in previous studies exploring individual differences in personality and visual attention (Risko et al., 2012; Wu, Bischof, Anderson, Jakobsen, & Kingstone, 2014). EEGs were recorded while participants performed the LAI task.

Each trial began with a centrally presented pre-cue fixation crosshair (200ms) on a black background. This was followed by an arrow-cue (100% valid), which flashed 1° of visual angle above the fixation, initiating a shift of attention to the side of the display on which the target and distractor were about to appear. Participants were instructed to maintain fixation for the duration of each trial, shifting their attention, and not their eyes, to the side of the display indicated by the arrow-cue. After 200ms, the arrow disappeared, leaving the fixation cross on the screen (1000 to 1200ms, randomly jittered by 50ms), which was followed by the search display (200ms) and then another fixation during the response interval of 2300ms. At the end of the response delay the trial self-terminated, regardless of whether a response had been given. A ‘blink-break’ screen was shown after each trial and the participant initiated the next trial by pressing the space bar with his/her left hand.
**Stimuli:** The search display was composed of an array of 18 letters (one L and 17 Ts, each 1.2° x 1.2°), each positioned at equal intervals (approximately 2° of visual angle) in a circular formation (radius 6° of visual angle) around the central fixation cross. Sixteen of the letters were placeholders in the form of gray Ts, randomly rotated to the left or right by 90°. The other two letters were a green or yellow target T and distractor L (colour was pseudo-randomly determined, as target colour varied randomly, but T and L were always different in colour from each other). A single target T and single distractor L were present on every trial and were always oriented right-side up or upside down. The target and distractor were separated by either one space (NEAR, immediately adjacent, 2° of visual angle apart), three spaces (MID, 6° of visual angle apart) or five spaces (FAR, 10° of visual angle apart) on a given trial. The target and distractor could appear either on the left or the right side of fixation. Right-sided and left-sided trials for each condition were balanced within blocks and presented in random order. Participants completed ten blocks of 60 trials each, yielding 200 trials per Separation condition for a total of 600 trials. The task took approximately one hour. We measured behaviour (accuracy) and electrophysiological outcomes.

**EEG Recording & Processing:** Continuous, unreferenced EEG was recorded at a sampling rate of 512 Hz using a BioSemi ActiveTwo system with 64 Ag/AgCl scalp electrodes in standard 10-20 placement with additional electrodes at each mastoid for off-line re-referencing, below each eye for blink detection, and at the outer canthus of each eye for lateral eye movement detection. All re-referencing and filtering was done off-line using ERPLAB software. Each individual data set was filtered using a finite impulse response (FIR) filter high-passed at 0.01 Hz and low-passed at 30 Hz. The continuous data were then re-referenced to the average of the two mastoids. Lateral eye movements were detected using a step-like function (horizontal eye electrodes, threshold: 80 µv) and blinks were detected using a moving window peak-to-peak threshold (vertical eye electrodes: threshold: 35 µv). Data was segmented into 800ms analysis windows – composed of the 200ms immediately preceding search-array onset as the baseline period, which was baseline corrected to zero, and 600ms post search-array onset as the critical window. The rejection window spanned from arrow offset to 600ms after the search array onset. Difference waves were generated for
each of the three conditions by subtracting activity in the ipsilateral electrode sites from the contralateral electrode sites (relative to the attended side of the display). Analyses focused on two posterior electrode pairs, PO3/PO4 and P7/P8, as used previously (Hilimire et al., 2009, 2010). ERPs were calculated as mean amplitude within the following windows: P1 between 125ms – 175ms; N2pc between 175ms – 225ms; Ptc between 260ms – 310ms.

*Exclusions:* Entire data sets were excluded if more than 50% of trials were rejected due to artifacts or noise. Consequently, nine out of the sixty-eight data sets were excluded from ERP analyses. Although all trials contributed to behavioural analyses, within the 59 remaining data sets, an average of 16% of trials were rejected from ERP analyses due to excessive EEG artifacts.

![Figure 5. Localized Attentional Interference (LAI) Task:](image)

**Figure 5. Localized Attentional Interference (LAI) Task:** Participants search for the coloured target letter T that appears at three different distances from the distractor letter L, NEAR, MID or FAR. Demands on attentional selectivity are modulated by this target-distractor separation, with greatest interference occurring in the NEAR condition and the least interference in the FAR condition.

### 3.3 LAI Results

**Whole Group Analyses**

Attentional selectivity accuracy data was submitted to a RM-ANOVA, with the 3 degrees of Separation as within-subject factors (NEAR, MID, FAR). Accuracy was significantly impacted by target-
distractor separation, $F(2, 116) = 33.40, p < 0.001, \eta^2 = .37$ Pair-wise comparisons revealed a significant accuracy cost for the NEAR condition relative to MID, $t(58) = -7.82, p < 0.001, d = 0.54$, and FAR conditions, $t(58) = -5.93, p < 0.001, d = 0.55$, however, MID and FAR were not significantly different, $t(58) = -5.93, p > 0.9, d = 0.003$ (Figure 6a).

The whole group ERP data were submitted to a RM-ANOVA, with Separation (NEAR, MID, FAR) and Electrode (PO34 and P78) as a within-subject factors. There was no main effect or interactions ($F < 1.9, p > 0.17$) so results reported here focus on key manipulation of Separation on the P1, N2pc and Ptc (Figure 6b). The main effect of Separation in the P1 is not significant, $F(2, 56) = 0.089, p = 0.456, \eta^2 = .003$. A significant effect was detected in the N2pc, $F(2,16) = 16.27, p < 0.001, \eta^2 = .22$, with a significantly smaller N2pc in the NEAR condition, relative to the MID $t(58) = 4.29, p < 0.001, d = 0.42$, and FAR conditions $t(58) = 4.69, p < 0.001, d = 0.49$. The N2pc for MID and FAR did not differ $t(58) = 1.37, p = 0.53, d = 0.01$. Interestingly, the Ptc did not replicate previous results and was not modulated by the separation between the target and distractor ($F(2,116) = 0.29, p = 0.75, \eta^2 = .005$). When these results were explored further, guided by the hypothesis that differences in personality might play a role in behaviour and the Ptc response in particular, a different picture emerged.
Figure 6. LAI Results (a.) Accuracy scores for LAI task. Accuracy for NEAR was significantly lower than for MID and FAR conditions. (b.) Waveforms plotted as a function of target-distractor proximity. As expected, the N2pc is modulated by target-distractor separation. The Ptc did not scale with target-distractor separation for the group of participants as a whole. Error bars reflect the standard error of the mean (SEM).

Individual Differences in the Selectivity of Attention

Pearson’s correlations were used to first assess whether there were any relationships between the 5 personality traits and accuracy on the LAI task. These analyses revealed that only one personality trait is a significant predictor of accuracy. The relationships between Openness and accuracy is near zero and fails to reach significance (NEAR, $r^2 = 0.002, p = 0.762$; MID, $r^2 = 0.002, p = 0.746$; FAR, $r^2 = 0.001, p = 0.780$). Conscientiousness, on the other hand predicts accuracy, at the closer target/distractor proximities (NEAR and MID), when attentional selectivity is most challenged (NEAR, $r^2 = 0.07, p = 0.043$; MID, $r^2 = 0.120, p = 0.007$), consistent with hypotheses (Figure 7a and 7b). There is no significant relationship between reaction time and Conscientiousness or Openness on this task, $r < .09, p > 0.5$. The correlations between Conscientiousness and LAI accuracy were followed up with multiple regression analyses to ensure that Conscientiousness does in fact account for a unique amount of variance in LAI performance and that
it is not accounted for by general intelligence or VWM item capacity. These models included 5 centered predictor variables: Openness, Conscientiousness, the interaction between Openness and Conscientiousness, Raven’s task, and K-estimate. This revealed that Conscientiousness remained a unique predictor of accuracy in the NEAR, \( r = .27, pr = .26, p = 0.04 \), and MID condition, \( r = .36, pr = .35, p = 0.006 \).

For the following analyses the data was split into groups based on Conscientiousness, focusing on the highest and lowest quartiles. There are several reasons for analyzing the data in this way. First, unlike scope, individual differences in the selective mechanism of attention may be associated with a more discrete mechanism (e.g., early vs. late attentional processing), resulting in either early (P1) or late (Ptc) effects or dissociations in behavioural effects that only appear in the upper and lower ranges. Thus understanding dissociations in how attention functions in those high and low in Conscientiousness in this task may be clarified by focusing analyses on those individuals that are truly ‘high’ or ‘low’. This practice of splitting continuous data is also common in behavioural research on attention (Dale & Arnell, 2010) and EEG research on attention and working memory (Gazzaley et al., 2008; Vogel et al., 2005), in particular when examining individual differences (Washburn, Smith, & Taglialatela, 2005). One of the most common practices is in electrophysiological explorations of aging, where analyses include upper and lower age ranges (e.g., Gazzaley et al., 2008; Lorenzo-López, Amenedo, & Cadaveira, 2008). Similar to this work on aging and attention, I expect these attentional affects to manifest most strongly in individuals particularly high and low in Conscientiousness.

Given that there is little evidence of a relationship between Openness and performance on this task the rest of the analyses focus on this relationship between Conscientiousness. Behaviour is explored first, with the prediction that high and low Conscientious individuals should both show a benefit at the intermediate distance relative to when target and distractor are most proximal (MID versus NEAR), however, the two groups may diverge when comparing the intermediate distance to the most distal
separation (MID versus FAR). More specifically, I predict that those particularly high in Conscientiousness will show stronger or more spatially specific selectivity. This heightened selectivity may result in a more narrow focus of attention, only encompassing the NEAR and MID distances, but may actually come at a cost for the greatest target/distractor separation (FAR). In other words, the selectivity and spread of attention may interact here, such that highly Conscientious individuals may restrict the scope of attention in order to, or as a function of, heightening selectivity, facilitating performance when interference is high, but resulting in a cost when the stimuli are distal and fall outside the scope/focus of attention.

RM-ANOVA was used, with Separation as the within-subject factor and Conscientiousness Group as the between-subject factor. Based on the above predictions, hypothesis-driven one-tailed tests of simple effects are used for this behavioural analysis. There is a main effect of Conscientiousness-Group, such that the High-Conscientiousness (H-C) individuals show higher accuracy than the Low-Conscientiousness (L-C) individuals overall, $F(1, 28) = 2.68, \, p = 0.05, \, \eta^2 = .1$ (Figure 7b). However, there is a significant interaction, $F(2,56) = 2.32, \, p = 0.05, \, \eta^2 = .1$. Both groups show a benefit for MID over NEAR (L-C, $t(14) = -4.11, \, p < 0.001, \, d = -.37$ and H-C, $t(58) = -4.93, \, p < 0.001, \, d = -.85$) and for FAR over NEAR (L-C, $t(14) = -4.12, \, p < 0.001, \, d = -.57$ and H-C, $t(14) = -4.12, \, p = 0.005, \, d = -.59$). For FAR, however, as predicted, the H-C group show an accuracy cost, relative to MID ($t(14) = 1.91, \, p = 0.039, \, d = .27$), whereas the L-C group show the opposite pattern ($t(14) = 1.91, \, p = 0.054, \, d = -.19$). The significantly higher accuracy overall present in the H-C group is driven by their superior performance when the spatial selectivity of attention is required, showing a trend for NEAR, $t(28) = 1.5, \, p = 0.072, \, d = -.57$ and significant relationship for MID, $t(28) = 2.09, \, p = 0.023, \, d = -.79$, however, the H-C group lose their advantage in the FAR condition, though this relationship did not quite reach significance, ($t(28) = 1.13, \, p = 0.132, \, d = -.43$). This accuracy cost for the most distal target/distractor pairing (FAR) in the group of highly Conscientious participants is consistent with the findings of Experiment 1.
Figure 7. Individual Differences Behaviour in Attentional Selectivity Task: (a.) Conscientiousness was a significant predictor of accuracy for both NEAR and MID conditions, when attentional selectivity is most pronounced. (b.) Accuracy for the Low-Conscientiousness Group improved with each increase in separation, whereas the High-Conscientiousness Group showed an impairment for FAR. Error bars reflect SEM.
Figure 8. Individual Differences in Electrophysiological Measures of Attentional Selectivity: High- and Low-Conscientiousness groups differ in their modulation of amplitude in the P1, N2pc and Ptc ERP components in response to target-distractor separation. a.) Average waveforms for the Low-Conscientiousness and High Conscientiousness groups. b.) High Conscientious group show significant modulation of the early P1, but not the Ptc, while Low-Conscientious group do not show this modulation of the P1, but rather show modulation in the later Ptc. An interaction in the N2pc shows a greater cost in the Near condition for Low Conscientious group. N2pc in Error bars reflect SEM.
RM-ANOVA were conducted for each ERP with Separation as a within-subject factor and Conscientiousness Group as a between-subject factor (see Figure 8a for waveforms). Given that the predicted directionality of ERP amplitude is unclear, two-tailed tests of simple effects were used. There is no main effect of Conscientiousness on the P1, \( F(1,28) < 0.01, p = 0.99, \eta^2 < .001 \). The interaction between Conscientiousness Group and Separation, however, was significant, \( F(2,56) = 3.52, p = 0.04, \eta^2 = .11 \). Interestingly, only the H-C group showed a marginal effect of Separation, \( F(2, 28) = 2.99, p = 0.06, \eta^2 = .018 \), such that the H-C individuals show a larger amplitude in the P1 for FAR relative to NEAR \( \eta(14) = -2.1, p = 0.06, d = -0.46 \). The L-C group do not show an effect of Separation in the P1, \( F(2,28) = 1.05, p = 0.37, \eta^2 = .07 \). There is no main effect of Conscientiousness on the N2pc, \( F(1,28) = 0.20, p = 0.66, \eta^2 = .007 \). The interaction between Conscientiousness and Separation was marginally significant in N2pc amplitude, \( F(2,56) = 2.92, p = 0.06, \eta^2 = .094 \) (see Figure 8b). The H-C individuals show less differentiation or sensitivity in the N2pc than the L-C. The N2pc in the H-C group is significantly smaller for the NEAR condition, but only relative to the FAR condition, \( \eta(14) = 2.34, p = 0.04, d = 0.31 \), as the comparison between NEAR and MID does not reach significance, \( \eta(14) = 1.45, p = 0.17, d = 0.19 \), nor does the FAR relative to MID comparison, \( \eta(14) = 1.44, p = 0.17, d = 0.12 \). The N2pc in the L-C group is significantly smaller for the NEAR condition relative to the FAR condition, \( \eta(14) = 4.82, p < 0.001, d = 0.39 \), and relative to the MID condition, \( \eta(14) = 4.65, p < 0.001, d = 0.25 \), while the FAR relative to the MID comparison is not significant, \( \eta(14) = 1.17, p = 0.26, d = 0.14 \) The main effect of Conscientiousness on mean Ptc amplitude shows a trend, but does not quite reach significance, \( F(1, 28) = 1.65, p = 0.10, d = .49 \). Importantly, Ptc amplitude did show a significant interaction between Conscientiousness group and Separation, \( F(2,56) = 3.55, p = 0.04, \eta^2 = .11 \). The L-C group showed an enhanced Ptc response in the NEAR condition relative to the H-C group, \( F(2, 28) = 7.27, p = 0.01 \), while there was no significant difference in the other two conditions (for both MID and FAR: \( F(2, 28) = 0.25, p>0.62 \)). Furthermore, when considering these two groups separately, the L-C individuals show a commonly observed pattern in Ptc modulation, with the highest Ptc amplitude for adjacent target/distractor locations in the NEAR.
condition relative to FAR, \( t(14) = 1.92, p = 0.038, d = 0.43 \) and MID, \( t(14) = 1.56, p = 0.07, d = 0.36 \). The H-C group shows a marginal reversal in this pattern, such that the Ptc is attenuated for NEAR relative to MID, \( t(28) = -2.06, p = 0.06, d = -0.33 \), but this attenuation in the NEAR condition does not quite reach significance relative to FAR, \( t(28) = -1.41, p = 0.14, d = -0.27 \).

### 3.4 LAI Discussion

These results show an interesting relationship between Conscientiousness and the *selectivity of attention* – such that higher Conscientiousness is associated with greater accuracy in conditions that rely on effective and efficient engagement of attentional selectivity (NEAR and MID). These results may reflect the attentional manifestation of the Conscientious individuals’ thorough, controlled, and deliberate personality style, which results in a highly selective distribution of attentional resources. This selectivity, however, comes at a cost when target and distractor are most distal, as can be seen in the behavioural results of this study, as performance for the high Conscientious individuals declines in the FAR condition. One explanation of this effect in those higher in Conscientiousness is that the target and distractor may not be simultaneously encompassed within a single shift of attention, requiring a second shift to detect the target on some trials which would be challenging given the time constraints of the LAI paradigm (Posner, 1980). One mechanism that may result in this effect would be the engagement of selective attention early in processing, before attention has had time to spread around the target/distractor items.

The electrophysiological results provide support for distinct attentional processing between highly Conscientious individuals and those lower in Conscientiousness. Highly Conscientious individuals appear to engage selective attentional processing as early as 125ms (P1 component), while those lower in Conscientiousness do not show a modulation of this component, suggesting that attentional selection may not engage until a later stage. The earlier engagement of attention in those higher in Conscientiousness may result in a lower burden of processing as reflected in the evidence of a reduced effect of competition in the N2pc (around 210ms) in these individuals relative to those lower in Conscientiousness. Low
Conscientiousness individuals show evidence of enhanced modulation of the Ptc (around 280ms), particularly in the NEAR condition, which may reflect compensatory processing as a result of delaying attentional selectivity. Interestingly, high Conscientious individuals show some modulation, but in the opposite direction, where Ptc amplitude for the NEAR condition is actually smaller rather than larger, as is typically expected in LAI paradigms. The behavioural results suggest that there may be some additional compensatory processing required in the FAR condition for high Conscientious individuals. Thus this reversal in Ptc amplitude in high Conscientious individuals may reflect a cost associated with spreading their selective focus over a larger area. In other words, their earlier engagement of a selective focus (P1) may facilitate processing when the target and distractor in close proximity (NEAR), however, this early selective mechanism may not provide sufficient time for attention to spread and efficiently identify the target and distractor when they are further apart (FAR). It should be noted here, however, that this is a fairly liberal interpretation from the Ptc results, as the Ptc in the FAR condition was actually not significantly different from the NEAR and MID conditions. The more conservative interpretation is simply that the Ptc in high Conscientious individuals does not respond to spatially mediated competition the way it does in low Conscientious individuals and this is likely due to the earlier, more efficient engagement of selective attention as indexed by the P1.

If the spatial scope of attention is broader or more diffuse in Open individuals and the selectivity of attention is functioning earlier and more effectively or efficiently in Conscientious individuals, then we should expect to see some relationships between personality and cognitive functions that are modulated by attention. Specifically, individual differences in the broad visual memory store, iconic memory, may emerge as a function of differences in the spatial scope of attention and or the selectivity of attention related to Conscientiousness. Given the close relationship between VWM and the selectivity of attention, it is possible Conscientiousness may predict performance on VWM tasks. In Experiment 4 and 5 the relationships between personality, iconic memory and VWM are explored, respectively.
Chapter 4
Individual Differences in Iconic Memory

4 Experiment 3

4.1 Early Visual Processing & Iconic Memory

Iconic memory is a form of visual sensory memory, which lies at the intersection between temporarily fleeting perception and more durable VWM. Iconic memory is estimated to hold approximately 75% of perceptual information in mind after that visual input has been removed from sight, however, this memory trace decays very quickly (200-500ms) (Gegenfurtner & Sperling, 1993). Aside from iconic memory having a much larger capacity and more fragile and shorter representational capacity relative to VWM, there is evidence of a functional distinction between these two short-term memory stores. For instance, memory traces are destroyed by masks that quickly follow the offset of stimuli (within the iconic memory latency, prior to 500ms), however, when masks are presented later (within the VWM latency post 1000ms) the masks do not impede later recall (Gegenfurtner & Sperling, 1993). This functional dissociation in the effects of masking on memory, depending on when in processing the mask occurs, suggests there are two distinct memory stores with two different mechanisms of forgetting: one that is overwritten by perceptual masks (iconic) and another (VWM) that is not. Iconic memory is much closer to a broad or detailed perceptual representation that fades quickly, while storage in VWM is reserved for a few items that receive additional processing/resources that enable those items to be preserved with higher durability. Iconic memory, however, cannot be explained as merely perceptual persistence (i.e., an after effect of activation in visual network), as there is evidence of a functional distinction here as well. Specifically, iconic memory does not show the typical inverse relationship with stimulus duration (longer stimulus, shorter persistence) and stimulus intensity (more intense stimuli, shorter persistence) that is characteristic of perceptual persistence (Coltheart, 1980). Thus iconic memory lies at the intersection between visual perception and VWM. The process of transferring information from this large, but brief
memory store to the more temporally stable VWM store relies on and is intimately related to the selectivity of attention (Gegenfurtner & Sperling, 1993).

There are individual differences in the rate at which representations decay in iconic memory, which vary with age (Lu, Neuse, Madigan, & Dosher, 2005). Given that age-related changes in cognition are linked to changes in selective attention (Gazzaley, Cooney, Rissman, & D’Esposito, 2005; Hasher, 2007; Hasher & Zacks, 1988; Kosslyn, Brown, & Dror, 1999; McCarley et al., 2004) and attention plays a key role in iconic memory (Gegenfurtner & Sperling, 1993), attention may be one of the main mediating factors in this age-related changes in iconic memory specifically and individual differences in iconic memory more broadly. Decay rate and iconic memory duration are typically probed using a partial-report memory paradigm, where participants are shown an array of 8-12 letters followed by a cue asking them to report on the identity of the letter(s) at the cued location. In fact, this partial report method is what led to the discovery of iconic memory (Sperling, 1960). We typically cannot report the identity of all 8-12 items in the entire display (whole report), because the image decays faster than our rate of reporting. Using the whole report technique individuals typically are able to report only about 4 items, reflecting the capacity of VWM. Individuals can, however, report on a subset of letters anywhere in the display when a cue quickly follows the display (partial report), suggesting we do in fact have a representation of the entire display, but this representation decays quickly. Paradigms of this nature provide measures of visual perceptual processing, and perceptual memory. In addition to age-related variance in iconic memory, one can see from individual plots in some early iconic memory experiments (e.g., Sperling, 1960) that there are clearly individual differences in the decay rate (slope of decay) and the duration of iconic memory. These have not been explored or explained in the literature to date.

Experiment 3 addresses the question of whether personality and iconic memory are related and whether some of the variance in iconic memory may be explained by individual differences in personality. The Attention and Personality Framework suggests that aspects of visual cognition that are impacted by
the scope and selectivity of attention will also show individual differences related to personality. Further, the results of this experiment may corroborate the results of Experiment 1, if there is evidence of a broader initial representation in iconic memory in those that are higher in trait Openness. This study may also corroborate the findings of Experiment 2, if Conscientiousness is associated with a faster rate of iconic memory decay, reflecting a tendency towards earlier selection and transfer from iconic memory to VWM.

4.2 Iconic Memory Methods

Participants. Eighty-three undergraduate students (60 female, age range: 18 – 35 years; \( M = 21.7 \)) were recruited from the University of Toronto undergraduate population and were included in these analyses (see section 2.2 for details on participant consent, compensation and ethics).

Procedure. Participants performed the same personality questionnaire as in the previous 3 experiments, the K-estimate task (VWM-capacity), and Raven’s Progressive Matrices task (intelligence), as described in Experiment 1. These two tasks were followed by the iconic memory task. This task replicated the paradigm used in Lu et al., (2005), where individuals were shown an array of eight capital letters (‘D’, ‘F’, ‘J’, ‘K’) situated on an invisible circle, centered around a fixation cross. Individuals were cued to report on the identity of a single letter within that array and asked to respond by pressing the matching letter key on the keyboard (see Figure 9). The timing of the cue was manipulated such that the cue could appear at the same time as the memory array, for a duration of 105 ms (Simu-cue: providing a measure of ability to use the cue and perform the target discrimination task), or at eight different stimulus offset asynchronies (SOAs) after the array (post-cues: 11ms, 32ms, 74ms, 221ms, 516ms, 800ms, 1105ms, and 2000ms, which provide an index of the temporal decay rate). Accuracy at the longest latency 2000ms provided a measure of information transferred and maintained in VWM, when the cues offer no more benefit, as this latency far exceeds the temporal duration of iconic memory (Coltheart, 1980). The probed letter and location of target item were selected randomly from trial-to-trial. There were 80 trials per condition, totaling of 720 trials. The temporal decay rate of iconic memory was assessed by fitting the following exponential decay function, used by Lu et al., (2005), to the data:
\[
\text{accuracy (SOA)} = a_0 + a_1 e^{SOA/\tau}
\]

In this formula \(a_1\) reflects the initial sensitivity or availability of visual information in iconic memory, \(\tau\) reflects the time constant of the decay in sensitivity that represents the duration of iconic memory, and \(a_0\) reflects the sensitivity after longer delays and the transfer of information into more durable short-term storage.

**Figure 9. Iconic Memory Task:** Participants were shown an array with 8 letters centered around a fixation cross and were asked to report on the identity of a cued letter with a key press (‘F’, ‘J’, ‘D’, ‘K’). The timing of the cue was varied such that it could either at the same time as the array (simu-cue) or at 8 different lag times after the onset of the array (post-cue SOA: 11, 32, 74, 221, 516, 800, 1105, 2000ms).

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*Stimuli:* Each of the eight letters were 1.29° x 1.29° of visual angel, situated on an invisible circle, with a radius of 3.5° of visual angel. A fixation cross was positioned at the center of the circle, also 1.29° x 1.29° of visual angel, and switched to an arrow cue at probe.

### 4.3 Iconic Memory Results

*Iconic Memory Model Parameters Across the Whole Group*
Averaging across the whole group of 83 participants, performance on the Simu-cue condition indicated that participants were able to use the cue and discriminate target information well, as average accuracy was high, $M = 0.90, SE = 0.01$. Inclusion in analyses was based on accuracy being within 3 standard deviations of the mean and performance is within this range across the entire group. There is a clear pattern of exponential decay in accuracy as a function of time (SOA) (see Figure 10). The average decay rate of iconic memory, $a_1$, was $M = 0.43, SE = 0.01$ (this is like a rate of change or slope value, that has a maximum value of 1). The average duration of iconic memory, $\tau$, was $M = 294.12\text{ms}, SE = 32.3$. The average amount of information transferred into VWM, $a_0$, was $M = 0.42, SE = 0.01$, or approximately 3.36 items (derived by multiplying $a_0$ by the total number of items in the array, 8). This estimate of VWM item capacity derived from the iconic memory task aligns remarkably closely with the mean estimate derived from our binary change detection task, K-estimate, $M = 3.39$ items, showing a good degree of internal consistency between these measures. Overall, the model parameters for this group are consistent with previous research, which estimates average iconic duration to be about 200-300ms (Gegenfurtner & Sperling, 1993; Lu et al., 2005; Sperling, 1960) and VWM to be about 3-4 items (Vogel et al., 2005).

Figure 10. Iconic Memory Group Decay Functions: a.) Whole group (N=83) average decay in accuracy as a function of memory array/stimulus offset asynchrony (SOA) – post-cues: 11ms, 32ms, 74ms, 221ms, 516ms, 800ms, 1105ms, and 2000ms. b.) Decay function, starting with SOA of 11ms. b.) Plot of just the post-cue conditions, which shows the point at which accuracy decays by 10% or is at 90% of maximum (green asterisks) once items are in iconic memory.
To explore individual differences in iconic memory performance, separate multiple regressions were performed for each of the model parameters, as well as accuracy in the post-2000 conditions. The regressions contained 5 predictors: Openness, Conscientiousness, the interaction between Openness and Conscientiousness, K-estimate, intelligence (Raven’s task). The predictor variables were centered to reduce the influence of collinearity between the interaction variable and the two personality variables.

Consistent with predictions, the parameter reflecting the rate of decay in iconic memory, $a_1$, shows a trending relationship with Conscientiousness, such that higher Conscientiousness is associated with faster decay or a steeper decay slope in iconic memory (smaller $a_1$), $r = -.18, p = 0.10, pr = -.17$ (see Table 2. for model coefficients and Figure 11 for correlations plots).

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<th>Personality Factors</th>
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<th>SE $B$</th>
<th>$\beta$</th>
<th>Semi-Partial Correlation</th>
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<td>.18</td>
<td>.12</td>
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*Single asterisk indicates a trend (p> 0.05, <0.11) and **double asterisk indicates p<0.001.

**Table 2.** Iconic Memory Regression Coefficients ($a_1$): Regression coefficients for the degree to which $a_1$ is predicted by the Big 5 personality traits, interaction between Openness and Conscientiousness, intelligence and VWM capacity. All predictors are centered. Conscientiousness showed a trending relationship with this measure of decay in iconic memory, consistent with predictions, $p = 0.10$. $B$ is the unstandardized coefficient and $\beta$ is the standardized coefficient.
The parameter reflecting the duration of iconic memory, $\tau$, was not significantly predicted by Openness or Conscientiousness, however, Extroversion showed a marginal relationship, $r = -0.21, p = 0.07$, $pr = -0.19$ (see Table 3.), suggesting this personality trait is associated with shorter iconic memory duration. K-estimate accounts for a significant amount of unique variance, with longer iconic duration related to higher VWM, $r = 0.33, p = 0.002, pr = 0.32$. The relationship between iconic memory duration and Intelligence shows a trending relationship in the same direction as VWM, $r = 0.18, p = 0.09, pr = 0.17$.

<table>
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<th>Personality Factors</th>
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<th>SE $B$</th>
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<th>Semi-Partial Correlation</th>
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<tr>
<td>VWM</td>
<td>102.890</td>
<td>32.447</td>
<td>0.33**</td>
<td>0.32</td>
</tr>
<tr>
<td>Intelligence</td>
<td>11.354</td>
<td>6.567</td>
<td>0.18*</td>
<td>0.17</td>
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</tbody>
</table>

*Single asterisk indicates a trend ($p > 0.05$, $<0.11$) and **double asterisk indicates $p < 0.001$.

Table 3. Iconic Memory Regression Coefficients ($\tau$): Regression coefficients for the degree to which $\tau$ is predicted by the Big 5 personality traits, interaction between Openness and Conscientiousness, intelligence and VWM capacity. All predictors are centered. VWM accounted for a significant amount of unique variance ($p = 0.002$), while Extroversion and intelligence both showed trends ($p = 0.07$ and $p = 0.09$ respectively). $B$ is the unstandardized coefficient and $\beta$ is the standardized coefficient.

The parameter reflecting the amount of information transferred from iconic memory to VWM, $a_0$, is not significantly predicted by any personality trait (see Table 4.). K-estimate accounts for a significant portion of unique variance in this measure of transfer of information into VWM, $r = 0.24, p = 0.03, pr = 0.23$, as does intelligence, $r = 0.22, p = 0.05, pr = 0.21$. To further validate the reliability of this measure, accuracy at the 2000ms SOA (when information should already be stored in VWM) was explored using this 5-
predictor model, which revealed a similar pattern of results. Personality does not significantly predict accuracy at 2000ms (see Table 5), while K-estimate does, $r = .29$, $p = 0.01$, $pr = .28$. Intelligence shows a relationship that does not quite reach significance, $r = .17$, $p = 0.13$, $pr = .16$.

<table>
<thead>
<tr>
<th>Personality Factors</th>
<th>$B$</th>
<th>SE $B$</th>
<th>$\beta$</th>
<th>Semi-Partial Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Openness</td>
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<td>.01</td>
<td>.01</td>
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<td>Conscientiousness</td>
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<td>.09</td>
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<tr>
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<td>.08</td>
</tr>
<tr>
<td>Neuroticism</td>
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<td>.01</td>
<td>.01</td>
</tr>
<tr>
<td>Extroversion</td>
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<td>0.001</td>
<td>.07</td>
<td>.06</td>
</tr>
<tr>
<td>Agreeableness</td>
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<td>0.001</td>
<td>-.10</td>
<td>-.10</td>
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<td>VWM</td>
<td>0.025</td>
<td>0.011</td>
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<td>.23</td>
</tr>
<tr>
<td>Intelligence</td>
<td>0.004</td>
<td>0.002</td>
<td>.22**</td>
<td>.22</td>
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</tbody>
</table>

*Single asterisk indicates a trend ($p > 0.05$, <0.11) and **double asterisk indicates $p < 0.001$.

Table 4. Iconic Memory Regression Coefficients ($a_0$): Regression coefficients for the degree to which $a_0$ is predicted by the Big 5 personality traits, interaction between Openness and Conscientiousness, intelligence and VWM capacity. All predictors are centered. VWM accounts for a significant amount of unique variance ($p = 0.03$), as does intelligence ($p = 0.05$). $B$ is the unstandardized coefficient and $\beta$ is the standardized coefficient.
<table>
<thead>
<tr>
<th>Personality Factors</th>
<th>B</th>
<th>SE B</th>
<th>$\beta$</th>
<th>Semi-Partial Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Openness</td>
<td>$&lt;0.001$</td>
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<td>.02</td>
<td>.01</td>
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<td>Conscientiousness</td>
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<td>Open x Conscientious</td>
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<td>-.15</td>
<td>-.14</td>
</tr>
<tr>
<td>VWM</td>
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<td>0.011</td>
<td>.29**</td>
<td>.28</td>
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<tr>
<td>Intelligence</td>
<td>0.003</td>
<td>0.002</td>
<td>.17</td>
<td>.16</td>
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</tbody>
</table>

*Single asterisk indicates a trend ($p > 0.05, <0.11$) and **double asterisk indicates $p < 0.001$.

Table 5. Iconic Memory Regression Coefficients (2000ms post): Regression coefficients for the degree to which accuracy at 2000ms post memory array (a measure of information stored in VWM) is predicted by the Big 5 personality traits, interaction between Openness and Conscientiousness, intelligence and VWM capacity. All predictors are centered. VWM accounts for a significant amount of unique variance ($p = 0.01$), while intelligence does not quite reach significance ($p = 0.12$). B is the unstandardized coefficient and $\beta$ is the standardized coefficient.

Upon visual inspection of the individual data sets it appears that some participants’ performance decays very quickly in the first 100ms of iconic memory (fast initial decay), while others show relatively little initial decay. A prolonged duration of time before performance significantly drops may be taken as indication that more information is initially being maintained in iconic memory. Given that higher trait Openness is related to a more broad distribution of attention, might these individuals retain more information initially in iconic memory, through a broader distribution of attention or postponed selection? This question was addressed by calculating the duration of time before there is evidence of significant decay for each individual. This measure of iconic maintenance prior to decay was quantified by finding the time point on each individual’s iconic memory decay function where performance had declined by only 10%. Figure 10b shows this point where performance has dropped by 10% (green asterisk) in the whole group data, which occurs at an average of about 117ms. A multiple regression, with the same 5 predictors
as in the above analyses, reveals a relationship between Openness and the ability to hold more information in iconic memory before significant decay occurs, which trends towards significance, \( r = .20, p = 0.10, \rho r = .18 \). K-estimate was also a significant predictor of this measure of early representation in iconic memory, \( r = .32, p = 0.005, \rho r = .31 \). No other predictors in the model showed a notable relationship with this measure (see Table 6).

### Table 6. Iconic Memory Regression Coefficients (Point of 10% Iconic Decay)

Regression coefficients for the degree to which the point at which memory has decayed by 10% (a measure of initial capacity or retention in iconic memory) is predicted by the Big 5 personality traits, interaction between Openness and Conscientiousness, intelligence and VWM capacity. All predictors are centered. A trending association with Openness suggests greater retention of information in iconic memory initially (\( p = 0.10 \)). VWM accounts for a significant amount of unique variance (\( p = 0.005 \)), while intelligence does not quite reach significance (\( p = 0.12 \)). \( B \) is the unstandardized coefficient and \( \beta \) is the standardized coefficient.

<table>
<thead>
<tr>
<th>Personality Factors</th>
<th>B</th>
<th>SE B</th>
<th>( \beta )</th>
<th>Semi-Partial Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Openness</td>
<td>0.883</td>
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<td>.23*</td>
<td>.18</td>
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<td>Conscientiousness</td>
<td>0.142</td>
<td>0.504</td>
<td>.03</td>
<td>.03</td>
</tr>
<tr>
<td>Open x Conscientious</td>
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<td>0.035</td>
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<td>-.03</td>
</tr>
<tr>
<td>Neuroticism</td>
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<td>.06</td>
</tr>
<tr>
<td>Extroversion</td>
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<td>-.06</td>
<td>-.05</td>
</tr>
<tr>
<td>Agreeableness</td>
<td>-0.050</td>
<td>0.532</td>
<td>-.01</td>
<td>-.01</td>
</tr>
<tr>
<td>VWM</td>
<td>18.07</td>
<td>6.26</td>
<td>.32**</td>
<td>.31</td>
</tr>
<tr>
<td>Intelligence</td>
<td>0.665</td>
<td>1.266</td>
<td>.06</td>
<td>.06</td>
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</tbody>
</table>

*Single asterisk indicates a trend (\( p > 0.05, < 0.11 \)) and **double asterisk indicates \( p < 0.001 \).
Figure 11. Individual differences in Parameter $a_1$ & Initial Iconic Memory Decay: a.) Relationship between Conscientiousness and rate or shape of decay in iconic memory, $a_1$. b.) Correlation between Openness and time point at which iconic memory accuracy drops by 10% or to 90% of maximum performance. A larger value reflects a longer duration of preserved representation in iconic memory.

4.4 Iconic Memory Discussion

Overall, participants are able to perform the target discrimination aspect of this task well, as evidenced by the high degree of accuracy in the Simu-cue condition, despite presentation time being rather brief (105ms). The parameter estimates are consistent with the results of previous research, showing exponential decay in the group data, duration of iconic memory ($\tau$) of about 300ms, and VWM capacity of between 3 and 4 items (3.36 in this sample). Further, there is good internal consistency between this estimate of VWM capacity and the K-estimate task, which provides a remarkably consistent average VWM capacity estimate of 3.39 items. There are, however, individual differences in the parameters of iconic memory.

Iconic Memory and Personality

The shape of the decay curve, as measured by $a_1$ varies between individuals. Some individuals show a more gradual decay rate (reflected by larger $a_1$ estimates) while other show a steeper drop in iconic retention. Conscientiousness accounts for a moderate amount of variance in iconic decay rate, such that
higher scores in Conscientiousness are moderately predictive of steeper decay. This faster rate of decay may reflect earlier selection and transfer of items to VWM. Gegenfurtner & Sperling (1993) proposed two types of transfer from iconic to visual working memory, one form of selection prior to the cue and another elicited by the cue. Pre-cue transfer is taken to reflect the endogenous process of selecting and transferring items from iconic memory to more durable VWM storage prior to the cue. These authors suggest that individuals seem to choose this form of pre-cue transfer when memory representations are fading, which on average occurs during longer SOAs. Some individuals, however, may either experience more rapid fading or have a lower tolerance for fading and tend to store items at a higher degree of resolution, transferring items to VWM before they have decayed. Thus a faster drop in accuracy in iconic memory may reflect a tendency to store individual items at a higher degree of resolution in VWM.

Given the proposed relationship between Openness and the breadth or scope of endogenous attention, Openness is expected to predict greater initial representation in iconic memory. Upon visual inspection of individual decay plots it is apparent that some individuals show decay immediately (starting between 11 and 30ms), while others show very little initial decay (only a relatively small drop in accuracy in the first 100ms). Thus a measure of the amount of initial decay was calculated as the time point at which an individual’s iconic memory performance had dropped by 10% (90% of maximum). Openness shows a trending relationship with this measure of initial retention in iconic memory, suggesting that Openness may be associated with a small amount of variance here and associated with greater initial breadth of representation and retention in iconic memory.

Iconic Memory, Visual Working Memory and Intelligence

Iconic memory duration (\( \tau \)), which reflects the point at which an individual’s performance asymptotes and information is transferred into VWM, is predicted by K-estimate. Specifically, shorter iconic memory duration and is related to lower VWM capacity reflecting an early loss of benefit from the cue as the smaller VWM store in those low capacity individuals may simply fill up faster than those with a
larger store. Alternatively, they simply may not be able to benefit from the broad storage capacity of iconic memory, placing greater demands on VWM earlier in processing. K-estimate was also predictive of $a_0$, the model's estimate of the amount of information transferred into VWM, such that lower capacity estimates significantly predicted lower $a_0$. Furthermore, accuracy at 2000ms, an alternative measure of VWM retention, was also correlated with K-estimate. These results suggest that the proposed deficit in efficient/effective selective attentional filtering, which may be the key mechanism underlying individual differences in VWM item capacity (e.g., Awh & Vogel, 2008; Awh et al., 2006; Cowan, 2001; Vogel et al., 2005) may also impact visual processing prior to VWM. A lower attentional capacity in some individuals may result in a reduced ability to encode and preserve items in iconic memory (e.g., faster initial decay), which may necessitate a quicker process of transfer from iconic memory to VWM ($\tau$). This faster transfer may result in a precision benefit, having transferred individual items before they decay in iconic memory, but the problem is this transfer may occur prior to the probe, likely resulting in the transfer of the wrong items sometimes. Intelligence also accounted for some unique variance in rate of decay/transfer ($\tau$), amount of information transferred to VWM ($a_0$) and to a lesser extent, accuracy at 2000ms.

Taken together the results of Experiment 3 provide some preliminary evidence that personality is related to individual differences in early visual memory and are related in a manner that is consistent with the Attention and Personality Framework. Though the amount of unique variance accounted for by Conscientiousness and Openness only trended towards significance, these trends did emerge in the measures predicted and in the direction predicted. Specifically, the selectivity of attention associated with Conscientiousness can explain the greater propensity to pre-select information from iconic memory early, before icons have decayed much ($a_1$), and transfer that information to a more stable and robust representation in VWM. Openness, on the other hand is moderately predictive of a more sustained and stable representation in the first 100ms of iconic memory, which may reflect an ability to broadly distribute attentional resources in order to maintain items in iconic memory with less initial decay or a lower initial
decay cost. These analyses of individual differences also shed further light on the nature of variance in VWM item capacity, suggesting that differences how information is attended and processed in iconic memory may impact VWM capacity estimates.

In experiment 4 we move further along the visual processing stream to explore the potential relationship between personality and VWM. Given the close relationship between attention and VWM, the Attention and Personality Framework predicts a relationship between personality and VWM. Specifically, the tendency of individuals with higher trait Openness to engage a broader scope of attention (Exp1) and allow more information initially into iconic memory and/or maintain more items in iconic memory (Exp3) may result in the storage of more items in VWM, but at the cost of resolution or precision. The propensity of Conscientious individuals to engage selectivity earlier (Exp2) may lead to earlier selective transfer of information from iconic memory to VWM (Exp3). If this is the case then we should see a precision benefit in VWM, as items transferred earlier should have decayed less. Alternatively, it is possible that the faster decay rate for those high in Conscientious individuals may simply reflect faster passive fading. If this is the case, then precision in VWM should be compromised as a result of this faster fading and loss of fidelity. Thus in Experiment 4 these hypotheses were tested using a continuous response change-detection task, which provides various different measures of the VWM performance, including the precision of VWM representations.
Chapter 5
Individual Differences in Visual Working Memory

5 Experiment 4

5.1 Colour-Wheel Change Detection

Visual working memory is a temporary form of visual memory that maintains fleeting perceptual representations from iconic memory in a more durable form. A common way to measure VWM is through estimates of the number of items an individual can hold in mind, in other words, their item capacity. Item capacity is often probed using *binary forced-choice change detection* tasks. In a typical change detection task, participants are briefly shown a memory array of coloured items, ranging from 1-6 items. After a short delay (~1000ms) a single probe item appears in one of the memory array item locations. Participants are simply asked to indicate whether the probe item is the same or different colour as the item presented in that location in the previous memory array. The following formula is applied to calculate an estimate of the number of items held in mind, per set size: $K = S \times (H + CR)$. Here ‘$K$’ represents capacity, ‘$S$’ is the set size, ‘$H$’ is the proportion of hits and ‘$CR$’ is the proportion of correct rejections (Cowan, 2001). Though average VWM capacity estimated by this formula is about 3-4 items in younger adults, there is a fair amount of variance between individuals, with estimates ranging from as low as 1.5 up to 6 items.

*Individual Differences in VWM Item Capacity*

The variance in VWM capacity estimates, derived from these types of binary VWM tasks has been linked to individual differences in selective attention (Vogel et al. 2005). As mentioned in the introduction to this thesis, the electrophysiological correlate of VWM, the CDA, scales with the number of items stored in VWM and asymptotes at an individual’s behavioural capacity. Vogel et al. (2005) show, that the CDA in L-VWM individuals increases when distracting/irrelevant items are added to a memory display, while the CDA of H-VWM individuals does not. This is taken as evidence that L-VWM individuals have weak selective attention and allocate limited VWM resources to task irrelevant details.
This electrophysiological marker of individual differences in VWM is corroborated by functional magnetic resonance imaging research. Low VWM individuals show increased activation in the parietal lobe in the face of distractors, while high VWM individuals show little differential modulation of the parietal when distractors are present (Todd & Marois, 2004), similar to the pattern observed in the CDA. There is strong support for the notion that individuals differ in terms of what is encoded and selective attentional filtering. It is unclear, whether or not there may also be differences in terms of how resources are allocated or distributed within memory.

Indiscriminate encoding or less selective attention may be part of the reason why some individuals perform worse on VWM tasks, however, this explanation may be incomplete. For instance, some individuals may delay selectivity, as we saw in the low Conscientious individuals in Experiment 2, which results in encoding all items in VWM memory initially, leaving the process of filtering until a later stage. This strategy may be easier for some, given that transferring items to memory selectively (selective encoding) is effortful and may interfere with the consolidation process for some individuals (Cowan & Morey, 2006). This leads to several other questions about the nature of individual differences in VWM. For instance, do individuals store items at different degrees of precision or resolution? If some individuals are indiscriminately allowing all items into VWM then one would expect precision to be lower. What is the nature of the kinds of errors that result from this initial unselective encoding? Do some individuals have fewer relevant items in memory, resulting in more guessing or are all items stored, but weaker selective attention results in misbinding and swapping item identity and location? Does personality predict some of this variance in how information is stored in VWM? These specific questions about the nature of storage in VWM are not easily answered by binary change detection tasks.

The 3-Component Probabilistic Mixture Model of VWM

Though the use of binary, forced choice, change detection tasks provide fairly stable estimates of how many discrete items (quantity) an individual can hold in mind, this method does not have the
behavioural or methodological resolution to address deeper questions about the nature of individual differences in VWM. These binary change detection tasks do not provide information regarding the degree of precision at which items are stored (quality) or the different ways in which one's memory can be incorrect (lack of precision, no information present vs. incorrectly bound information). Bays, Catalao & Husain’s (2009) 3-component probabilistic mixture model of VWM is used in Experiment 4 to address some of these questions. This model estimates the probability of responses of three types, *target-response* (accurate representation of target information in memory), *guesses* (inaccurate or lack of representation of information in memory), and *non-target-responses* (reporting an item that was in the display, but confused location; a swap error). Estimates for these three parameters and precision can be derived from continuous-response change detection paradigms. In these continuous response tasks participants are not merely asked a forced-choice question (e.g., ‘same or different’) about a single probed item, but selects the precise colour on a continuous colour wheel that best matches the colour of the item they are holding in memory. As such, this method provides greater insight into the inner structure of and representation within VWM and may help to further clarify the nature of individual differences in VWM.

*VWM and Personality*

Attention plays a critical role in VWM, as there is evidence that resources can be distributed across items in memory, which arguably relies on how attention is allocated (Cowan, 2001; Cowan & Morey, 2006). The amount of resources or attention allocated to a particular item determines the precision with which that item is represented and recalled (Bays et al., 2009). Given that individual differences in VWM performance are clearly impacted by visual attention and there appears to be a relationship between visual attention and personality, there is good reason to believe that personality may explain variance in some of these model parameters. Individual differences in the selectivity of visual attention, as predicted by Conscientiousness, may be related to the ability to individuate items (bind features to locations) and represent items with a high degree of resolution. The degree of resolution or precision of VWM
representations, however, is not necessarily directly reflective of the amount of resource that is available (i.e., number of items that can be stored). For instance, one may store only a couple items at either a high degree or low degree of resolution, depending on how one allocates their visual attention and VWM resources. Bays & Husain’s (2009) three-component mixture model is well-suited to the study of individual differences in VWM. This model provides measures of the amount of attentional resources allocated to items and the ability to: report item features (precision); remember target items in VWM (pTarg); and properly bind objects to locations avoiding swap errors where non-target items are mistakenly selected (pNonTarg), which is differentiated from random guessing (pGuess). This model may help to refine our understanding of individuals who show low item capacity, as well as reveal the extent to which individual differences in personality and attention may impact VWM performance.

In Experiment 4, a continuous-response colour wheel change detection paradigm is used to explore whether personality predicts VWM performance, as estimated by the three-component model. A manipulation of load (set sizes: Set 2 and Set 4) was included, as well as a manipulation of selectivity or filtering. Participants were asked to either attend to all items in a display (i.e., Sets 2 and 4, half circles and half squares) or selectivity attend to a subset of those items (i.e., Sets 2 and 4, but only attend squares, ignore circles). In addition, a separate item-capacity change detection task was used to obtain an individual difference measure of item capacity, comparable to what is used widely in the literature. Several predictions follow from the Attention and Personality Framework. Given the evidence presented thus far, Conscientiousness appears to be related to the selectivity of attention, which plays a critical role in VWM, as well as how information is selected and transferred from iconic memory to VWM. We might expect to see a relationship between Conscientiousness and how attention is used to precisely select and store information in VWM. Specifically a positive relationship with precision is predicted. A relationship between personality and the amount of VWM resource one has or how many items can be held in memory (e.g., pTarg) is not anticipated, particularly because K-estimate has not been found to correlate with our personality measures in Experiments 1-3. It is possible, however, that a higher degree of selectivity may
enable greater binding in memory and fewer swap errors (pNonTarg). Given that Openness is predictive of
greater scope and perhaps more broad representation of information in iconic memory, there may be a
trade-off in terms of the number of items stored in VWM (pTarg) and precision. Further, there should be
strong relationships between VMW item capacity as assessed by the traditional approach, and estimates of
VWM storage and representation as predicted by this model.

5.2 Colour-Wheel Methods

Participants. Sixty-seven undergraduate students (35 female, age range: 17 – 31 years; M = 20.9),
recruited from the University of Toronto undergraduate population, participated in this experiment and
were included in these analyses (see section 2.2 for details on participant consent, compensation and
ethics).

Procedure: Just as in the first three experiments, participants completed the same 120-item IPIP-
NEO questionnaire. Participants also completed a short (~10 min) colour change detection task,
described in the introduction to this chapter, which is commonly used to estimate VWM item capacity or
K, using the following formula: K = S* (H + CR). This K-estimate task was followed by the main
experimental colour wheel task, which was presented on the same type of monitor with the same viewing
distance as in experiment 1 and 2. In this task, participants were briefly presented (500ms) with an array of
coloured items (circles and squares). Participants were asked to maintain central fixation and try to
remember the colour of the items. Following a delay (1000ms), they were shown a probe screen containing
placeholders where the coloured items were presented previously. One of these placeholders had a thicker
outline and participants were asked to recall what colour this particular item had been. Participants
responded by clicking with a computer mouse on the colour on a colour wheel surrounding the display
that matched their memory of the probed item (see Figure 12). This task also included a manipulation of
the selectivity of attention and a manipulation of item load or set size. To challenge the selectivity of
attention, participants were asked to either remember all the items presented in the memory array,
composed of an equal number of circles and squares (Remember All condition, referred to as RemAll) or were asked to selectively attend to just one type of item (e.g., circles) while ignoring the other type (e.g., squares) (Filter condition). In the Filter condition, only the relevant objects were probed (e.g., in the circles task only circles were probed). The set size of the memory array was also manipulated, such that half the trials contained 2 items (1 circle, 1 square) and the other half contained 4 items (2 circles, 2 squares). In the Filter condition, only half the items were to be remembered, so if participants filtered items as instructed, the Filter Set 4 condition would entail maintaining only 2 items in VWM. Participants performed either the ‘circles’ or ‘squares’ task, in which either circles or squares (respectively) were deemed the relevant item for the Filter block throughout the task. The RemAll and Filter conditions, were blocked, so participants could establish an attentional control set within block. Participants completed a total of 6 blocks of 60 trials each (3 Filter and 3 RemAll), with equal number of Set 4 and Set 2 trials randomly intermixed. Whether the probed item appeared on the left or right of fixation was also pseudo randomly counterbalanced, such that 50% of trials were right-sided in each block, but trial order was randomly assigned within block.

Stimuli: The memory items (circles and squares) were 1.2° x 1.2° of visual angle in size, in variable locations around an invisible circle with a radius of 5.4° of visual angle, centered around a fixation cross (1.2° x 1.2° of visual angle) each appearing as one of 9 potential colours, selected pseudo-randomly on each trial, such that no two colours were the same on a given trial and all were separated by at least 15 values in colour space. The colour wheel had an inner radius of 7.6° of visual angle and outer radius of 10.8° of visual angle. Memory items were randomly chosen from selection of 180 colours from the colour wheel (centered at L = 65, a = 5, b = 5) in the CIEL*a*b* colour space, a colour space based on human colour perception and discrimination. Luminance, brightness, intensity were held constant.
5.3 Colour-Wheel Results

Analyses of the behavioural data were conducted in line with the procedures of Bays et al. (2009; http://www.bayslab.com). The actual probe item’s colour and participants’ colour selections (responses) were coded as angular measures (from -pi radians to pi radians) and performance error was calculated as the difference between the actual target colour and the colour selected by the participant. A probabilistic mixture model, developed by Bays et al., (2009) was employed in order to estimate the source of error in participants’ responses (see Figure 12b). This model proposes that VWM performance can be accounted for by three types of responses: target responses (pTarg), characterized by a normal distribution of variance
around the target color; non-target responses or swap errors \( (p_{NonTarg}) \), characterized by a normal distribution of variance around the other non-probed or non-target items in the array; and random guesses \( (p_{Guess}) \), characterized by a uniform distribution. The shape or spread of the error distribution (standard deviation) around pTarg and pNonTarg colours provides a measure of the precision in response or representation of items in VWM. Analyses were performed using repeated-measures analysis of variance (RM ANOVA), with Bonferroni correction for multiple comparisons.

**Probability of Target Responses**

First, the probability, as calculated by the probabilistic mixture model, of making target \( (p_{Targ}) \) responses was analyzed using RM ANOVA, with two within-subject factors of set size (Set 2 and Set 4) and the selectivity manipulation (Filter vs. RemAll). A significant main effect of set size on pTarg was observed, \( F(1,66) = 436.28, p < 0.001, \eta^2 = .87 \), with a greater probability of target responses for Set 2 \( (M = 0.91) \) than Set 4 \( (M = 0.65), p < 0.001 \). Selective filtering, employed in the Filter condition, had a significant impact on pTarg, \( F(1,66) = 337.62, p < 0.001, \eta^2 = .84 \), with a greater probability of target response for Filter \( (M = 0.88) \) than RemAll \( (M = 0.68), p < 0.001 \). A significant interaction was also revealed, \( F(1,66) = 151.89, p < 0.001, \eta^2 = .70 \). The simple effects of this interaction were explored with Bonferroni-corrected, pairwise t-tests. All comparisons were significant. An increase in set size came at a cost in pTarg for the RemAll condition, \( M_{diff} = 0.36, t(66) = 22.70, p < 0.001, d = 2.20 \), and the Filter condition, \( M_{diff} = 0.15, t(66) = 10.53, p < 0.001, d = 1.31 \), and this cost of set size (difference in pTarg) was significantly greater in the RemAll condition, compared to the Filter condition, \( t(66) = 12.32, p < 0.001 \). There is also a benefit of Filtering over RemAll at Set 4, \( M_{diff} = 0.32, t(66) = 20.76, p < 0.001, d = .90 \), and Set 2, \( M_{diff} = 0.10, t(66) = 7.33, p < 0.001, d = 1.87 \), however, this effect is significantly stronger when VWM is under a greater load at Set 4, relative to Set 2, \( t(66) = 12.32, p < 0.001 \) (Figure 13a). Taken together these results suggest that individuals were able to employ selective attention in the Filter condition to enhance processing of the relevant items (circles or squares) and inhibit irrelevant items and this affords
a greater benefit when there are more items in the array resulting in a greater reduction in load with filtering, consistent with the conclusions of Vogel et al., (2005) and theories of the role of attention in VWM (Cowan & Morey, 2006).

Pearson’s correlations were used to explore whether Conscientiousness or Openness are significant predictors of pTarg. Neither Conscientiousness ($r = .15, p = 0.23$), nor Openness ($r = .07, p = 0.59$) show a reliable relationship with pTarg. Openness is not correlated with performance in the RemAll condition, $r = .07, p = 0.59$, and there is a small relationship with Conscientiousness: $r = .19, p = 0.13$, however, this did not quite reach significance. Performance in the Filter condition was not significantly related to Conscientiousness, $r = -.01, p = 0.96$, or Openness, $r = .11, p = 0.38$. Thus there is little evidence that personality is related to the probability of remembering target items or the amount of VWM resources. The relationship between our model parameters and our binary measure of item capacity (K-estimate) was also tested using Pearson’s correlation to ensure the two measure of VWM were closely related, which showed a strong relationship, $r = .53, p < 0.001$. 
Figure 13. Colour Wheel Whole-Group Results: (a.) Probability of Target (pTarg) responses, by set size and Filter condition; (b.) Probability of Non-Target (pNonTarg) responses, by set size and Filter condition; (c.) Probability of Guess (pGuess) responses, by set size and Filter condition; (d.) Precision of responses (distribution around target and non-target responses), by set size and Filter condition. Error bars reflect the SSE.

Probability of Non-Target Responses

Next, binding or swap errors were explored, as the probability of making a non-target (pNonTarg) response as estimated by the probabilistic mixture model, just as pTarg was analyzed. A significant main effect of set size on pNonTarg was observed, $F(1,66) = 87.34, p < 0.001, \eta^2 = .57$, with a greater probability of non-target responses for Set 4 ($M = 0.12$) than Set 2 ($M = 0.02$), $p < 0.001$. The engagement of selective attention in the Filter condition had a significant effect on pNonTarg, $F(1,66) = 45.76, p < 0.001, \eta^2 = .41$, with a greater probability of non-target responses for RemAll ($M = 0.11$) than Filter ($M = 0.2$).
0.04), \( p < 0.001 \). A significant interaction was also present, \( F(1,66) = 12.44, p < 0.001, \eta^2 = .16 \). All comparisons were again significant. As can be seen in Figure 13b, there is an increase in pNonTarg associated with set size in the RemAll condition, \( M_{\text{diff}} = 0.13, t(66) = 7.58, p < 0.001, \quad d = 2.20 \) and in the Filter condition, \( M_{\text{diff}} = 0.06, t(66) = 6.05, p < 0.001, \quad d = 1.31 \), and the magnitude of this difference is greater in the RemAll relative to Filter, \( t(66) = 3.53, p < 0.001 \). Filtering, relative to RemAll, has the benefit of reducing pNonTarg at Set 4, \( M_{\text{diff}} = 0.10, t(66) = 5.35, p < 0.001, \quad d = 1.87 \), and at Set 2, \( M_{\text{diff}} = 0.04, t(66) = 7.2, p < 0.001, \quad d = 0.75 \), however, this effect is greater when memory is near capacity, at Set 4 relative to Set 2, \( t(66) = 3.53, p < 0.001 \). Similar to the pTarg analyses, these results suggest that individuals are using the selectivity of attention in the Filter condition, which affords a greater benefit in terms of a reduction in pNonTarg or swap errors when there are more items on display.

Pearson’s correlations were used to explore whether Conscientiousness or Openness are significant predictors of pNonTarg. Neither Conscientiousness \( (r = -.11, p = 0.39) \), or Openness \( (r = .007, p = 0.95) \) are significantly related to pNonTarg. Neither of these personality traits are predictive of performance in the RemAll condition (Conscientiousness: \( r = -.07, p = 0.57 \); Openness: \( r = .05, p = 0.67 \)) or the Filter condition (Conscientiousness: \( r = -.11, p = 0.4 \); Openness: \( r = -.07, p = 0.56 \)). Thus there is little evidence here suggesting that personality is related to non-target memory errors or swapping items in VWM (binding errors). The relationship between K-estimate and pNonTarg errors was also tested which showed a marginal relationship, \( r = -.23, p = 0.06 \).

**Probability of Guesses**

Random guesses (pGuess) were explored as the probability of making a Guess response by the probabilistic mixture model. A significant main effect of set size on pGuess was observed, \( F(1,66) = 86.71, p < 0.001, \eta^2 = .57 \), with a greater probability of guess responses for Set 4 \( (M = 0.23) \) than Set 2 \( (M = 0.07) \), \( p < 0.001 \). A significant main effect of selective attention (Filter) on pGuess was found, \( F(1,66) = 72.15, p < 0.001, \eta^2 = .52 \), with a greater probability of guess responses for RemAll \( (M = 0.22) \) than Filter
(M = 0.08), p < 0.001. A significant interaction was once again present, F(1,66) = 30.02, p < 0.001, \( \eta^2 = .31 \).

Simple effects were explored using Bonferroni corrected pair-wise t-test. All comparisons were again significant, such that pGuess increases with set size in the RemAll condition, \( M_{diff} = 0.23, t(66) = 8.82, p < 0.001, d = 1.20 \), and in the Filter condition, \( M_{diff} = 0.9, t(66) = 5.40, p < 0.001, d = 0.60 \), with a greater cost of set size in the RemAll compared to Filter \( t(66) = 5.48, p < 0.001 \). Filtering is associated with lower pGuess compared to RemAll at Set 4, \( M_{diff} = 0.21, t(66) = 7.86, p < 0.001, d = 1.06 \), and at Set 2, \( M_{diff} = 0.063, t(66) = 4.88, p < 0.001, d = 0.62 \). This difference is also significantly greater at Set 4, \( t(66) = 5.48, p < 0.001 \) (see Figure 13c).

Pearson’s correlations were used to explore whether Conscientiousness or Openness were significant predictors of pGuess. Neither Conscientiousness (r = -0.11, p = 0.36) nor Openness (r = -0.08, p = 0.55) were significantly related to pGuess. Neither of these personality traits were predictive of performance in the RemAll condition (Conscientiousness: r = -0.14, p = 0.25; Openness: r = -0.13, p = 0.30) or the Filter condition (Conscientiousness: r = -0.02, p = 0.85; Openness: r = 0.05, p = 0.71). Thus there is little evidence that personality is related to guessing errors in VWM. K-estimate was negatively correlated with average pGuess \( r = -0.46, p < 0.001 \).

**Precision in VWM**

A significant main effect of set size on precision was observed, \( F(1,66) = 12.16, p = 0.001, \eta^2 = .16 \), with higher precision at Set 2 (M = 11.88) requiring resources to be spread over fewer items, relative to Set 4 (M = 9.75), p = 0.001. A significant main effect of selective attention or filtering on precision was also observed, \( F(1,66) = 6.93, p = 0.01, \eta^2 = .10 \), with higher precision for Filter (M = 11.71) than RemAll (M = 9.93), p < 0.01. A significant interaction was also present, \( F(1,66) = 27.582, p < 0.001, \eta^2 = .30 \). Simple effects were explored using pair-wise t-test with Bonferroni correction, which revealed that Filtering facilitates precision at Set 2, \( M_{diff} = 4.69, t(66) = 7.03, p < 0.001, d = 0.97 \), however, this difference was not significant at Set 4, \( M_{diff} = 1.12, t(66) = 1.08, p < 0.29, d = 0.18 \). Further, when only considering the
Filter condition, precision decreases with set size, \( M\ diff = 5.04, t(66) = 7.93, p < 0.001, d = 0.98 \), as expected. In fact, Filter Set 4 and RemAll Set 2 did not significantly differ, \( M\ diff = 0.34, t(66) = 0.82, p = 0.42, d = 0.09 \), suggesting that participants were in fact only encoding the 2 relevant items, as per task instructions. In the RemAll condition, however, performance unexpectedly remains constant across set size in the RemAll condition, \( M\ diff = 0.78, t(66) = 0.80, p = 0.43, d = 0.13 \) (see Figure 13d).

Pearson’s correlations were used to explore the relationship between personality and precision. A marginal relationship between Conscientiousness and average precision was found, \( r = .23, p = 0.06 \), while Openness did not significantly predict precision overall \( r = -.05, p = 0.70 \). K-estimate was marginally predictive of precision, \( r = .22, p < 0.08 \).

The relationship between personality and precision was further explored using multiple regression, with 8 predictor variables: Openness, Conscientiousness, Extroversion, Agreeableness, Neuroticism, the interaction between Conscientiousness and Openness, K-estimate, and a measure of intelligence (Raven’s). The predictor variables were centered to reduce the influence of collinearity between the interaction variable and the two personality variables. This analysis revealed that in the Filter condition, Conscientiousness accounts for a significant portion of unique variance in precision, \( b = .34, p = 0.02 \) pr = .28, as does K-estimate, \( b = .40, p = 0.002 \) pr = .37 (see Table 7 and Figure 14). In the RemAll condition Conscientiousness, accounts for a marginal amount of unique variance, \( b = .28, p = 0.07 \) pr = .23. Openness also emerges as marginal predictor of unique variance, which trends towards significance, \( b = -.23, p = 0.10 \) pr = -.20, however, individuals higher in Openness appear to represent information in VWM at a lower degree of resolution or precision (see Table 8).
<table>
<thead>
<tr>
<th>Personality Factors</th>
<th>B</th>
<th>SE B</th>
<th>β</th>
<th>Semi-Partial Correlation</th>
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</thead>
<tbody>
<tr>
<td>Openness</td>
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<td>.08</td>
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<td><strong>.28</strong></td>
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<td>Extroversion</td>
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<td>Agreeableness</td>
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<td>0.062</td>
<td>-.25</td>
<td>-.22</td>
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<tr>
<td>VWM (K-estimate)</td>
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<td><strong>0.651</strong></td>
<td><strong>.40</strong></td>
<td><strong>.37</strong></td>
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<tr>
<td>Intelligence</td>
<td>-0.017</td>
<td>0.117</td>
<td>-.02</td>
<td>-.02</td>
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*Single asterisk indicates a trend (p > 0.05, <0.11) and **double asterisk indicates p < 0.001.

Table 7. Colour Wheel Regression Coefficients (Filter Precision): Regression coefficients for the degree to which precision in the Filter condition is predicted by the Big 5 personality traits, interaction between Openness and Conscientiousness, intelligence and VWM capacity. All predictors are centered. Conscientiousness accounts for a significant amount of unique variance in this measure of precision, suggesting higher Conscientiousness is associated with higher precision (p = 0.02). VWM also accounts for a significant amount of unique variance (p = 0.002). B is the unstandardized coefficient and β is the standardized coefficient.

<table>
<thead>
<tr>
<th>Personality Factors</th>
<th>B</th>
<th>SE B</th>
<th>β</th>
<th>Semi-Partial Correlation</th>
</tr>
</thead>
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<td>VWM (K-estimate)</td>
<td>0.155</td>
<td>0.765</td>
<td>.03</td>
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<tr>
<td>Intelligence</td>
<td>-0.101</td>
<td>0.137</td>
<td>-.10</td>
<td>-.09</td>
</tr>
</tbody>
</table>

*Single asterisk indicates a trend (p > 0.05, <0.11) and **double asterisk indicates p < 0.001.

Table 8. Colour Wheel Regression Coefficients (RemAll Precision): Regression coefficients for the degree to which precision in the RemAll condition is predicted by the Big 5 personality traits, interaction between Openness and Conscientiousness, intelligence and VWM capacity. All predictors are centered. Conscientiousness accounts for a some unique variance, suggesting higher Conscientiousness is modestly associated with greater precision in the RemAll conditions (p = 0.02), while Openness
shows a trending relationship in the opposite direction, suggesting that Openness is associated with less precision in the RemAll condition ($p = 0.10$). $B$ is the unstandardized coefficient and $\beta$ is the standardized coefficient.

Figure 14. Colour Wheel Precision & Conscientiousness Correlations: (a.) Correlation between Conscientiousness and precision, in the Filter condition; (b.) Correlation between Openness and precision, in the RemAll condition.

**Precision & Individual Differences in VWM item-capacity estimate**

As mentioned above, precision was not found to decrease with an increase in Set Size in the RemAll condition. This unexpected finding was explored further, guided by the hypothesis that individual differences in VWM item capacity may correspond with different behaviour in the high load (4 items) condition. It is possible that individuals with lower item capacity estimates use a different strategy on these high load trials, as close to half of this sample has a VWM capacity estimate of 2.5 items or less (K-estimate range: 1.9 – 5.2 items; Median of 3.2 items). Further, K-estimate was marginally predictive of precision, $r = .22$, $p < 0.08$. Individuals with Low VWM item capacity (L-VWM) may be storing information differently when memory arrays exceed their capacity. To explore this possible explanation, in line with previous research (e.g., Vogel et al., 2005), a median split was performed based on capacity derived from the K-estimate task. The average capacity estimate for each group was as follows: High VWM (H-VWM) group capacity, $M = 4$, and L-VWM group capacity, $M = 2.5$. There were 8 individuals (middle 12%) that
had the exact same score as the median (3.2), thus they were excluded from the analyses below, as it is ambiguous as to whether they belong to the high or low VWM group.  

The same analyses were conducted as in the initial analysis of precision above, with an added between-subject variable of VWM capacity. This new analysis of precision produces the same main effects and interactions as above, thus only those results that differ from what is already reported are discussed here (e.g., between-subject results and interactions). There is a main effect of the between-subject factor of VWM capacity group that trends towards significance, $F(1,57) = 2.85, p = 0.09, \eta^2 = .05$, with higher precision in the H-VWM group ($M = 11.65$) relative to the L-VWM group ($M = 9.83$). In addition, there are significant two-way interactions between VWM group and Filtering, $F(1,57) = 9.21, p = 0.004, \eta^2 = .14$, and set size $F(1,57) = 12.56, p = 0.001, \eta^2 = .18$. As can be seen in Figure 15a and 15b, the pattern of results for precision are quite different for the L-VWM group compared to the H-VWM group. In the Filter condition, L-VWM individuals are performing as expected, with higher precision in Set 2 (remember 1 item) relative to Set 4 (remember 2 items), $M_{diff} = 2.57, t(29) = 3.76, p = 0.001$. This suggests that they are in fact effectively filtering in the Filter Set 4 condition. In the RemAll condition, however, they show a trending reversal of the typical pattern, with higher precision at Set 4, relative to Set 2, $M_{diff} = -2.98, t(29) = -1.67, p = 0.10$. L-VWM individuals may actually only maintain 1-2 items on the RemAll Set 4 condition. When the number of items is within these individuals’ capacity, we see the expected filtering benefit, a difference in precision between Filter Set 2 and RemAll Set 2 clearly, $M_{diff} = 2.57, t(29) = 3.76, p = 0.001$. When the number of items in the array is above their capacity, however, we see a trending reversal of the expected effect, RemAll 4 precision is higher than Filter Set 4 (when they are only holding 2 items in memory), $M_{diff} = 3.4, t(29) = 1.7, p = 0.10$. The L-VWM group doesn’t show a significant difference between RemAll Set 4 and Filter Set 2 (when only one item is being stored), $M_{diff} = 0.42, t(29) = 0.21, p = \ldots$

\footnote{The same set of analyses was also conducted with all 67 individuals included. Of those 8 individuals that shared a k-estimate with the median, half were randomly assigned to the H-VWM and the other half to the L-VWM group. Thais analysis also produced similar results to those presented here.}
0.83, suggesting they may in fact only be storing 1-2 items in the RemAll 4 condition. The H-VWM group, show the expected effect of higher precision in the Filter condition for Set 2 relative to Set 4, \( M_{diff} = 6.83, t(29) = 6.25, p < 0.001 \), and a similar expected pattern in the RemAll condition, \( M_{diff} = 1.69, t(29) = 1.94, p = 0.06 \). H-VWM individuals also show a filtering benefit at Set 2, \( M_{diff} = 6.19, t(29) = 5.81, p < 0.001 \), however, the filtering benefit does not reach significance at Set 4, \( M_{diff} = 1.05, t(29) = 1.29, p = 0.21 \).

What might be driving this high precision in RemAll Set 4 for L-VWM individuals, when these individuals are characterized by a low item capacity? It is possible these individuals are prioritizing precision over number of items stored in VWM by either only encoding part of the memory array or by dropping items after encoding. If this is the case then there should be a negative relationship between precision and target memory (pTarg) in RemAll Set 4, specifically for the L-VWM group. The whole group (\( N = 67 \)) was included in a Pearson’s correlation analysis, which revealed a significant negative correlation between precision and pTarg in the RemAll Set 4 condition (lower pTarg score, higher precision), \( r = -0.47, p < 0.001 \). When splitting the data again, based on VWM group, we can see that this relationship exists primarily in the L-VWM group, \( r = -0.55, p = 0.001 \), rather than the the H-VWM group, \( r = -0.19, p = 0.28 \). The difference between these two correlations was tested using hypothesis driven one-tailed Fisher’s Z, which was significant, \( z = -1.66, p = 0.05 \).
5.4 Colour-Wheel Discussion

In Experiment 4, the relationship between personality and various parameters of VWM were explored using a probabilistic mixture model (Bays et al., 2009). In this paradigm, two key features of visual processing were manipulated: VWM load, through the number of items presented (Set 2 vs. 4); and the degree of attentional selectivity, through the requirement to select or inhibit a subset of the items presented in half of the blocks of trials (Filter vs. RemAll). These manipulations have a significant impact on all parameters of the model and estimates of probability of target responses (pTarg), non-target responses (pNonTarg), guesses (pGuess) and precision, consistent with previous findings. As expected, the probability of selecting targets (pTarg) is higher when individuals are required to hold only two items in...
mind, opposed to 4 items (Set 2 relative to Set 4) and when only half the items need to be attended/remembered opposed to all of them (Filter condition relative to the RemAll condition). Filtering offers a performance benefit, in terms of $p_{\text{Targ}}$, which is greatest when VWM load is high (Set 4), suggesting that on average participants are selectively attending to and encoding only the relevant information in the Filter condition. Efficient filtering/selection enables individuals to store information for just 1 item in Set 2 and just 2 items in Set 4. This is corroborated by performance in the Filter condition, which shows a benefit in terms of the probability of target responses when set size is increased, relative to the RemAll condition. The probability of non-targets selected ($p_{\text{NonTarg}}$), a type of swap error suggesting information is in memory although feature/locations were mis-bound, is also reduced in the Filter condition relative to the RemAll condition and this difference is greatest when VWM load is highest (Set 4). Inline with the $p_{\text{Targ}}$ analyses, an increase in set size in the RemAll condition results in a greater cost or increase in $p_{\text{NonTarg}}$ relative to the Filter condition. The same relationships also hold for the probability of guesses, errors suggesting information was not in memory or not retrievable from memory. Personality does not significantly predict any of these measures of VWM performance.

Precision, a measure of the distribution of response error around the true target and non-target colours, shows a slightly different pattern of results. Overall, Filtering affords a benefit in precision in VWM representation and is most precise when there is less information to remember (Set 2), which makes good intuitive sense. This is consistent with previous findings showing that response error increases with the number of items in a display, suggesting that distributing attentional resources over a greater number of items decreases the resolution of representation in VWM (Bays, Catalao & Husain, 2009; Emrich & Ferber, 2012). A significant interaction, however, can clearly be observed in Figure 13d, which shows precision in the Filter condition decreases with set size (from holding 1 item in Filter Set 2 to holding 2 items in Filter Set 4), such that the precision in the Filter 4 condition is equal to precision at RemAll Set 2. Something a little unexpected is found in the RemAll Set 4 condition (the highest information load), as this condition does not show the expected decrease in precision relative to RemAll Set 2, as a result of storing more
information in memory and spreading attentional resources more thinly. This suggests that some individuals may be doing something different in this high load condition, in RemAll Set 4.

Individual Differences in Personality and Precision in VWM

Personality was explored, as a possible predictor of variance in precision using correlation and multiple regression analyses, which included all personality traits as measured by the NEO-IPIP, the interaction between Openness and Conscientiousness, intelligence and K-estimate. It is this measure of precision in VWM that appears to be related to personality. Both Openness and Conscientiousness were predictive of precision in the condition that requires the storage of the most information, the RemAll condition. Higher Openness scores were associated with lower precision in this condition. Though this relationship emerged only as a trend, it is consistent with the Attention and Personality Framework and the results of Experiment 1 and 3. Given that Open individuals appear to have a more broad attentional scope and greater capacity to retain more information in iconic memory initially, this relationship between precision in VWM and Openness may reflect a cost in precision that coincides with a tendency to simply take more information into iconic memory initially, but at a cost in resolution. Open individuals may prioritize holding more information initially in iconic memory, however this may be possible due to holding representations at a lower degree of resolution, which is later reflected in VWM representation. The question remains as to whether Open individuals are also holding more items in VWM. Openness is not predictive of pTarg, so this suggests that Open individuals are not storing more items in VWM per se. An alternative speculative hypothesis is that Open individuals may in fact be holding more items at a lower degree of resolution, but the representation is degraded to the point that responses are characterized as either a non-target or guess responses by the model, thus deflating pTarg estimates.

Conscientiousness is associated with greater precision in the RemAll condition, suggesting that individuals higher in this trait store VWM representations at a higher degree of resolution. Conscientiousness is also positively related to precision in the Filter condition, when attention and memory
resources are dedicated to only a subset of items in the memory array. These results imply that Conscientious individuals may more reliably/efficiently use selective attention to encode only the relevant items when attentional filtering is required, further bolstering their ability to focus attentional resources on enhancing item representation/resolution of only those relevant items. Individuals lower in Conscientiousness, on the other hand, may not have the selective power to sufficiently suppress the irrelevant information in the Filter condition, encoding more of the irrelevant items, consuming valuable resources and reducing precision. These results provide some support for the conclusion that the faster decay rate associated with higher Conscientiousness, observed in the iconic memory experiment in Chapter 4, reflects an early selective mechanism leading to earlier transfer of information from iconic memory to VWM. Here we see evidence of that early efficient selective attention, observed in Experiment 2, impacting iconic and finally VWM function. These results do not fully explain the unexpected result in the RemAll precision, however, thus the factor of individual differences in VWM item capacity was explored.

*Individual Differences in VWM Item Capacity & Precision*

A final set of analyses, exploring the curious lack of a load effect on precision in the RemAll condition, was guided by the hypothesis that the amount of VWM resources one has may lead to different means of dealing with memory arrays that contain information that exceeds one’s capacity. For instance, holding 4 items in memory is beyond the item capacity of L-VWM individuals (~2 items or less in this sample), while it is within the capacity of H-VWM individuals (~3 items or more in this sample), thus individuals may treat the RemAll Set 4 condition differently. A median split, based on K-estimate scores derived from a separate change detection task, was performed to explore whether individual differences in VWM item capacity estimates show divergent results on this task.

This median split analysis revealed that L-VWM individuals’ pattern of precision is quite different compared to H-VWM individuals. The L-VWM group’s precision actually increases in RemAll Set 4, relative to RemAll Set 2, returning to a level of precision comparable to Filter Set 2, when only 1 item is
stored. It is possible that L-VWM individuals are either selectively encoding part of the memory array (pre-encoding spatial selection) or they may be initially encoding all items and later dropping several items from memory to reallocate resources to one or two items in order to bolster precision prior to probe onset. Returning to the iconic memory results of Experiment 3, it does appear that L-VWM individuals may drop items from memory earlier in visual processing, consolidating fewer items in VWM earlier in processing. L-VWM individuals may opt to store fewer items in order to preserve a higher degree of resolution. This may sound a bit counter-intuitive on first pass, but this may simply be a way to deal with a deficit in storage capacity. L-VWM individuals’ likely do not use a feature based selection strategy which is resource intensive and more difficult (Anllo-Vento & Hillyard, 1996; Shih & Sperling, 1996) and effortful than spatial selection (Cowan & Morey, 2006), and thus unlike the selective strategy used by high capacity individuals (Vogel & Machizawa, 2004). Rather, L-VWM individuals likely use an easier, but less effective spatial selection strategy, whereby they attend/encode a portion of the memory array, which may or may not contain the item that will be probed later. The items they do transfer and also happen to be probed will likely be stored at a relatively high degree of resolution. There is some evidence of this in the present results, as there was a significant negative correlation between pTarg and precision, but this relationship appears to be stronger or driven by the correlation in the L-VWM group in particular.

The H-VWM individuals show a pattern of results fairly consistent with expectation, showing a decrease in precision with increase in set size in both the Filter and RemAll condition and exhibiting higher precision overall, relative to L-VWM individuals. However, there is no Filtering benefit in precision at Set 4 for H-VWM individuals, as there is in L-VWM individuals. It is possible that H-VWM individuals are using a different strategy in Filter Set 4. Given that 4 items are still within the item capacity limit of H-VWM individuals (mean of ~4 items for this group), it may simply be easier for these individuals to encode the entire array on some trials. For instance, on some trials, the two target items may be grouped together in one area of the screen, away from the distractors and selective filtering is likely easier than storing all items in this case, even if one has enough resources to go around. On other Filter trials target and distractor
items are mixed within a region of the screen and feature-based selection is required. Given that this kind of feature-based selection has been shown to be more difficult than simple spatial selection (Anllo-Vento & Hillyard, 1996; Shih & Sperling, 1996) and this way of selectively attending to items pre-encoding is effortful (Cowan & Morey, 2006), H-VWM individuals may simply opt to store all 4 items, since this is still within their capacity. If H-VWM individuals can hold 4 items without a large precision cost, then the question follows, why would they bother filtering 2 items, as they show a benefit with filtering? One reason may be that the act of selectively filtering in Set 2 is considerably easier than at Set 4 because this can be done through spatial selection. Further, because the load is smaller, there are fewer distractors and items to filter. Though these interpretations are speculative they are consistent with prior research and make intuitive sense, as it makes good sense that differences in the quantity of resource or storage capacity one has would impact how information is organized, selectively stored and represented.

The relationship between K-estimate and the parameters in this colour wheel task may reflect individual differences in the amount of information that can be maintained and precisely represented in memory. Personality, on the other hand, may not be related to the amount of resource per se, but rather how that resource is used, whether limited resources are dedicated to more selective encoding and higher precision (Conscientiousness) or more diffuse encoding and lower precision (Openness). Inline with the predictions of the Attention and Personality Framework, individual differences in aspects of visual cognition that rely on the selectivity of attention or the breadth of attention are related to Conscientiousness and Openness, respectively.
Chapter 6
Discussion

6 General Discussion

6.1 Summary of Thesis

The overarching aim of the present thesis was to address the question of what cognitive mechanism or process may account for the relationship between personality and cognition. In answering this question I propose the Attention and Personality Framework, which specifies that Conscientiousness is related specifically to the selectivity of visual attention, while Openness is related to the spatial scope of attention. This relationship between personality and visual attention has cascading effects throughout the visual processing stream, which may help explain some of the observed relationships between personality and cognitive outcomes, both in the lab and across the lifespan. This thesis not only contributes to the process of operationalizing the relationship between visual cognition and two of the Big Five Personality Traits, but may help visual cognition researchers account for variance in their data that typically remains unexplained. The Attention and Personality framework puts forth a unifying approach to the study of personality and visual cognition and this thesis provides some evidence in support of and demonstration of the utility of this framework.

6.2 Overview of Evidence for the Attention & Personality Framework

The results of this thesis provide an initial foundation of evidence in support of the Attention and Personality Framework. The results of Experiment 1 show that Openness is predictive of a broader distribution of attention around an irrelevant cue in an Inhibition of Return task (Experiment 1). This broader scope of attention may contribute to the greater breadth and initial retention of information in iconic memory, observed in Experiment 3. Representing more information in iconic memory may result in a trade-off in terms of the precision of those representations or may reflect a general cognitive permissiveness, simply allowing more information to enter capacity limited cognitive processing faculties.
This may explain why Openness is associated with a cost in precision or resolution in VWM, particularly when one is holding several items in mind (RemAll condition in Experiment 4). Experiment 2 shows behavioural and electrophysiological evidence that Conscientiousness is related to the degree of selectivity of attention in a Localized Attentional Interference task. This selectivity advantage may explain Conscientious individuals’ earlier selection and transfer of information from iconic memory to VWM (Experiment 3). This earlier selective transfer may enable individual items to be encoded in VWM before they have degraded much in iconic memory. This explains the observed positive relationship between Conscientiousness and higher precision responses on the VWM task in Experiment 4. The Attention and Personality Framework provides a useful way to make sense of and integrate these findings with previous research, linking these two personality traits to various cognitive processes.

6.3 Openness and the Scope of Visual Attention and Iconic Memory

The results of Experiment 1 show a clear relationship between Openness and the scope of spatial attention, consistent with the Attention and Personality Framework. Individuals that score higher in Openness have a more diffuse spread of attention. This broader scope of attention that is associated with Openness in Experiment 1 (IOR) may help explain the moderate association between Openness and a more robust initial representation of information in iconic memory in Experiment 3 (iconic memory). The results of Experiment 1 and 3 are consistent with and may explain the relationship between Openness and lower precision when maximum VWM capacity has been reached (RemAll in the Colour-Wheel task) in Experiment 4. Arguably a more broad distribution of attention or diffuse mode of attending may enable a greater number of items to be initially encoded and maintained in iconic memory and perhaps more items transferred to VWM, albeit at a lower resolution.

Taken together results suggest that Open individuals may have a broader scope of attention or broader attetnional style, consistent with the Attention and Personality Framework. These results and this
Framework may help explain why previous research has found Openness to be associated with: a smaller attentional blink (MacLean & Arnell, 2010); more creative, divergent and flexible thinking, problem-solving, and decision making (LePine et al., 2000; McCrae, 1987); more diffuse exploration of scenes (Risko et al., 2012; Wu et al., 2014); and less latent inhibition and greater distractor-related processing (Peterson et al., 2002). The calibration of the scope of attention and tendency to maintain more information at lower resolution may contribute to Open individuals’ more open and flexible cognitive style. The Attention and Personality Framework suggests that the spatial scope of attention is related to Openness, while the selectivity of attention is related to Conscientiousness.

6.4 Conscientiousness and the Selectivity of Visual Attention, Iconic Memory and Precision in VWM

Conscientiousness appears to be related to the selectivity of attention and visual processing that relies on visual selective attention. The results of Experiment 2 show that Conscientiousness is predictive of feature-based target discrimination when distractors are in close proximity and the selectivity of attention is challenged (i.e., NEAR condition). Individuals high in Conscientious (upper quartile) show an unusual performance cost in the FAR condition, inconsistent with the typical benefit characteristic of an increase in separation and release from interference. This result suggests there may be a cost, in terms of the ability to distribute the spatial scope of attention for these individuals who are particularly high in Conscientiousness and perhaps have a stronger inclination towards a more selective or focused attentional style.

The EEG results of this experiment provide electrophysiological evidence of high Conscientious individuals selective attentional style, showing early modulation of the P1 component. This early processing may lead to less attentional processing later on, as there is less modulation of the N2pc and no modulation in the Ptc. Low Conscientious individuals, on the other hand do not show clear modulation of the P1, but rather only show later attentional modulation in the N2pc and the later Ptc. These results can be taken as
evidence that highly Conscientious individuals engage attention earlier in processing, thus not requiring later attentional filtering indexed by the PtC. Low Conscientious individuals may be slower to engage visual selective attention, requiring additional attentional compensatory processing later on, indexed by the PtC. This early engagement of selective attention is consistent with the results of Experiment 3, which show that Conscientiousness is predictive of a steeper decay function, suggesting that items in iconic memory are selected and transferred to VWM earlier in processing. This early transfer may help to explain the results of the higher degree of precision associated with Conscientiousness in the VWM task in Experiment 4.

The Attention and Personality Framework and the results presented in this thesis offer a mechanistic explanation as to why personality is associated with various cognitive outcomes. For instance, the selective focus of attention in Conscientious individuals may be the mechanism that leads to decreased ability to flexibly attend to and report on T2 in AB tasks (MacLean & Arnell, 2010). Due to an over investment or narrow selection of items in the stream T2 and even T1 may be missed. This pattern of missing T2 in AB paradigms has been associated with a local-feature processing bias (Dale & Arnell, 2010; Yovel et al., 2005). This local-feature bias may also be a consequence of highly focused visual selection, thus one might predict that highly Conscientious individuals may be prone to a local-feature biases, opposed to a global-feature bias. Conscientious individuals also tend to show difficulty when tasks require a shift and expansion of attention when transferring rules and knowledge to a new context (LePine et al., 2000). For instance, a high degree of selectivity has the benefit of focusing one’s experience, but that means that novel information, at times, is missed (e.g., in the LAI task or in AB tasks). This mechanism may lead to some performance costs, such as that observed by LePine et al., 2000, when one is trying to learn new rules and flexibly shift strategies or when information that was previously deemed irrelevant becomes relevant in a new context.
6.5 Utility of the Attention & Personality Framework

The results presented in this thesis demonstrate that there is utility and value to the Attention and Personality framework specifically and value in taking into consideration individual difference in general in the study of visual cognition. This individual difference approach to the data reveals results that otherwise would have been missed or difficult to interpret in Experiments 2, 3 and 4, without taking into account individual differences and the help of a guiding framework.

Experiment 2

In Experiment 2, the behavioural benefit that typically comes from a release from LAI in the FAR condition was not observed in the whole group analysis with this sample. The whole group analysis also did not show the previously reported effect of LAI on the Ptc ERP. The sample used in this experiment is much larger than that typically used in ERP studies, thus the lack of an effect is not likely due to insufficient sample size or power. The design of the experiment was also identical to that used in previous ERP studies of LAI (Hilimire et al., 2009, 2010). Guided by the Attention and Personality Framework, an individual difference approach was applied to these data. Dividing the data based on Conscientiousness, revealed that an increase in spatial separation provides a small additional release from interference, but only to an extent for low Conscientious individuals. Highly Conscientious individuals actually show a cost associated with spreading one’s attention, which may reflect a trade-off between the selectivity of attention and the scope of attention, as outlined by the Zoom Lens and Biased Competition Models of attention (Desimone & Duncan, 1995; Eriksen & St. James, 1986; Kastner et al., 1998; Müller et al., 2003).

The behavioural results of Experiment 2 add to our understanding of the relationship between selectivity and scope. These data show that the point at which this trade-off between visual scope and selectivity (broader scope, less selective power) starts to impact performance varies between individuals. The ERP data, show that Conscientious individuals engage the selectivity of attention earlier in processing, affording a selectivity benefit in terms of overcoming spatially mediated competition in vision (most
evident in the NEAR condition), however, this may be at the cost of sufficiently distributing attention so as to process the entire display when stimuli are more distributed (FAR condition). The cost observed in the FAR condition for highly Conscientious individuals may reflect a somewhat rigid commitment to the selectivity of attention and the focusing of selective resources in a narrow range of space. The scope/selectivity trade-off is typically demonstrated in terms of spreading scope at the cost of selectivity (Eriksen & St. James, 1986; Müller et al., 2003), however here we observe the prioritization of visual attentional selectivity, at the cost of visual attentional scope. The ERP results show that highly Conscientious individuals engage selectivity quite early in processing. This early prioritization of selectivity may be a mechanism that acts to constrain the natural spread of attention.

The typical effect of LAI on the Ptc was not found in the whole group analysis, but rather only emerged in the Low Conscientiousness group. Conversely, the high Conscientiousness group showed earlier attentional engagement, reflected in modulation of the P1 that was not evident in those lower in Conscientiousness. These results reveal that when and how one engages attention varies between individuals, which impacts not only behavioural but electrophysiological results. Thus, accounting for Conscientiousness is arguably an important step for those interested in exploring affects on early or late attentional processing and selection.

**Experiment 3**

In Experiment 3, we see interesting variance in iconic memory decay, with some individuals showing iconic decay right away, while others do not show appreciable iconic decay until later. This is a novel finding, as iconic memory is believed to decay in an exponential fashion and this decay is assumed to start as soon as items are taken into iconic memory. The results show that the process of decay in iconic memory may not operate in the same way for everyone. Specifically, Open individuals may retain a more broad representation of information that decays very little in the first 100 ms in this form of perceptual memory. Conscientious individuals, however show a faster decay rate, suggesting that some individuals
may transfer items earlier in processing to VWM, prior to the probe. This may eventually result in a cost in terms of transferring the correct items, however, there may be a benefit in terms of the preserved resolution of each item. Applying the Attention and Personality Framework to this typical iconic memory paradigm illuminates how individuals attentional style (broad spatial scope or focused selectivity), may utilize this resource differently. These insights lead to interesting predictions about how variance in iconic memory may play out in VWM.

Experiment 4

In Experiment 4 the Attention and Personality Framework and the results of the previous 3 experiments lead to fruitful predictions about VWM. This approach revealed the individuals store information a different degrees of resolution, such that individuals higher in Openness show lower precision when all items are stored in memory, while Conscientious individuals show higher precision.

Interestingly, in the whole group analysis of this VWM task there was an unexpected lack of an effect of load on precision in the RemAll condition. Specifically, precision was actually higher in the RemAll Set 4 condition, relative to RemAll Set2. Initially, this finding may be taken to reflect challenges with the experimental design/implementation. Alternatively, an individual difference approach would suggest this unexpected finding may reflect a dissociation in how people deal with high load conditions. It was not personality that revealed this dissociation, but individuals’ item capacity, as measured by the K-estimate task. Individuals with low VWM capacity may not get 4 items past iconic memory into VWM, thus precision remains low due to only holding 1-2 items, rather than attempting to hold 4 items. Though this does not directly demonstrate the utility of the Attention and Personality Framework, it more generally illustrates the value of taking into account individual differences in core traits. This approach provides a means of accounting for more variance in human cognition and refining our understanding of how these cognitive faculties operate/vary between individuals.
6.6 Sample Size and Individual Differences

Patterns where some individuals show an effect while others do not are not uncommon in visual cognition research or psychological research more generally and likely contribute to many null findings and failed replications. Experiment 2 and 4 provide good examples of how individual differences can be strong enough that they obscure an effect when considering a larger group. The sample sizes used in Experiments 1 through 4 were between about 50 to 70 people and are larger than typical visual cognition experiments (historically many are in the range of about 10-20 people). With smaller sample sizes we expect more sampling error and it is more likely we will end up with samples that contain a disproportionate number of individuals that may happen to be lower or higher in Conscientiousness (or lower or higher in Openness). For instance, there is good reason to believe that personality is not independent of the time in the term students show up to participate in an experiment. Students that have more conscientious traits may be more likely to participate early in the term (Evans & Donnerstein, 1974; Zelenski, Rusting, & Larsen, 2003), thus it is quite possible that a study that relies particularly on the selectivity of attention may have very different results in a sample collected early in the term relative to a sample collected later in the term. These differences in results across the term, however, are only expected on those tasks that rely on the selectivity of attention and performance varies with Conscientiousness. This Attention and Personality Framework offers a systematic way to understand how/when samples may differ and on which tasks might be show the most variance across samples.

To illustrate this point, lets return to the LAI study. It is possible that Hilimire et al’s (2009) research, where the PtC is first identified as a component reflecting a later attentional compensatory mechanism may have, by chance, contained more low Conscientious individuals. With larger samples, like the one used in this thesis, where we would expect personality to be more normally distributed the effect of LAI on the PtC is lost. Without taking personality into consideration this study, which used a task identical to Hilimire et al’s (2009), would have been chalked up to a failed replication, bringing about questions about the reliability/legitimacy of the PtC or trying several more modifications of the experiment.
to try and replicate. This example may be extended to some of psychology’s effects which are being called into question due to failed replication with larger samples (e.g., the work on Ego Depletion) (Lurquin et al., 2016). Some of these more ‘fragile’ effects may in fact be psychological effects that are more heavily influenced by individual differences in personality and attention. The problem in dealing with failed replication is answering the question of why the effects were found in the first place and why they cannot be reliably reproduced. The Attention and Personality Framework may prove particularly useful in this domain.

This discussion of sample sizes and replication brings us to one of the limitations of the studies in this thesis. Though the sample sizes used in this thesis are much larger than many cognitive psychology studies, some of the effects in the present thesis are small and only trending and may have benefited from larger sample sizes. The sample sizes for this novel research were estimated based on past research in the area of visual cognition, however samples sizes in personality research tend to be a little larger. Replication of these results with larger sample sizes is an important next step. Although the marginal results should be treated with some caution, they should not be overlooked. Given the degree to which the pattern of results followed the predictions of the Attention and Personality Framework and the relatively intuitive way the results of each experiment inform the next, the more modest results may still hold some value, however these results should be replicated with larger samples. The work in this thesis provides some early evidence for a potentially promising and fruitful framework. The Attention and Personality Framework holds utility in its power to predict and uncover patterns in visual cognition data that otherwise would be missed or result in non-replication.

6.7 The Relationship Between Selectivity and Scope

The effect of a trade-off between selectivity and scope is predicted by the Zoom Lens and Biased Competition Models of attention (Eriksen & St. James, 1986; Müller et al., 2003), however, the degree to
which there is a trade-off likely varies with task demands, with greater trade-off occurring in conditions requiring more extreme expansions of attention or challenges to selectivity. Further the relative challenge or what counts as ‘extreme’ likely varies between individuals. For instance, the relative cost of spreading one’s attention over space may have to do with the degree to which one invests attentional resources in the process of feature-based visual selection, which is resource intensive (Anllo-Vento & Hillyard, 1996). In Experiment 2 highly Conscientious individuals show a benefit over low Conscientious individuals when selectivity is particularly important for task performance (i.e., the NEAR condition), however they show a cost in the FAR condition, when the scope of attention must be expanded. Thus individuals particularly high in Conscientiousness may habitually engage such a degree of selectivity that there is a consequential narrowing of the scope of attention in order to optimize selectivity. This relationship between scope and selectivity in this experiment may reflect what happens in the upper ranges of Conscientiousness and selectivity. There is some evidence that Conscientious individuals also have a more narrow scope in Experiment 1, however, the relationship is lost when Openness is accounted for. Visual attentional scope and selectivity may be quasi-orthogonally. Just as there are many camera lenses that vary in width/depth and focus/resolution, there are many attentional lenses that vary in scope and selectivity and we may each have our own favorite lens.

Just as Conscientiousness and Openness reflect distinct latent variables (DeYoung, 2006), the mechanism of selectivity and spatial scope may be quasi-orthogonal between individuals. In other words, someone who is high in both Openness and Conscientiousness may prioritize attentional scope, while maintaining a relative degree of selectivity and precision or may be more flexible in how they prioritize one over the other. The extent to which or the point at which one experiences a clear trade-off between scope and selectivity (i.e., how broadly one can attend while maintaining selectivity) likely reflects individual differences in attentional capacity or how much resource one has available. The Attention and Personality Framework does not propose that personality reflects differences in attentional capacity, but rather that Openness and Conscientiousness reflect how attentional capacity is used. If we take the capacity of VWM
to be a correlate of raw attentional capacity, then this thesis provides some evidence that Openness and Conscientiousness (Scope and Selectivity) are independent of this capacity limitation, as these personality traits were not predictive of VWM capacity or number of target responses. Rather, Openness and Conscientiousness predict how limited capacities are utilized and whether scope or selectivity are prioritized.

6.8 Considering Other Individual Differences: VWM Item-Capacity

Though the main purpose of this thesis was to explore the relationship between attention and personality specifically, it did employ an individual difference approach more broadly, taking into consideration other individual difference measures, such as VWM item capacity. Openness and Conscientiousness were not correlated with item capacity (K-estimate) and personality and VWM item capacity (K-estimate) accounted for unique variance in the results of experiments 3 and 4. The results of experiment 3 and 4 provide some novel insight into the mechanism that may underlie individual differences in VWM performance, which deserve some discussion here.

In Experiment 4, the colour-wheel VWM study, the expected effect of Set Size or memory load and attentional filtering on precision was not observed in the whole group analysis. Instead of observing lower precision in the RemAll Set4 condition, there was no difference between Set2 and Set4 in this condition and no benefit with filtering. Taking into account personality and VWM item capacity (as measured by K-estimate task) revealed differences in how individuals may use the limited resources they have. Individuals with high and low VWM capacity performed differently on this task, such that those with lower VWM capacity appear to use a different strategy when their VWM capacity is exceeded. Everyone in the low capacity group had a VWM item capacity of less than 3 items, thus Set4 was beyond their capacity. Low VWM individuals appear to have higher precision in the RemAll Set4 condition, the highest VWM load condition. While this result may seem a little odd at first glance, there may be a rather
simple explanation. These individuals may simply not encode or maintain all those items in the RemAll Set4 array. There was some evidence of a tradeoff between precision and pTarg for the low VWM individuals, such that higher precision was associated with lower pTarg. This result may be explained by an underlying difference not only in attentional selection, as has been previously proposed (Vogel & Machizawa, 2004), but also in the amount of resources dedicated to maintaining items in VWM and how those resources are allocated.

When an individual’s capacity is exceeded not all the items in the array will make it from iconic memory to VWM. Thus, individuals need to ‘choose’ how their limited resources will be dedicated; either to more items, but at a lower resolution or to fewer items, but at a higher resolution. Low capacity individuals may indiscriminately encode all items, as previous research has suggested (Awh & Vogel, 2008; Vogel et al., 2005), as this may initially be easier than engaging an early feature-based selection strategy (Anllo-Vento & Hillyard, 1996). If they are able to encode all the information in VWM, however, why are these individuals characterized as having lower item capacity? Why do they perform worse on simple capacity estimate tasks that require they only identify a single target item? Their lower performance may be due not only to ineffective filtering but may also reflect difficulty storing multiple items with sufficient precision to accurately report the identity of those items.

Capacity may not reflect the number of items one can hold in mind per se, but rather the amount of attentional resources available to individuate and identify a number of items. When more items are held in memory a greater amount of resources will be required to be sufficiently distributed across those items for accurate reporting (Cowan, 2001; Xu, 2009; Xu & Chun, 2006). In other words, if a memory array includes more information than an individual has resources to maintain, individuate, and identify with sufficient precision, then memory errors will arise. These errors may be due to holding more information at a very degraded level of detail or holding fewer items at higher resolution. If one attempts to hold a
number of items in mind that exceed VWM capacity, then those items (or some of those items) will essentially remain in iconic memory, in a more fragile form, prone to decay.

The results of Experiment 4 suggest that individual differences in VWM capacity may not be completely the result of inefficient filtering. These results may reflect fewer attentional resources in low capacity individuals, which they must sparingly distribute within VWM. In order to work with this limitation low VWM individuals may initially encode items indiscriminately, as Vogel et al., (2005) suggest, however, these representations may be of lower resolution or remain subject to decay, like in iconic memory. In order to cope with task demands that exceed one’s capacity, low VWM individuals may drop items from VWM, while allocating their full capacity/resources to maintaining fewer items at a higher resolution/precision. Individuals with high VWM item capacity have a greater amount of attentional/VWM resource to spread around and thus when the number of items within an array fall within their capacity, they may not need to selectively filter. This explains why these individuals did not show a filter advantage for Filter Set4. The results from Experiment 3 suggest that VWM item capacity is related to various aspects of iconic memory, which further supports this interpretation. Low capacity individuals show evidence of a shorter iconic memory duration \( \tau \), which may reflect a greater need to quickly consolidate limited resources in order to maintain just a few items in a more durable and stable form.

The interpretations in this section are speculative, as the studies conducted in this thesis are not able to discern what is being stored exactly and in what format. The results here, however, suggest that there may be more to consider when running studies of VWM, as individuals differ in their attentional capacity and they may differ in how they respond when they have reached that capacity. The use of different attentional strategies, such as focusing resources on a few items or spreading resources thinly over many items (as a conscious or subconsciously process) inevitably impacts how individuals respond to different manipulations of VWM. This has consequences for research, as our understanding of how visual
attention, iconic memory, and VWM function assumes that these functions operate in the same manner across individuals. When assessing the capacity and limitations of VWM and what factors impact VWM performance, there may be quite different answers to this question across individuals.

6.9 What is Next: The Question of Automatic vs. Controlled Attention

Attention is a resource that can be spread or focused and within the scope of attention, selective attention acts to bias behavioural and neural responses: select relevant or salient information and inhibit irrelevant information. Both the scope and selectivity of attention may be modulated in endogenously controlled fashion, e.g., related to goals and task instructions (e.g., attend to the T’s ignore the L’s or attend to the circles and ignore the squares) or may be modulated by salient factors that operate more automatically and exogenously (e.g., irrelevant cues that capture attention). There is ample behavioural and neural evidence that selective attention operates in these two modes (Connor, Egeth, & Yantis, 2004). There is some research suggesting that modulation of the spatial scope of attention is a relatively automatic process, at least compared to feature-based selection (Anllo-Vento & Hillyard, 1996; Shih & Sperling, 1996). Research on the use of different search strategies, however, suggest that the scope of attention can be modulated by more endogenous or controlled influences as well, such as task instructions and goals (Smilek, Dixon, et al., 2006; Smilek, Enns, et al., 2006). One interesting question that remains to be answered is whether Openness and Conscientiousness are related specifically to exogenous or endogenous modes of visual attention. We may glean some information from the tasks used in this thesis, however, the experiments were not designed to address this question directly, thus research that targets this question more directly is needed.

The IOR task arguably measures an exogenous form of visual attention, as attention is attracted to and spreads around an irrelevant cue, which captures attention in an automatic fashion. The cues are non-informative and thus not relevant to the task at hand, so the degree of attention paid to them and the
distribution of attention around the cue is not governed by goal-directed endogenous attention. It is unlikely that participants would endogenously attend to the cue as a strategy, as participants were told explicitly to ‘ignore the irrelevant cues, as they are distractors and will not help you on this task’. After performing the task for a few moments it becomes quite clear that the cues are not helpful. Openness was the main predictor of scope on this task, suggesting a relationship with the automatic scope of visual attention, such that Open individual may have a more broad default scope of attention. A measure of exogenous selective attention could be derived from the RT to targets that appear at the cued location, as attention is captured (an automatic process) by not only the onset of the cue, but also the onset of the target (Abrams & Christ, 2003). Personality was not predictive of RT to targets, but rather the relationship only appears as a function of how RT changes over space. Thus, there is little evidence in this paradigm that personality is related to automatic selective attention, in so far as it is probed on this task.

The LAI task and the Colour Wheel task (particularly the Filter condition) can be characterized as a controlled or endogenous selective attention tasks. Participants are told what to attend to and selection is based on attentional control sets for those specific objects (i.e., T’s in the LAI task and either circles or squares in the Filter condition of the Colour Wheel task). Conscientiousness predicts performance on these tasks, particularly when endogenous selective attention is challenged (i.e., in the NEAR condition in LAI and in the Filter condition in the Colour-Wheel task). These results suggest that the Conscientiousness is related to the endogenous control of visual selective attention.

As far as iconic memory goes, the distinction of exogenous and endogenous becomes a little blurry, however since iconic memory occurs so early in visual processing, it is not likely participants have a large degree of endogenous control. The initial uploading and maintenance of information in iconic memory is likely not under an individual’s control as this happens very quickly and rather automatically. Openness showed a small relationship with initial representation in iconic memory, consistent with what we might expect of individuals with a naturally broad scope of attention. It is possible that some sort of endogenous
Attentional scope strategy was employed throughout the task to try and broaden one’s attention, if participants believed this would help them on the task. If this is the case, however, this strategy was only employed by or effective for the Open individuals. Given the IOR and iconic memory results, I suspect that the effect here reflects a natural disposition to maintain a more broad scope of attention in Open individuals. Individuals likely have a degree of control over the scope of visual attention, however, Open individuals may be more likely or apt at deploying a broad scope.

Once an item is cued in iconic memory, if it is still being held in iconic memory, it can be selectively transferred to VWM for reporting. This can be considered a form of endogenous or controlled attention, as one uses selective attention to transfer the item, in accordance with the task instructions. We do not, however, have a direct measure of probed selective transfer, as transfer to VWM and reporting depends also on the rate of decay and pre-cue selective transfer. It is unclear the extent to which this pre-cue selective transfer from iconic memory to VWM on this task is under participants’ control or awareness. Conscientiousness was predictive of the decay rate or pre-cue selective transfer of information from iconic to visual working memory, which likely reflects less of a controlled process and more of a dispositional tendency.

Given that Conscientious individuals tend to be goal-oriented individuals, one alternative interpretation of the results in this thesis is that individuals high in Conscientiousness may use a different strategy on these tasks or may adhere more closely with task demands/instructions. In other words, they may use specific strategies that help them endogenously control their attention. If Conscientiousness is related specifically to the endogenous control of selective attention, then the use of different strategies or task compliance are factors that may particularly influence performance on tasks that rely on or probe endogenous selective visual attention. This interpretation, that the relationships observed in this thesis are due to conscious strategies and differences in task compliance, does not sufficiently account for all the results observed here. For instance, Conscientious individuals did not perform better overall on the tasks
used throughout this thesis, which is expected if general task compliance is a key factor. Rather the effects that coincide with Conscientiousness are more specific to conditions in which the selectivity of attention is challenged. For example: (a.) there is no relationship between Conscientiousness and RT to the target at the cued location in the IOR task; (b.) in the LAI task Conscientious individuals show NEAR and MID advantage, but a performance deficit in FAR; (c.) in the iconic memory task we see a relationship with earlier transfer of information to VWM and no relationship with overall accuracy on the task; (d.) in the Colour Wheel task the relationship with Conscientiousness emerges specifically for precision in the Filter condition and not in the proportion of target, non-target, or guess responses.

Further work is required to discern the degree to which Openness and Conscientiousness are related specifically to endogenous vs. exogenous modes of visual attention and the degree to which conscious strategies may influence these effects. Future research should question individuals on the amount of effort they feel they put into a task and whether they use any conscious strategies. Without this information it is difficult to completely rule out the possibility that Conscientious individuals’ goal-oriented mentality may have influenced their approach to these tasks to some extent. On the other hand, it is precisely these goals, motivations, and cognitions that are what comprise personality (Zillig et al., 2002). We might expect personality to lead to different approaches to these tasks, just as in life more generally. If these different approaches are contributing to the results in this these, then these are important to explore, as they impact how these individuals use their attention in a rather consistent way.

If Conscientious individuals’ conscious strategies account for some of the relationships presented in this thesis, learning what these strategies are would be incredibly useful, particularly if they are modulating attentional performance as early as 100ms post stimulus onset, as observed in the LAI study and altering representation in iconic and VWM. If these strategies are conscious, they can likely be taught and learned. The Attention and Personality Framework provides an explanation as to who might use
attentional strategies and why. Fascinating future research might focus on revealing the extent to which these differences in approach are under the individuals control and/or are plastic and trainable.

6.10 What is Next: The Question of Training and Causality

Attention is known to be a malleable and trainable trait, at least to a certain extent. Thus the question follows, if we can train and modify our attention, can we also modify our personality through the same mechanism? There is some evidence that the answer to this question is, yes. It has been shown that Openness can be increased in older adults through cognitive training in inductive reasoning (Jackson, Hill, Payne, Roberts, & Stine-Morrow, 2012). There is some evidence that one form of attentional training – meditation – is both predicted by personality and may also alter personality (Lesh, 1970).

In a study of meditation by Lesh (1970), participants partook in a meditation course and their level of empathy was measured. This study revealed that open individuals who underwent meditation training and practice showed greater improvement in empathy than non-meditating controls, suggesting a greater benefit of meditation for Open individuals. Interestingly, individuals in the meditation training group, relative to control, also increased in their degree of trait Openness. Though these results may be taken as evidence that attentional training, such as meditation, may alter personality, there are some limitations to this study that should be considered. For instance the meditation group was self-selected and were thus higher in Openness to begin with. Openness is predictive of the impact meditation can have, which likely is related to Open individuals willingness to meditate in the first place. There is a circularity here, as Open individuals may be more willing to meditate, thus benefiting more greatly from the impact of meditation, which may further bolster their naturally Open disposition.

Another consideration with respect to Lesh’s (1970) study is that the outcome effect was a measure of empathy, rather than attention. It remains unclear whether attention was in fact trained or altered with this particular meditation intervention. That being said, the meditation used in this study was a form of
Zen meditation, which relies on the focusing of the mind on the breath and observation of one’s entire experience in the present moment, which may be described as a more open monitoring form of meditation. There is a great deal of prior research that shows meditation alters various aspects of attention and single pointed relative to open monitoring meditation may have differential affects on attention (Brefczynski-Lewis, Lutz, Schaefer, Levinson, & Davidson, 2007; Dickenson, Berkman, Arch, & Lieberman, 2013; Lutz, Slagter, Dunne, & Davidson, 2008; Slagter et al., 2007).

What we can take away from Lesh’s (1970) study that is relevant to the present discussion is that personality likely influences what we enjoy, how we choose to spend our time, the activities we engage in, and consequently strengthening certain aspects of who we are. It is possible that different forms of meditation may train different aspects of attention and thus differentially impact personality. If Lesh (1970) had used a more single-pointed and focused from of meditation (e.g., observe just the breath, do not attend to other experiences or thoughts) rather than the form of open monitoring involved in the Zen meditation, this relationship with Openness may not have emerged. In other words, one’s personality may predict which form of meditation one may be drawn to or find more success with.

The Attention and Personality Framework makes some predictions about the influence of meditation on personality. Specifically, training in focused meditation enhances selective attention, thus this should reinforce Conscientiousness. Training in open monitoring meditation may have an effect of broadening the scope of attention, reinforcing aspects of trait Openness. If attention and personality are independent, counter to the framework laid out in this thesis, then using meditation to train attention should have no impact on personality. If attention is intimately related to personality, then we should see changes in personality in line with these predictions.

One alternative interpretation that is rarely considered in the meditation research is that personality may be modulated by meditation training and it is this mechanism that leads to changes in attention. Clarity on the question of the direction of causality between personality and attention requires
longitudinal/developmental studies. The present thesis makes no strong claims about the directionality of the relationship between personality and attention. Rather, they likely emerge together, dynamically mutually reinforcing one another. The point here is that some activities, such as meditation, may alter our attention and feedback to further alter or reinforce our personality, which reflects the complex cluster of behaviours, cognitive and affective characteristics that motivate us to choose the activity in the first place.

6.11 What is Next: What About the Rest of the Big Five?

Emotional processing affects the scope and selectivity of attention (Becker, 2009; Fredrickson, 2001; Fredrickson & Branigan, 2005; Rowe et al., 2007; Schmitz et al., 2009) and two personality traits in particular are associated with more negative affective states (Neuroticism) and positive affective states (Extroversion). So why do Neuroticism and Extroversion not emerge as reliable predictors of attention? Extroversion did show a small negative relationship with the duration of iconic memory, however, it is not clear what is driving this effect, as Extroversion was not related to any other measure in the 4 experiments described here.

One reason a reliable relationship between trait Extroversion and Neuroticism and the measures in this thesis was not observed may be due to the fact that the relationship between these personality traits and attention is mediated by emotion. Emotional states are transient and were not directly controlled or induced in the experiments presented here. Though individuals high in Neuroticism and Extroversion may show more negative or positive emotion in general, that does not mean they are experiencing those emotions all the time or while performing these tasks in the laboratory. Finding a reliable relationship between attention and these two personality traits may require an emotional manipulation that tips these individuals into a positive or negative state. Experiments that find a relationship between emotion and attention typically employ mood inductions (e.g., Rowe et al., 2007; Schmitz et al., 2009). There has been work showing a relationship between neuroticism and attention, however, most of these experiments
involve a mood induction or emotionally salient stimuli, showing an attentional bias specifically towards threatening stimuli (Derryberry & Reed, 2002; Osorio, Cohen, Escobar, Salkowski-Bartlett, & Compton, 2003; Reed & Derryberry, 1995). It may be the case that it is easier to generate a successful positive mood induction in extroverts and negative mood induction in more neurotic individuals leading to more robust affects of mood on attention. With a positive mood induction, Extroverted individuals may show evidence of a more broad scope of attention in the IOR task. With a negative mood induction, Neurotic individuals may show evidence of more narrow or selective visual attention.

The predictions of the Attention & Personality Framework were focused on Conscientiousness and Openness because these two traits are operationalized as more cognitive, opposed to behavioural or affective traits, thus there is greater reason to believe that these more cognitive personality traits would be associated with behavioural differences on cognitive tasks. The Attention and Personality Framework emerged as a theory able to account for the particular relationships between these more cognitive personality traits and cognitive outcomes. The experiments in this thesis aimed to measure or challenge the scope and selectivity of visual attention, as predicted by the Attention and Personality Framework. There are, however, other aspects of attention that are distinct from scope and selectivity, such as alertness (Posner & Boies, 1971) and orienting (Petersen & Posner, 2012). It is possible the tasks in this thesis did not sufficiently manipulate the particular aspect of attention that may correspond with these other personality traits. In other words Extroversion and Neuroticism may not be related to selectivity and scope per se, but may be related to other aspects of attention.

There are a few studies that explore the relationship between Neuroticism and attention where emotional stimuli and mood inductions were not used (Wallace & Newman, 1997; 1998; Eisenberger et al., 2005). This work reveals that Neurotic individuals have more difficulty controlling attentional orienting or the reflexive movement of attention (Eisenberger, Lieberman, & Satpute, 2005; Wallace & Newman, 1997, 1998). This research shows that Neurotic individuals exhibit less control over the automatic or reflexive
orienting towards irrelevant distractors and evidence of impaired disengagement, the ability to shift attention away from an attended item (Bredemeier, Berenbaum, Most, & Simons, 2011). These findings suggest there may be a stronger bottom-up influence on the regulation of movement of attention in these individuals. Had the tasks in the present thesis included more direct measures of bottom-up orienting of attention, perhaps using as a simple cuing task where participants were to ignore a salient yet irrelevant cue, Neuroticism may have emerged as a significant predictor.

It is possible that levels of alertness may be predicted by Extroversion, as the relationship between Extroversion and cognition or attention seems to be related to arousal and emerges on tasks of sustained attention or vigilance (Beauducel, Brocke, & Leue, 2006; Howarth & Eysenck, 1968; Matthews, 1985; Matthews, Davies, & Holley, 1990; Matthews et al., 1990) and orienting may be related to Neuroticism. Future work may focus on expanding the Attention & Personality Framework to include other components of attention (e.g., orienting, arousal) and their relation with other personality factors.

6.12 Conclusion

In this thesis a novel theoretical framework was presented, the Attention and Personality Framework, as a means of addressing the question of how visual cognition and personality are related. With the aim of further operationalizing the relationship between personality and visual cognition and testing the utility of this individual difference approach to exploring visual cognition, four experiments were employed. The Attention and Personality Framework, which posits that Openness is associated with a broader spatial scope of visual attention while Conscientious is associated with the selectivity of visual attention, was largely supported by the results reported in this thesis. Specifically, we see a relationship between trait Openness and diffusion of the scope of visual attention (Experiments 1, 3, and 4). There is evidence that trait Conscientiousness is associated with a higher degree of selective visual attention (Experiments 2, 3, and 4). The utility of this framework was revealed as this individual difference approach
illuminated some interesting patterns in the data that otherwise would have been missed. For instance, splitting the LAI data based on Conscientiousness revealed an effect in early visual processing that has not been reported in the LAI literature and an effect on the Ptc that was expected, but not detectable in the whole group analysis. This approach revealed that the scope of visual attention in Open individuals and selective visual attention in Conscientious individuals differentially influence iconic memory and precision VWM, providing a novel perspective on questions regarding these capacity limited resources.

Though this Framework requires further validation through replication, the work in this thesis may stand as a starting point, stimulating fruitful future research. Some exciting questions to explore next are questions about the extent to which attentional training may be used to modulate and develop one’s personality in strategic ways. On the other side of the coin, personality may be used to estimate one’s attentional proclivity and where attentional issues or failures may arise, which may have application in the areas of organizational psychology and pedagogy. There are many new and exciting frontiers to which this Framework may be applied. There is also room for this framework to evolve and grow to include more clear predictions about the possible relationship between Neuroticism and attentional orienting/engagement/disengagement and Extroversion and attentional alerting/arousal/vigilance. It is my hope that the work laid out in this thesis will act as a formative step towards a more refined understanding of the relationship between personality and visual cognition, facilitating our ability to better understand the more fine-grained nuances of visual attention and the processes it influences.
References


Copyright Acknowledgements

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