

Running head: INDIVIDUAL DIFFERENCES AND THE ATTENTIONAL BLINK

An Investigation of Individual Differences in Diffusion of Attention
and the Attentional Blink

by

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Abstract

When identifying two targets in rapid serial visual presentation (RSVP), accuracy on the second target is reduced if presented shortly after the first target -- an attentional blink (AB). Some individuals appear to be immune to the AB, whereas others are variously susceptible to this effect. Recent studies suggest that when a broadened or diffused attentional state is induced, the AB can be attenuated. Therefore, in the current study, individual differences in diffusion of attention and processing speed as assessed by a variety of cognitive tasks (e.g., global/local task) were examined in order to determine whether these differences could predict AB magnitude. Performance on the global/local task predicted AB magnitude in a manner suggesting that dispositional diffusion of attention reduces the AB, however measures of processing speed predicted target accuracy, but not AB magnitude, providing evidence for the dissociability of these measures. Finally, performance on other tasks thought to provide indices of diffusion did not relate to performance on the AB task, as was the case for measures of personality and affect that were expected to relate to diffusion of attention and hence to the AB. Results are discussed in terms of the need for a more finely honed account of the construct of diffusion.

TABLE OF CONTENTS

ABSTRACT.....	ii
TABLE OF CONTENTS.....	iii
LIST OF TABLES.....	v
LIST OF FIGURES.....	vi
LIST OF APPENDICES.....	viii
LIST OF ACRONYMS.....	ix
INTRODUCTION	
Selective Attention	
Filter Theories of Selective Attention.....	2
Visual Search and Feature-Integration Theory.....	7
Dual-Task Attention.....	8
Attentional Blink	
Original AB Study and Model.....	10
Late Selection Interference Model of the AB.....	14
Bottleneck Models of the AB.....	16
The Temporary Loss of Control (TLC) Model.....	22
Manipulations of AB Performance	
AB Differences in Naturally Occurring Participant Groups.....	29
Age and the AB	
Mood Disorders and the AB	
Schizophrenia and the AB	
Brain Damage and the AB	
ADHD, Dyslexia and the AB	
Pharmacology and the AB	
Non-Blinkers	
Individual Differences Investigations of the AB.....	36
Video Game Players and Attentional Enhancement	
Green and Bavelier: Video Game Experiments.....	40
Related Video Gaming Studies.....	48
Diffusion of Attention and Cognitive Tasks.....	50
Diffusion in VGP Tasks.....	50
Flanker Compatibility	
Enumeration	
Useful Field of View (UFOV)	
Diffusion in non-VGP Tasks.....	53
Visual Search	
Posner Cueing Paradigm	
Stroop	
Global/Local Task	
Current Study	
Relationships between AB Performance and Other Cognitive Tasks.....	60
Predicting RSVP Target Accuracy.....	63
Relationships Among Cognitive Task Performance and Affect.....	64
Relationships Among Cognitive Task Performance and Personality.....	65
METHODS	
Participants.....	67
Apparatus and Materials.....	68
Personality Questionnaire: Modified NEO-PI	
Trait Affect Measure	

State Affect Measure	
Stimuli and Design.....	70
AB	
Stroop	
Enumeration	
Visual Search	
UFOV	
Posner Cueing	
Flanker Compatibility	
Global/Local	
Procedure.....	80
RESULTS	
Outlier Removal.....	82
Participants	
Trials	
Performance Patterns in Each of the Cognitive Tasks.....	83
AB	
Stroop	
Enumeration	
Visual Search	
UFOV	
Posner Cueing	
Flanker Compatibility	
Global/Local	
Relationship between AB Magnitude and Cognitive Measures.....	95
AB Magnitude	
Target Accuracy	
Lag-1 Sparing	
Relationships among Affect Measures.....	111
Relationships between Affect and the AB.....	112
Relationships between Affect and Other Cognitive Performance Measures.....	112
Relationships between Personality Factors and Affect.....	117
Relationships among Personality and Cognitive Performance Measures.....	120
Openness to Experience	
Extraversion	
Agreeableness	
Neuroticism	
Intercorrelations among Cognitive Measures.....	124
Reliability of the Measures.....	127
DISCUSSION	
AB Magnitude.....	133
Target Accuracy.....	144
Lag-1 Sparing.....	147
Affect and Personality.....	148
Future Considerations.....	152
REFERENCES	160
APPENDICES	177

List of Tables

Table 1.	Correlations among Measures of the AB and Cognitive Performance.
Table 2.	Summary of Simultaneous Multiple Regression for Variables Predicting AB Magnitude.
Table 3.	Summary of Simultaneous Multiple Regression for Variables Predicting T1 Accuracy.
Table 4.	Summary of Simultaneous Multiple Regression for Variables Predicting T2 Sensitivity.
Table 5.	Summary of Simultaneous Multiple Regression for Variables Predicting Lag-1 Sparing.
Table 6.	Means, SDs, and Range for All Affect Measures.
Table 7.	Correlations between Affect and Measures of the AB.
Table 8.	Correlations among Affect and Cognitive Performance Measures.
Table 9.	Means, SDs, and Range for All Personality Measures.
Table 10.	Correlations between Personality and Affect.
Table 11.	Correlations between Measures of the AB and Personality.
Table 12.	Correlations among Personality and Cognitive Performance Measures.
Table 13.	Significant Intercorrelations among Cognitive Measures.
Table 14.	Split-half Reliability Estimates for all Cognitive Performance Measures.
Table 15.	Internal Consistency Values for Affect and Personality Measures.

List of Figures

- Figure 1. Typical AB Stimuli. From Raymond, Shapiro and Arnell (1992).
- Figure 2. Sample AB Pattern: T2 Accuracy Given T1 Correct. From Raymond, Shapiro and Arnell (1992).
- Figure 3. Example of “away” star-field condition. From Arend, Johnston and Shapiro (2006).
- Figure 4. Representation of Overinvestment Hypothesis. From Olivers and Nieuwenhuis (2006).
- Figure 5. Modified Flanker Compatibility Task. From Green and Bavelier (2003).
- Figure 6. Performance of VGPs and NVGPs on an Enumeration Task. From Green and Bavelier (2003).
- Figure 7. Sample UFOV Task. From Green and Bavelier (2003).
- Figure 8. Sample Navon Stimuli. From Frederickson and Branigan (2005).
- Figure 9. T2 sensitivity (proportion hits – proportion false alarms) given T1 correct as a function of lag in the AB task.
- Figure 10. Mean RT in ms as a function of condition in the Stroop task.
- Figure 11. Mean proportion correct on the enumeration task as a function of number of boxes presented.
- Figure 12a. Mean visual search RTs as a function of target presence/absence and number of distractors.
- Figure 12b. Proportion of mean visual search errors as a function of target presence/absence and number of distractors.
- Figure 13. Mean proportion correct on UFOV task as a function of target eccentricity.
- Figure 14. Mean RT for Posner cueing task as a function of cue type.
- Figure 15a. Mean flanker task RTs as a function of target/flanker compatibility and number of distractors.
- Figure 15b. Mean proportion errors in the flanker task as a function of target/flanker compatibility and number of distractors.
- Figure 16a. Mean RT on global and local tasks as a function of target congruency.
- Figure 16b. Mean proportion errors on global and local tasks as a function of target congruency.

- Figure 17. Correlation between AB magnitude and visual search slope (RT with 64 distractors – RT with 2 distractors) on target absent trials such that greater positive values reflect steeper visual search slopes.
- Figure 18. Correlation between AB magnitude and Stroop facilitation (neutral RT – congruent RT) such that greater positive numbers represent greater Stroop facilitation.
- Figure 19. Correlation between AB magnitude and local interference (global task & incongruent – global task & congruent) such that higher scores reflect more interference from local features on global incongruent trials.
- Figure 20. Correlation between AB magnitude and global precedence (global interference – local interference) such that higher global precedence scores reflect greater global bias (i.e., greater interference of global on local relative to interference of local on global).
- Figure 21. Correlation between T1 accuracy during the AB task and overall UFOV accuracy.
- Figure 22. Correlation between T1 accuracy during the AB task and fall-off in UFOV accuracy (accuracy for far eccentricity – accuracy for close eccentricity).
- Figure 23. Correlation between T1 accuracy during the AB task and RT on Posner neutral trials.
- Figure 24. Correlation between T2 sensitivity on the AB task and overall mean RT for the 0 distractor condition in the flanker task.
- Figure 25a. Correlation between T1 accuracy from the AB task and overall accuracy on the enumeration task.
- Figure 25b. Correlation between T2 sensitivity from the AB task and overall accuracy on the enumeration task.
- Figure 26. Correlation between lag-1 sparing in the AB task and overall interference on the flanker task.
- Figure 27. Correlation between lag-1 sparing in the AB task and RT on the flanker task for 5 distractors.
- Figure 28. Correlation between lag-1 sparing in the AB task and the overall difference in mean RT for 5 and 0 distractors in the flanker task such that larger positive numbers represent a greater increase in RT when distractors were present in the circle array.
- Figure 29. Correlation between lag-1 sparing in the AB task and overall global RT for the global/local task.

List of Appendices

Appendix A: Questionnaires.....	173
Appendix B: Forms.....	181
Appendix C: Verbal Script.....	186

List of Acronyms

AB: Attentional Blink
ADHD: Attention Deficit Hyperactivity Disorder
ANOVA: Analysis of Variance
cm: Centimeters
EEG: Electroencephalography
ERF: Emotion Report Form
ERP: Event-related Potential
GSR: Galvanic Skin Response
M: Mean
MOT: Multiple Object Tracking
ms: Milliseconds
NA: Negative Affect
NEO-Pi: Neuroticism, Extraversion, and Openness-Personality Inventory
NVGP: Non-video Game Player
OSPAN: Operation Span Task
PA: Positive Affect
PANAS: Positive and Negative Affect Schedule
RSVP: Rapid Serial Visual Presentation
RT: Reaction Time
SD: Standard Deviation
SPM: Standard Progressive Matrices
STC: Short-term Consolidation
T1: First target
T2: Second target
TLC: Temporary Loss of Control
UFOV: Useful Field of View
VSTM: Visual Short Term Memory
VGP: Video Game Player
WM: Working Memory

Introduction

The topic of attention has long been a focus of research. Many attempts have been made to understand and define attention over the years, but it has proven to be notoriously difficult to pin-down this remarkably complex concept (Driver, 2001; Cowan, 2005). William James in his pivotal 1890 book *Principles of Psychology* defined attention as “taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought” (in Cowan, 2005). Although this definition appears to be accepted by the general public, attention researchers are still striving to identify the various aspects comprising attention (Cowan, 2005). This is because attention can mean many different things, can manifest itself in many different ways, and is examined across many different time courses (Cowan, 2005). For example, attention can involve sustained focus while awaiting a stimulus or performing a particular task, or it can include the passive unconscious capture of awareness by a salient stimulus. It can involve the division of conscious effort while performing multiple tasks, or the selection of relevant information from amongst multiple stimuli. As attention is such an integral component of the human experience, it is important to understand the complexities of this concept.

The purpose of the first section of the Introduction is to introduce the concepts of attentional selection and attentional processing, and to give a brief overview of key attention paradigms and theories. The second section “The Attentional Blink” will examine specifically the attentional blink (AB) paradigm and various models of the AB. The third section “Manipulations of AB Performance” will examine the literature on group and individual differences in AB performance. The fourth section of the

Introduction “Video Game Players and Attentional Enhancement” will introduce the concept of dispositional diffusion of attention and the measures used to examine this attentional diffusion. The fifth and final section “Diffusion of Attention and Cognitive Tasks” will examine the possible role of diffusion of attention in several different cognitive tasks, outline the present study, and present hypotheses regarding how individual differences in diffusion of attention, as measured by a variety of tasks, may predict the AB.

Selective Attention

Filter Theories of Selective Attention

Humans are inundated with a vast amount of useful and useless information every second of their waking lives. To attend to all of this information and attempt to address everything that one perceives would prove to be both unmanageable and unnecessary. Therefore, our brains are designed in such a way that we have the ability to select or extract relevant information from our environment, and dismiss irrelevant information (Broadbent, 1958; Treisman, 1960; 1969). This ability is known as selective attention (Broadbent, 1958; Treisman, 1960; 1969). Bottom-up factors from the stimulus itself (e.g., rapid onset, novel colour or movement), and top-down factors, such as expectations and task goals, influence what information is selected and the efficiency of that selection (e.g., Desimone & Duncan, 1995).

Most of the early studies on selective attention used auditory presentations to examine what information could be used as a basis for selection, and the fate of unselected information. These studies typically used a dichotic listening task, in which individuals selectively attend to auditory stimuli played in one ear, while actively

ignoring the stimuli in the other, unattended, ear (Broadbent, 1958; Cherry, 1953; Moray, 1959). Cherry's (1953) and Broadbent's (1958) experiments had participants 'shadow' an auditory message presented to one ear by repeating the message back to the experimenter as it played. A different message played simultaneously in the other ear. Participants in these studies were able to shadow the attended message, but were unable to report semantic (meaning) information about the material in the unattended ear, and failed to notice the same word repeated over and over in the unattended ear, a change of topic in the material, or even a change in the language that was spoken (Cherry, 1953; Moray, 1959; Driver, 2001). They did, however, have the ability to report physical information about the unattended stimulus such as changes in the pitch of the voice (male to female), as well as changes such as loudness and pacing (Moray, 1959; Driver, 2001).

To explain these findings, Broadbent (1958) proposed a two-stage early selection filter theory of attentional selection. In the first phase, physical characteristics (e.g., ear or pitch) of incoming stimuli are extracted in a parallel manner for stimuli from all channels. Based on this physical information alone, our brain must determine which information is relevant and which is irrelevant. Unselected information is rejected by the filter without being processed for semantics. In Broadbent's model, higher level characteristics (e.g. meaning) are extracted later, and only for information selected to proceed through the filter. This, according to Broadbent (1958), is the reason why only physical sensory information can be reported from the unattended channel in a dichotic listening task. Content was selected on the physical attribute of "ear", and only the content from the selected ear was processed for semantics. This is an example of an early-selection theory

of selective attention, and was the basis for later theories of attention in both temporal and spatial attention (e.g. Raymond, Shapiro & Arnell, 1992).

Although Broadbent's (1958) early selection theory of attention explained the dichotic listening results observed by Cherry (1953) and Broadbent (1958), Moray (1959) and Wood and Cowan (1995) were able to show that approximately one-third of participants were able to notice their own name when it was inserted into the speech stream in the unattended ear, despite being instructed to ignore that ear. This effect is likened to standing in a room of people having a conversation, and having your attention suddenly drawn to the opposite side of the room as someone mentions your name. Fittingly, this phenomenon has affectionately become known as "the cocktail party effect".

Moray's (1959) results contradict Broadbent's (1958) early selection theory by showing that some higher-level semantic information can be extracted from an unattended channel. Several other studies emerged that also showed evidence for semantic processing of unattended information. For example, Corteen and Wood (1972) paired target words (city names) with a mild shock, conditioning participants to respond physiologically to the shock-paired city names. Participants were then given a separate dichotic listening task in which they were instructed to ignore the message in one ear, and shadow a prose passage in the other ear. The unattended channel contained nouns and occasional city names. Although participants did not report hearing the city names, they nonetheless showed an increased galvanic skin response (GSR) to city names suggesting that words in the unattended ear were processed for semantics. Peters (1954) showed that when an unattended message in a dichotic listening task contained similar content to the

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attended message, significant interference was observed. This also contradicts early-selection models because it shows that semantic information can be processed from the unattended channel.

Treisman (1960; 1969) proposed an alternate model which helped explain results such as Moray's (1959) while still retaining an early filter position as proposed in Broadbent's (1958) theory. Treisman's model suggests that while incoming stimuli may well be filtered before semantics, filtering is not performed in an all-or-none fashion, and that unselected stimuli are simply attenuated, rather than removed by the filter (Treisman, 1960; 1969; Driver, 2001). If the stimulus is relevant enough to the participant (such as their own name, or potentially threatening material) then these weak representations can compete for awareness. This led to the idea that different stimuli may have different thresholds for identification (Treisman, 1960; 1969; Shapiro, Caldwell, & Sorenson, 1997), with personally relevant items being easier to recognize, and unfamiliar stimuli being more difficult to recognize.

In light of multiple studies providing evidence of semantic processing in the unattended channel, Deutsch and Deutsch (1963) proposed a late-selection model of attention. Deutsch and Deutsch propose that all information, regardless of attention, is processed to a semantic level first, and is weighted based on relevance. This weighting is dynamic, such that incoming stimuli can change the weight of other stimuli based on changes in perceived importance. This allows the most important or relevant information to take priority. The highest weighted items are then attended to, and thus reach conscious awareness. This model can explain why salient stimuli, such as a person's own name, reach conscious awareness from the unattended channel (e.g., Moray, 1959), and

why material in the unattended ear interferes more with a shadowing task when it is semantically similar to the shadowed material (Deutsch & Deutsch, 1963). In both cases the unattended material is highly weighted for importance given its personal or contextual relevance. This type of late-selection model has been the basis for many models of dual-task and selective attention, some of which are reviewed in the next chapter.

If attentional selection is always late as suggested by Deutsch and Deutsch (1963), then why does it appear to be early in some studies? Lavie (1995) proposed a model of selective attention which allows for both early and late attentional selection. Lavie (1995) reported evidence from flanker and visual search studies showing that distractor interference was at its greatest when perceptual load was low. This means that when targets and distractors are very simple and easy to discriminate, paradoxically, there is a greater chance that irrelevant information will interfere with relevant information. When stimuli were more complex, and thus required deeper processing in order to make decisions, distractor interference appeared to be lower. Thus, Lavie (1995) proposed a perceptual load theory of selective attention in which she posits that attentional selection is sometimes early and other times late, depending on the degree to which the person can afford extra processing of distractors. If the perceptual load is low then both target and distractor information can be processed to a deeper level, thus causing interference. When perceptual load is high only the most important or relevant items are thought to undergo deeper processing.

In sum, in the past few decades there has been general consensus that stimuli compete for attention, and are selected to receive attention and enter awareness based on their importance or relevance. The level of processing that determines which stimuli are

relevant or irrelevant may vary depending on specific task goals or perceptual load. This system, however, is imperfect, thus relevant information is occasionally missed, and irrelevant information is sometimes fully processed.

Visual Search and Feature-Integration Theory

After deciding how information is selected to receive attention, the next question is what happens to information when it receives attention? This issue has been addressed by Treisman and Gelade (1980) in their feature-integration theory which is based largely on results from the visual search paradigm. In visual search, participants are required to detect a target as quickly as possible from within a spatial array of competing distractors. The number of distractors is varied and reaction time (RT) to detect the target is measured (Eriksen, 1955; Treisman & Gelade, 1980).

Similar to other attention theories, the first stage in the feature-integration theory is a preattentive processing stage, in which individual features of the stimuli, such as colour or general location, are extracted. This is done in parallel across the display, so in simple search paradigms where targets and distractors differ only on a single easily discriminable feature (e.g., red amongst green or moving amongst stationary), the target tends to “pop-out” of the display and RTs are fast and roughly equal regardless of the number of distractors (parallel search). In more complex displays when two or more features must be combined to separate targets from distractors (e.g., a green circle target amongst green square distractors and red circle distractors), the features extracted in the parallel processing stage must be integrated in order to determine the difference between target and distractor. This integration of features is often referred to as binding.

Binding is attention demanding and must be performed in a serial fashion, therefore in visual search increases in target detection RT are evident as the number of distractors increases (serial search). Thus, in feature-integration theory attention permits binding where features are “glued-together” to form “object files” which are conscious intact representations of stimuli situated in time and place. While feature integration theory is no longer regarded as the premiere theory of visual attention (Driver, 2001), it has helped pave the way towards future theories of selective visual attention. The idea that attention is required for binding features into a cohesive object for awareness remains a central and important tenet in the attention literature.

Dual-Task Attention

If binding is required for conscious awareness, yet binding requires attention which is a limited resource, then one can examine the costs of attention using dual-task paradigms where more than one attention-demanding task must be performed. It is very difficult to divide one's attention effectively, therefore performance is often impaired in dual-task paradigms. In early dual-task paradigms participants typically performed two continuous tasks at the same time. They compared performance when the tasks were performed together to performance when each task was performed alone (e.g., Allport, Antonis & Reynolds, 1972; Bourke, Duncan & Nimmo-Smith, 1996; Moray & O'Brien, 1967). For example, in a dichotic listening task, if participants were instructed to attend to one ear, and ignore the other, shadowing accuracy for the attended channel was quite high (about 90%) (Moray & O'Brien, 1967). However, when Moray and O'Brien (1967) gave participants the same task but also explicitly instructed them to divide their attention by shadowing the attended message while simultaneously attempting to detect

intermittent tones or words in the other channel, performance on both tasks suffered (80-85% shadowing accuracy and 8-9% detection accuracy in other channel). This is an early example of how it is very difficult for humans to simultaneously attend to multiple stimuli. These findings sparked further research into dual-task attention in the visual domain (e.g., Treisman, 1969) and cross-modally (e.g., Allport et al., 1972).

Although one can readily observe dual-task performance costs in such dual-task paradigms, the continuous nature of tasks such as prose shadowing may minimize these costs. Participants can engage in strategies of switching and buffering information, and take advantage of the inherent structure, redundancy and repetition in externally valid stimuli such as prose and music, all of which can mask the true magnitude of performance deficits. Continuous tasks are extremely useful if one wants to see how individuals can attempt to overcome dual-task processing limitations, but are less useful if one wants to examine the nature and true magnitude of these effects. To remedy this concern, most modern studies of dual-task attention use unpredictable, independent discrete tasks, and these studies will be discussed next.

The Attentional Blink

One way in which we can study the costs of paying attention to an item is through the use of the rapid serial visual presentation (RSVP) paradigm. In RSVP, a series of stimuli are rapidly presented serially in the same spatial location, with a 50-100 ms average presentation time for each item in the stream (Lawrence, 1971; Potter, 1976; Raymond et al., 1992; Raymond, Shapiro, & Arnell, 1995). Participants are typically asked to report the presence or identity of one or two targets from within the RSVP stream, and response accuracy to each target is examined. The temporal proximity of two

targets can be varied, and performance on the second target (T2) can be used to examine the cognitive costs of paying attention to the first target (T1). Interestingly, when T2 is presented temporally close (within 200-500 ms) to T1 in RSVP, T2 accuracy is markedly decreased relative to longer target separations, resulting in what is now known as an “attentional blink” (AB) (Raymond et al., 1992; 1995; Shapiro, Arnell & Raymond, 1997). This chapter will focus on our understanding of the AB deficit, namely the attentional processes thought to be occurring during an AB episode, and the requirements for obtaining a typical AB pattern, paying particular attention to prominent models which have been proposed over the years.

Original AB Study and Model

Raymond et al.’s (1992) original study on the AB followed from previous multi-target RSVP findings by Broadbent and Broadbent (1987) and Weichselgartner and Sperling (1987). In Weichselgartner and Sperling’s (1987) experiment, participants were asked to report a lone white letter from the RSVP stream, as well as the three items that immediately followed this letter. They observed that items appearing two to four positions after the white letter were rarely reported, whereas items six to eight positions later were often reported.

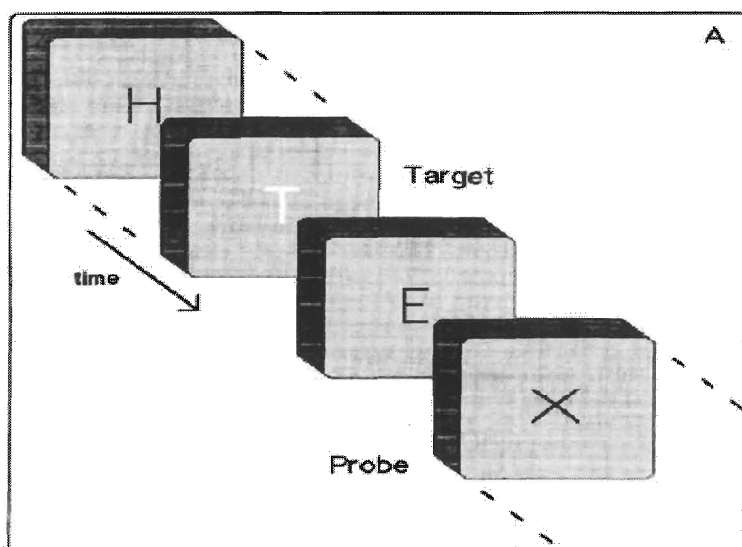


Figure 1. Typical AB Stimuli (Raymond et al., 1992)

Raymond et al. wondered whether the relatively difficult task of identifying three items after the first target contributed to the large deficit observed by Weichselgartner and Sperling (1987). Raymond et al. (1992) retained the T1 identification task used previously, but altered the Weichselgartner and Sperling (1987) study, creating a simpler single T2 detection task, wherein participants had to detect a black “X” which was presented 50% of the time after T1 at varying lags (T1 and T2 separated by 1-8 items) (see Figure 1 which shows a lag 2 trial). They also included a single-task control condition in which participants ignored T1 and only reported detection of T2. In the control condition, participants showed excellent (>85%) T2 detection accuracy at all lags, but in the dual-task experimental condition participants again showed reduced T2 accuracy when T2 was presented 2 to 5 items after T1 (see Figure 2). Raymond et al. (1992) coined the phrase “attentional blink” (AB) to describe the apparent absence of attention when T2 was presented temporally close to T1. These results showed that this dual-task limitation could be observed even when T2 was fully specified and simply required detection. These results also suggested that the AB was attentional, and not due

to visual limitations such as forward contrast masking by the white T1, as control participants who viewed T1 without attending to T1 did not show deficits in T2 accuracy.

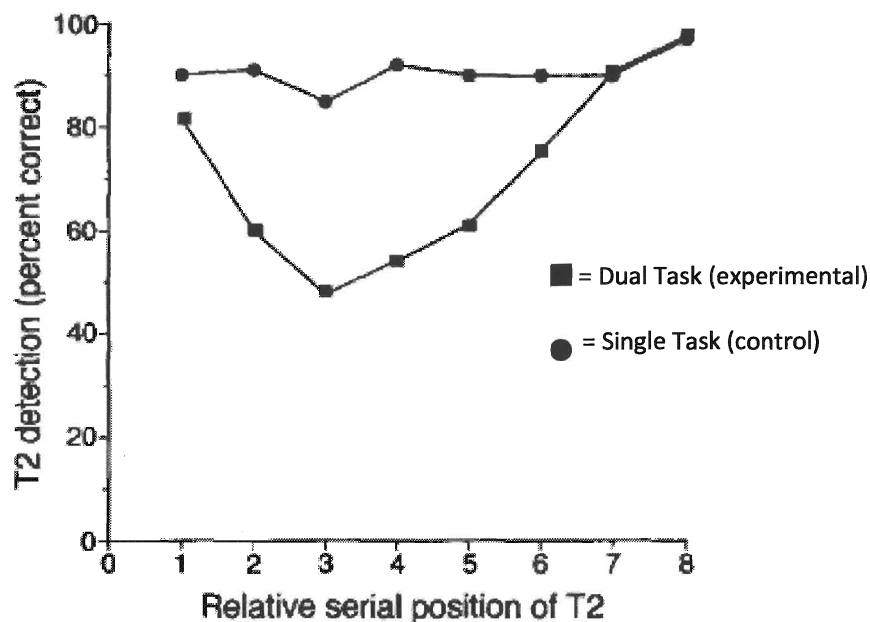


Figure 2: Sample AB Pattern: T2 Accuracy Given T1 Correct (Raymond et al., 1992)

Raymond et al. (1992) proposed an early-selection model of the AB. They suggested that when attention is focused on T1 for identification, the presence of the distractor immediately following T1 creates confusion amongst features. In response to the confusion, a theoretical attentional “gate” is closed which restricts subsequent high level feature gathering. Therefore, only T1 and the item immediately after T1 (the T1+1 item) enter into the first attentional window. The AB duration represents the recovery time required for the interference to be resolved and for the attentional “gate” to be reopened.

Raymond et al. (1992) examined the effects of placing blank spaces, rather than distractors, immediately following T1 presentation (T1+1 position) or two positions after T1 (T1+2 position). When a blank was inserted immediately after the presentation of T1

as the T1+1 item, the AB was drastically attenuated. However, when a blank was placed as T1+2, the AB occurred as usual. The authors proposed that when T1 is no longer masked by an immediate distractor (i.e., when a blank is inserted in the T1+1 position instead), competition between T1 and the following distractor is reduced, thereby keeping the attentional gate open for T2, and eliminating the AB. Thus, masking T1 is necessary in order to produce an AB. When the T1+2 distractor was replaced with a blank, the AB still occurred because the distractor presented immediately after T1 was still able to cause interference and the attentional gate was shut prior to the blank.

A recent study supports this attentional gate model of the AB. Olivers, Van der Stigchel, and Hulleman (2007) increased the number of targets in an AB design to include up to four different targets. They found that when the targets were presented one after the other in RSVP without any intervening distractors, report accuracy for all targets was very high. When a distractor was inserted between two targets, however, a typical AB deficit occurred. This suggests that a distractor per se must be in the T1+1 position, and that not just any masking stimulus can initiate the AB deficit. This supports an early selection model because it implies that when there is no confusion (i.e., no distractors) all targets are successfully processed and the attentional “gate” remains open. The inclusion of a distractor causes the gate to shut, thereby contributing to a deficit in reporting the following target. Olivers et al. (2007) returned to Raymond and colleagues’ (1992) idea that during T1 identification, attention is rerouted from filtering the stream to processing the target, thereby allowing the T1+1 item to create interference that disrupts T1 identification. According to Olivers et al. (2007), the duration of the AB reflects the time

required for attention to reinstate the filter so that later targets can be accurately separated from distractors.

Late Selection Interference Model of the AB

Shapiro, Arnell and Raymond (1994) and Raymond et al. (1995) later put forward a theory of the AB suggesting a late-selection interference model of attention. They proposed that we create templates matching target features to help discriminate targets from distractors in RSVP. All items in the RSVP stream are preattentively processed to some degree, and high-level visual and semantic representations are placed in a buffer, depending on their relationship to the pre-specified templates. Further attention is needed in order to bind these representations into object files and allow the targets to reach conscious awareness. Consistent with previous researchers (e.g., Potter, 1976), Shapiro and colleagues suggest that in order to be bound and enter awareness targets need to be consolidated into visual short-term memory (VSTM). This consolidation is capacity limited, and priority of processing depends both on the similarity of stimuli to the templates, and presentation order. Therefore T1 receives priority because it comes first and matches the template. Immediate post-target items are also admitted into this pre-consolidation buffer due to their temporal proximity to targets, and depending on their similarity with T1, can interfere with selection of the relevant targets. At short target separations T2 receives heavy interference, as T2 does not receive temporal priority. When T1 and T2 are separated by greater than 500 ms, T1 has been consolidated into VSTM, the T1+1 item has been rejected and T2 can now proceed to VSTM consolidation with relatively little interference.

This interference model requires that T2 achieve fairly high level featural and semantic representations before binding. Shapiro, Driver, Ward and Sorenson (1997) used behavioural measures to show that even when T2 could not be reported, T2 was processed beyond visual features. These authors examined the ability of blinked T2s to prime later items. On half of the trials, T2 and a third target (T3) were the same letter in different case (match), and on half they were different letters in different case (mismatch). Their results showed that even on blinked trials where participants were unable to report T2, significant T3 priming occurred (i.e., T3 accuracy was higher on match trials than on mismatch trials).

Consistent with the priming study and the late-selection model proposed by Shapiro et al. (1994) and Raymond et al. (1995), ERP studies showed that missed T2s during the AB period do receive full perceptual and semantic processing (Luck, Vogel & Shapiro, 1996; Vogel, Luck & Shapiro, 1998). Using electroencephalography (EEG) techniques, Luck et al. (1996) measured event-related potentials (ERPs) to T2 in the AB paradigm. The ERP components P1 and N1 are related to early visual processing, and were shown to be fully intact for blinked T2s during the AB interval (Vogel et al., 1998). The N400 ERP component was also examined. An increased N400 is elicited when there is a mismatch between a presented word and its semantic context (Kutas & Hillyard, 1980). For example, the sentence “I put on my coat and shoes” would elicit a small N400 to “shoes”, but the sentence “I put on my coat and pineapple” would elicit a large N400 to “pineapple” as it is unexpected based on the semantic context of the sentence. Luck and colleagues used the N400 to examine the extent to which T2 is processed semantically during ‘blinked’ trials. In an otherwise typical AB task, a word was

presented before each trial (e.g. 'kitchen') to create a semantic context for T2, and participants had to determine whether or not the T2 word was semantically related to the context word. Interestingly, although participants had a significant decrease in T2 accuracy at lag 3, the N400 amplitude (T2 activation on match trials subtracted from activation on mismatch trials) was unaffected and equal across all lags, suggesting that even when T2 is blinked, it is still semantically processed. This is of particular importance to late selection theories of attention, such as the one proposed by Shapiro et al. (1994) in that it shows that while participants do not have conscious awareness of having seen T2, they have still semantically processed T2. These findings also support the idea that preattentive semantic processing has little attentional cost, hence its ability to remain unaffected by the AB deficit (Luck et al., 1996; Treisman & Gelade, 1980).

Vogel et al. (1998) also showed that while the N400 was not reduced for blinked trials, the P3 ERP component to T2 was drastically impaired on trials where T2 was missed compared to trials where T2 was detected. The P3 is thought by some to reflect the updating of the contents of working memory (i.e., consolidation) and is sensitive to stimulus identification and categorization operations (Donchin, 1981). The reduction in P3 amplitude on blinked trials provides evidence that T2 does not undergo stimulus identification and consolidation, and suggests that attentionally costly VSTM consolidation is not performed on T2 during the AB, thus leading to its report failure.

Bottleneck Models of the AB

Chun and Potter (1995) further examined Raymond et al.'s (1992) finding that the AB may arise as a result of interference from the T1+1 distractor. They also posited that the distractors immediately following T2 interfere with the representation of T2 as it

awaits further processing, and aid in the decay and deterioration of T2. Chun and Potter questioned whether the source of the interference could be attributed to any visual event (i.e., any types of distractor or mask), or if the distractors had to be from the same category as the target. Chun and Potter created two experimental conditions: one of which contained distractors that were similar to the targets (digit distractors with letter targets), and one which contained extremely dissimilar distractors (keyboard symbols as distractors with letter targets). They found that the AB was modestly attenuated when distractors were slightly different from targets, but when the distractors were highly distinguishable from targets, the AB was almost completely eliminated.

Basing their model on previous two-stage models of visual search (e.g., Treisman and Gelade, 1980), Chun and Potter proposed a two-stage model of the AB, wherein a limited capacity second stage of processing results in the AB deficit. Similar to the model proposed by Shapiro et al. (1994) and Raymond et al. (1995), Chun and Potter (1995) posit that all information in the RSVP stream is preattentively processed to a semantic level. This is known in their model as Stage 1 processing. Stage 2 processing, where identification and stimulus consolidation into working memory are performed, is attention demanding and capacity limited, and thus acts as a bottleneck on processing information into awareness. Unlike the model of Shapiro et al. where all items compete for stage 2 consolidation and T2 suffers from interference, Chun and Potter conceptualize stage 2 processing as a bottleneck. According to Chun and Potter, if T1 is undergoing stage 2, then T2 must wait until T1 consolidation is complete before itself undergoing stage 2. At short lags T2's high-level visual representation will arrive at stage 2 prior to completion of T1 consolidation and will need to wait. While waiting, T2's representation

will be vulnerable to decay and masking by subsequent distractors, meaning that it will often be unavailable for consolidation once the bottleneck has cleared. However, at long lags T1 consolidation will be complete prior to T2 presentation and T2 will not need to wait, resulting in good T2 report accuracy. The duration of stage 2 processing for T1 determines how long T2 will need to wait, and therefore the magnitude and duration of the AB. If T1 and the immediately following distractor are similar to each other, greater interference will occur, resulting in increased Stage 2 duration for T1, and a higher probability of T2 degradation. If, however, T1 and the following distractor are highly distinguishable, T1 processing will be faster as the system can readily discard the distracting information, and the AB will be attenuated.

Seiffert and Di Lollo (1997) investigated T1 masking in order to test between the late-selection interference model of the AB (Shapiro et al., 1994; Raymond et al., 1995), and the two-stage model proposed by Chun and Potter (1995). Seiffert and Di Lollo created two experiments: one which superimposed features from the T1+1 distractor over T1 so that they overlapped at the same time and then were followed by a blank, and one which kept them separate in the traditional fashion. If the late-selection interference model is correct, superimposing T1+1 should create less AB, because T1 would not be backward masked by the trailing stimulus and removal of this strong competitor would create less interference in VSTM. If Chun and Potter's (1995) account was correct, the superimposed condition would create more interference and a larger AB, because it would increase the difficulty of processing T1, thereby lengthening the stage-2 period and leading to a higher incidence of blinked T2 trials. In the separate condition, an AB was consistently found. However, in the superimposed condition, the AB magnitude was

significantly larger, thus supporting the Chun and Potter (1995) two-stage bottleneck model.

Giesbrecht and Di Lollo (1998) found that a trailing T2 mask is also important to obtain an AB. Their study contained a series of experiments using a classic AB paradigm which presented either no mask after T2, a mask simultaneously presented with T2 (integration masking), or a mask presented after T2 (delayed or interference masking). When no mask was present, the AB did not occur. Similarly, in the integration masking condition when the mask occurred at the same time as T2, the AB pattern was markedly attenuated even though the mask reduced T2 accuracy well below ceiling performance. In the delayed masking condition, however, the classic AB pattern emerged suggesting both that masking is integral to producing an AB effect, and that the type of mask is crucial. In integration masking, the mask interferes with the representation of T2 by distorting it, but the representation is not replaced, and the T2 representation can receive bottom up support while it waits for the bottleneck to clear. With interference or delayed masking, the representation of T2 in iconic memory is replaced by the mask. If T2 can undergo Stage 2 processing immediately, the mask will not affect processing, but if T2 is presented temporally close to T1 and must wait for T1 to complete processing, then the mask will overwrite T2 in iconic memory, thereby removing bottom-up visual support to the T2 representation, making it more vulnerable to decay.

Interestingly, Giesbrecht and Di Lollo (1998) were also able to show that the number of items following T2 does not matter, so long as the initial T2+1 mask was present. This experiment further supports a bottleneck model of the AB, such that interruption of T2 processing by the T2+1 item interferes with the representations of T2,

aiding in the decay of this target. If T2 remained unmasked, it would have less of a chance to decay, and thus would likely be able to survive the bottleneck and undergo processing.

Bottleneck models of the AB suggest that the magnitude of the AB is dependent on T1 processing duration. Ouimet and Jolicoeur (2007) created an AB task in which T1 was either a no-load condition (the same digit used 4 times in a row), low-load condition (digits in ascending or descending order), or a high low condition (digits in random order). They reasoned that if a processing bottleneck underlies the AB, then altering the processing requirements of the T1 task should change the magnitude of the AB. Previous work by Jolicoeur (1999) had observed this pattern, but had used a speeded response task for T1. Using the difficulty load paradigm with an unspeeded T1 task, Ouimet and Jolicoeur (2007) found a significant increase in AB magnitude as task difficulty increased. This pattern persisted even when presentation time of T1 was doubled. The authors concluded that altering the difficulty of T1 can increase the magnitude of the AB, and that the results provide support for bottleneck models of the AB.

Working from the two-stage model of Chun and Potter (1995), Jolicoeur (1998, 1999) and Jolicoeur and Dell'Acqua (1998) proposed a similar AB model which they called the central-interference model or the short-term consolidation (STC) model. Jolicoeur's model has 3 stages. The first stage is thought to create sensory representations that are vulnerable to masking by trailing items in the stream. The second stage is thought to create high level visual and semantic representations that are resistant to masking, but that are fragile and decay quickly (stages 1 and 2 here are both part of stage 1 in Chun & Potter's model). The third stage requires that stimuli be consolidated into working

memory (WM) for later report (stage 2 in Chun and Potter's model). This consolidation allows information to be encoded into working memory, and thus reach conscious awareness.

Joliceur posits that stimulus consolidation is attention demanding and therefore gets bottlenecked in the same manner as Chun and Potter posit for stage 2 in their model. An AB is observed when the "processing bottleneck" prevents T2 from being consolidated in working memory before its stage 2 representations decay. This model is very similar to Chun and Potter's two-stage model (1995), but makes the distinction between lower and higher level representations, and specifies that the bottlenecked central processing limitations that underlie the AB are amodal limits on stimulus consolidation in working memory. Conceptualizing the AB in terms of a central (amodal) attentional bottleneck is consistent with findings showing that the AB can be found in the auditory modality (e.g., Arnell & Joliceur, 1998; Arnell & Larson, 2002; Duncan, Martens & Ward, 1997; Mondor, 1998), in the tactile modality (e.g., Hillstrom, Shapiro & Spence, 2002), when one target is visual and another is auditory (e.g., Arnell & Joliceur, 1998; Arnell & Larson, 2002), and when one target is visual and another is tactile (e.g., Dell'Acqua, Turatto, & Joliceur, 2001; Soto-Faraco et al., 2002).

Similarly, Bowman and Wyble (2007) have a two-stage ST² theory, or simultaneous type, serial token model of the AB where they suggest that binding is the bottlenecked process that underlies the AB, and that the time pressure created in RSVP interrupts the efficiency of this process. However, these authors also instantiate their ideas into a computational model of the AB. The creation of this computation model forces them to specify the neural architecture that they believe underlies the AB, and the

output produced by the computational model is quite a good fit to the behavioural data produced by humans. For example, the computational model has been able to account for effects such as target-distracter similarity and the reduction of the AB with a blank T1+1 interval.

The Temporary Loss of Control (TLC) Model

Lag-1 sparing refers to the finding that T2 accuracy at lag-1 is often extremely high despite the fact that this is the lag where T2 comes closest to T1 (Visser, Bischof & Di Lollo, 1999). Most AB models explain lag-1 sparing in terms of T1 and T2 being processed together in the same attentional window, which prevents the processing “bottleneck” from occurring. Some accounts say that lag-1 sparing occurs when the attentional gate closes too slowly, thus allowing both T1 and the T1+1 item to be consolidated at the same time (e.g., Chun & Potter, 1995; Shapiro et al., 1994). Others have suggested that the immediate post target item initiates the closing of an attentional gate, sparing itself (Olivers et al., 2007; Raymond et al., 1992). The temporary loss of control (TLC) model proposed by Di Lollo, Kawahara, Ghorashi and Enns (2005) suggests a special role for the T1+1 item.

In the TLC model, the attentional system is configured to select target items for further processing through a set of specially tuned input filters (i.e., attentional set). This allows for efficient selection and processing of T1. During T1 processing, resources are re-allocated to the processing of the target (to allow for maximal efficiency), thus leaving the input filters somewhat vulnerable to bottom-up capture and creating a temporary loss of control over incoming stimulus selection. If the T1+1 item is T2, the system still recognizes T2 as a target and T2 is properly processed, resulting in the lag-1 sparing

discussed above. If, however, the T1+1 item is a distractor, the input filter configuration is biased toward the T1+1 features. Under these conditions T2 will no longer match the attentional set, and will not be selected for further attentional processing. The attentional set template will come under attentional control and be corrected to match the target set once T1 processing is completed, at which time T2 accuracy will again be unimpaired. In support of the TLC model, and consistent with the results of Olivers et al. (2007), Di Lollo et al. (2005) found that when three sequential RSVP stimuli all had the same target defining feature (e.g., all three were letters amongst digits), there was no AB deficit observed and accuracy on the third item was equal to accuracy on the first item. However, when the second of the three items did not share the target feature (e.g., letter, digit, letter), the typical AB deficit was observed. Therefore a temporary loss of control over input filters may explain the phenomenon of lag-1 sparing, the finding discussed earlier in which multiple targets can be immune to the classic AB effect (Olivers et al., 2007).

Most of the AB studies presented above involved the manipulation of stimulus presentation factors in an attempt to better understand the AB. While this avenue of AB research is ongoing and extremely relevant to the field, researchers have begun to investigate the ways in which specialized groups of participants differ in their performance on an AB task, as well as to examine individual differences in AB performance. These studies will be examined just below.

Manipulations of AB Performance

Since the AB was first observed, studies have sought to understand the mechanisms behind the AB by manipulating the stimulus identity, task requirements, task

difficulty, or stimulus presentation conditions of distractors, and T1 and T2. While there are multiple variations on the classic AB task that can lead to differences in blink magnitude, a recent set of studies has sought to alter the size of the AB via manipulations outside of the RSVP stream and tasks. Interestingly, these studies have shown that the AB can be greatly attenuated and almost completely eliminated with the introduction of a simultaneous additional task (Olivers & Nieuwenhuis, 2005; 2006).

In their original study, Olivers and Nieuwenhuis (2005) had participants imagine their vacation, plan a shopping trip in their head, or detect “yells” randomly dispersed throughout a piece of music while simultaneously performing a classic AB task (Olivers & Nieuwenhuis, 2005). They found that completing an additional task at the same time as an AB task produced a counterintuitive decrease in blink magnitude relative to a control group who performed no additional task. In some cases the AB was eliminated entirely with an additional task. Olivers and Nieuwenhuis (2006) used a match-to-sample task where a random pattern of lines was presented before and after each stream. On each trial participants reported whether the line patterns matched or not.

Despite the task differences across papers, their results were the same—performing an additional task reduced the AB (Olivers and Nieuwenhuis, 2006). To further examine this effect, Olivers and Nieuwenhuis (2006) replaced the line drawings with blocks of trials that contained emotionally-laden positive, negative or neutral pictures, or scrambled control images. The AB was attenuated for blocks where the pictures were emotionally positive relative to the blocks with negative, neutral, or scrambled pictures. Olivers and Nieuwenhuis concluded that the additional tasks and

induction of positive affect used in their studies led participants to diffuse their attention rather than focusing too much on the AB task.

Arend, Johnston and Shapiro (2006) also conducted a study that examined the benefits of attentional diffusion for the AB. Their study was different than those of Olivers and Nieuwenhuis in that, rather than giving an additional task, they simply directed participants' attention away from the AB task through the use of a moving star-field (see Figure 3). They found that when a star-field that surrounded a central RSVP stream moved away from the stream, the AB was greatly attenuated relative to when the star-field was static. When the star-field moved towards targets or simply flickered, the AB was also attenuated relative to a static star-field, but to a lesser degree. These results suggested that any changes to the star-field could diffuse attention from the AB task, but that movement away (as if diffusing attention out across the screen) was particularly effective. Thus, this expanding stimulus was allowing participants to diffuse their attentional resources, rather than focusing on the AB targets, similar to the Olivers and Nieuwenhuis (2005; 2006) tasks.

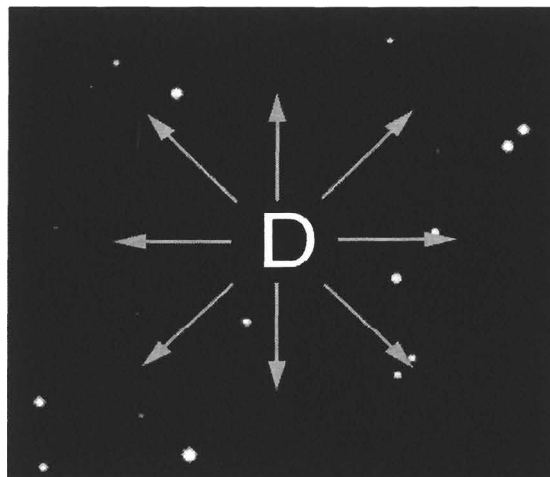


Figure 3. Example of “away” star-field condition (from Arend et al., 2006).

These findings are very counterintuitive, as the core of dual-task attention literature supports the notion that dividing one's attention causes deficits (e.g., Broadbent & Broadbent, 1987; Cherry, 1953; Raymond et al., 1992). As discussed previously, the AB is generally thought to reflect an inability to properly attend to T2 because T1 utilizes available attentional resources for about half a second (e.g., Raymond et al. 1992; Chun & Potter, 1995), so it would seem that further taxing the system should result in *greater* deficits, not fewer. A theory has been proposed to explain why an additional task introduced to the already difficult AB task would actually help reduce the AB. Olivers and Nieuwenhuis (2006) believe that the attentional resources that are available at a given time may actually be enough resources to process both T1 and T2. Their theory proposes that when individuals are tightly focused on correctly identifying targets in an AB task, there is an *overinvestment* of attention to T1 and distractors in the RSVP stream. This allows T1 to cross the threshold where it will receive attentional resources, but also allows some distractors, especially the ones presented near targets, to cross an activation threshold where they also receive attention. However, when an individual is forced to diffuse their attention through the use of an additional task, Olivers and Nieuwenhuis posit that each RSVP stream item receives less activation such that now only T1 will cross the threshold and receive attention. The fact that distractors are now less effective competitors for attention results in the attenuation of the AB (see Figure 4 for representation of the overinvestment hypothesis).

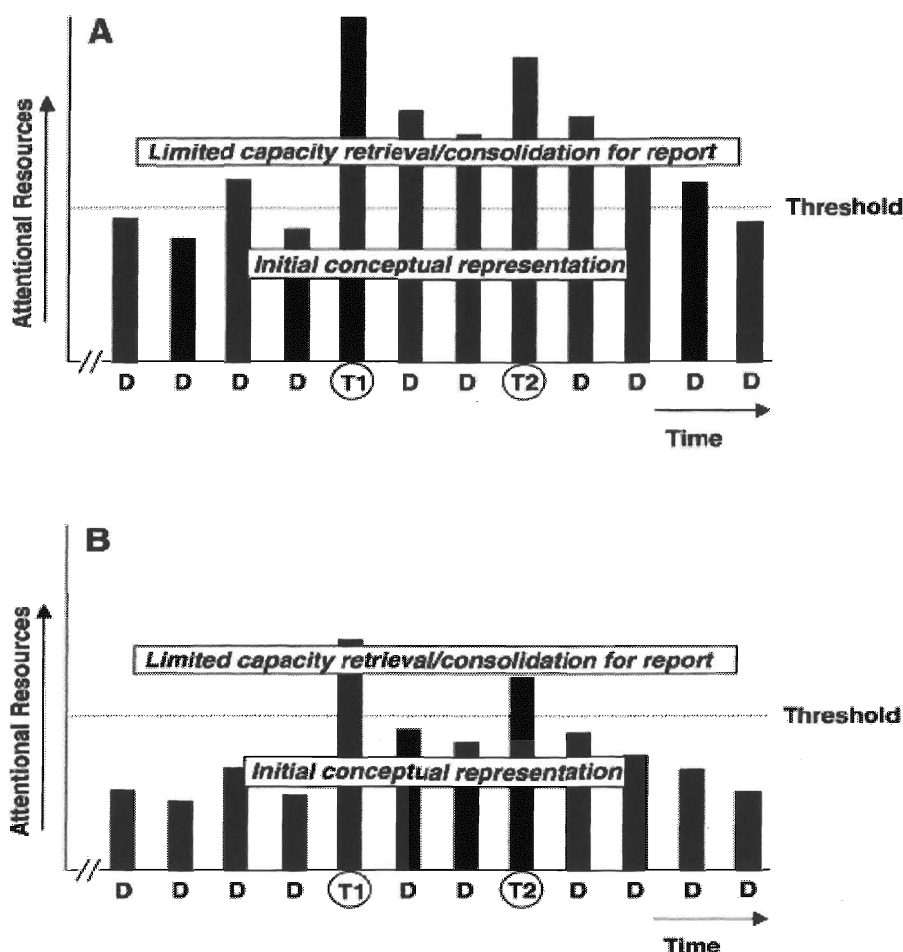


Figure 4. Representation of overinvestment hypothesis (from Olivers & Nieuwenhuis, 2006).

Panel A reflects competition for resources due to overinvestment of attentional resources to items in the AB stream. As too many resources have been invested here, T1, T2 and several distractors compete for consolidation. Panel B reflects less competition due to diffusion of resources. Only T1 and T2 reach the threshold for consolidation.

Olivers and Nieuwenhuis (2006) propose that positive affect also leads to attentional diffusion, as their results showed an attenuated AB when a positive picture was shown just prior to each RSVP stream. Positive affect has previously been suggested to broaden attentional span (e.g., Fredrickson, 2001). For example, the broaden and build model of Fredrickson (Fredrickson, 2001; Fredrickson & Branigan, 2005) argues that positive affect typically occurs in a safe environment and is associated with more diverse

nonspecific response, or “action” tendencies that afford opportunities for advantageous learning. In contrast, negative affect often occurs in the presence of environmental threat and is associated with specific action tendencies linked to fight or flight that afford opportunities for survival. Furthermore, data from numerous cognitive paradigms have provided evidence that positive affect is linked with a diffused state of attention (e.g., Dreisbach and Goschke, 2004; Fenske & Eastwood, 2003; Rowe, Hirsh, & Anderson, 2007). The positive affect results of Olivers and Nieuwenhuis are also supported by recent studies showing that induced positive affect (Jefferies, Smilek, Eich & Enns, 2008) and naturally occurring positive affect states (MacLean, Arnell, & Busseri, *in press*) are related to a decrease in overall AB magnitude. Thus, evidence suggests that positive affect tends to lead to a diffuse attentional state, thereby preventing overinvestment to items in the RSVP stream.

Arend et al. (2006) also endorse an overinvestment hypothesis, but emphasize that it is the overinvestment of T1 processing that is reduced in a diffused attentional state. They indicate that in both their task, which directed attention away from T1, and previous tasks used by Olivers and Nieuwenhuis (2005), attention was distracted or diffused, thus preventing overinvestment to T1, and allowing faster T1 processing. This faster processing of T1 allows T1 to clear the processing “bottleneck” sooner, allowing for T2 processing to begin earlier before T2 decays, thus attenuating the AB. Arend et al. (2006) believe that minimal outside interference may prevent confusion from taking place, thus allowing T1 to rapidly undergo processing, and thereby attenuating the AB. Regardless of the exact mechanism; overinvestment of attention appears to play an important role in the AB phenomenon.

In addition to the participant's state of focus while participating in an AB task, the specific task instructions used when conducting an AB study can influence the AB magnitude. Ferlazzo, Lucido, Di Nocera, Fagiolo, and Sdoia (2007) examined the way in which participants were asked to report T1 and T2. They presented T1 and T2 as digits embedded within letter distractors, and participants were asked to report the digit targets. They found that when participants were asked to report sequentially the identity of T1 and then T2, the typical AB pattern emerged. However, when participants were told to report T1 and T2 at the same time, essentially treating the targets as a set, the AB was modestly attenuated. The authors believe that giving participants a single task, even when presented as two separate targets, it allows T1 and T2 to be processed as a set in a single attentional window. This study is an example of how task instructions and participant goals can alter the magnitude of the AB.

Recent research has also begun to take a group differences or individual differences approach to the AB. Some studies have examined AB differences in pre-existing populations of individuals, and other individual differences studies have examined performance measures that may predict an individual's AB magnitude. A brief review of studies using both of these approaches will give greater insight into how the AB pattern varies for different individuals.

AB Differences in Naturally Occurring Participant Groups

Research on AB performance in select populations is quite prevalent, and many researchers are interested in examining naturally occurring groups of individuals and their performance on an AB task. A brief overview of a selection from the vast literature on

group differences and the AB should convey how broad this particular area of research has become.

Age and the AB. Previous work shows that there are significant age differences in AB performance, such that older adults show increased AB magnitude as compared to younger adults (e.g., Georgiou-Karistianis et al., 2006; Lahar, Isaak, & McArthur, 2001; Maciokas & Crognale, 2003). Lahar et al. (2001) examined younger adults under the age of 30, and older adults over the age of 65. Interestingly, older adults had an AB about twice as large as younger adults, and showed lower T2 accuracy (about 10% lower) even at the longest lags where the AB was no longer observed. Georgiou-Karistianis and colleagues (2006) replicated this result using participants who ranged in age from 18-82. They found a steady drop-off in AB performance starting around age 26. Both studies posited that inhibitory mechanisms that prevent individuals from processing the distractors begin to fail as a person ages (e.g., Tipper, 1991), thus preventing older participants from suppressing distracting information. As mentioned earlier, distractors which follow T1 can increase the consolidation period, lengthening the AB. Distractors following T2 can cause greater T2 decay or deterioration, preventing T2 from reaching conscious awareness. Therefore, inhibitory control is important in order to overcome the effects of the distractors, and the AB.

Mood Disorders and the AB. Researchers are finding that individuals with subclinical mood disorders may perform differently on the AB task than individuals without mood disorders (Rokke, Arnell, Koch & Andrews, 2002). Rokke et al. (2002) observed that dysphoric individuals reporting severe depression symptoms (as indicated by the Beck Depression Inventory or BDI) showed larger ABs as compared to individuals

reporting few to no depression symptoms or those reporting mild to moderate depression symptoms. However, all three groups had equal accuracy at the longest T1-T2 lags. Also, when the participants performed a single RSVP target condition, in which they were instructed to ignore T1, all three groups had similarly good T2 detection accuracy. Rokke et al. (2002) suggest that individuals experiencing a severely dysphoric mood state may experience difficulty disengaging attention from the T1 stimulus and take longer to consolidate T1 into short term memory—a deficit also shown in memory research (e.g. Hertel, 1998). If a bottleneck on stimulus consolidation into working memory underlies the AB as suggested by some AB theories (Chun & Potter, 1995; Jolicoeur, 1998), it follows that depressed individuals should therefore have a longer bottleneck, resulting in more T2 decay and larger ABs.

Schizophrenia and the AB. AB studies examining individuals with certain psychological disorders may also give insight into the nature of the AB task. For example, individuals with schizophrenia are thought to have a reduced ability to inhibit inappropriate stimuli (Cheung, Chen, Chen, Woo, & Yee, 2002). This should increase the AB, as the ability to inhibit irrelevant distractors should cause increased interference for relevant targets (Cheung et al., 2002). Cheung et al. (2002) examined the AB pattern of participants diagnosed with schizophrenia, and healthy controls. As expected, they found that schizophrenic individuals showed an enhanced AB effect, and significantly poorer target accuracy than controls. This result suggests the importance of inhibition in selective attention and the AB. Outside the AB paradigm, there is evidence to suggest that schizophrenics have slow working memory consolidation (Fuller, Luck, McMahon, & Gold, 2005). Given that several models of the AB suggest that limitations on stimulus

consolidation into working memory underlie the AB (e.g., Chun & Potter, 1995; Jollicœur, 1998; Shapiro et al., 1994) the slowed consolidation may also be responsible for schizophrenic individual's poor performance on AB tasks. Indeed, Wynn, Breitmeyer, Nuechterlein, and Green (2006) suggest that this poor consolidation may contribute to schizophrenic's susceptibility to masking in the AB paradigm, leading to enlarged ABs.

Brain Damage and the AB. Following a stroke, particularly one affecting the right parietal lobe, patients occasionally develop a condition called unilateral neglect, in which they have a substantial impairment in noticing and attending to objects in the opposite visual field (Halligan, Fink, Marshall, & Vallar, 2003). Attention appears biased toward the ipsilateral side of the damaged hemifield. However, patients also experience difficulties disengaging attention from objects on the ipsilateral side (Husain, Shapiro, Martin & Kennard, 1997). Husain et al. (1997) examined the performance of eight left-side neglect patients with right-hemisphere lesions on an AB task in order to examine whether patients with deficits in spatial attention would also show attention deficits in the temporal domain. Interestingly, the neglect patients had extremely large ABs (3 times as large as controls), and their AB was significantly protracted. This study provided evidence that in patients with unilateral neglect, the deficits are both spatial and temporal.

Another recent study examined participants with mild traumatic brain injury (mTBI) (McIntire et al., 2006). While these patients did not show the extreme AB deficits that neglect patients showed, there was evidence for increased interference from distractors and a significantly decreased T2 accuracy (McIntire et al., 2006). This indicates that even mild trauma to the brain can disrupt temporal attentional processing.

Other studies with Alzheimer's patients show that even when Alzheimer's disease is still at a relatively mild stage, AB magnitude is significantly increased, and the AB is protracted (Kavcic & Duffy, 2003). Therefore, healthy brain functioning appears to be associated with a smaller AB.

ADHD, Dyslexia and the AB. Visser, Boden, and Giaschi (2004) compared the AB performance of children with developmental dyslexia to the AB performance of age and reading-ability matched controls. They found that when T2 was presented in the same spatial location as T1 (as in the typical RSVP stream), children with dyslexia had larger ABs than age-matched controls. When T1 and T2 were presented in different spatial locations, dyslexic individuals performed significantly worse than both age and reading-ability matched controls. Lum, Conti-Ramsden, and Lindell (2007) found a similar result with dyslexic adolescents, and found that T2 accuracy was especially low in these individuals. This led Lum et al. (2007) to conclude that individuals with dyslexia may perform poorly on an AB task because they have difficulty disengaging their attention from T1, and are 'sluggish' to attend to the next target, a theory previously put forth by Hari and Renvall (2001).

Individuals with attention deficit hyperactivity disorder (ADHD) are also of interest, because they, by definition, have difficulty focusing and sustaining attention, and also tend to have poor impulse control (Hollingsworth, McAuliffe, & Knowlton, 2001). Studies show individuals with ADHD tend to have larger ABs (Mason, Humphries & Kent, 2005), more prolonged ABs (Hollingsworth et al., 2001), and more errors as compared to healthy controls (Li, Lin, Chang & Hung, 2004; Mason et al., 2005). These studies highlight the importance of attentional control in selective attention and the AB.

Pharmacology and the AB. Some studies have examined the effect of drug use on the AB. These studies are particularly interesting because knowing which drugs can modulate the AB may guide us to specific pathways or neurotransmitter systems that are involved. For example, Boucart, de Visme, & Wagemans (2000) examined the effect of benzodiazepines on the AB. Benzodiazepines, particularly Diazepam, have previously been shown to impair visual processing, yet no studies had directly examined this finding with temporal attention. Thus Boucart et al. (2000) decided to see if benzodiazepines could affect performance on an AB task. They randomly assigned 54 healthy participants to one of three groups: two benzodiazepine drug groups (Lorazepam and Diazepam respectively) and a placebo group as a control. They administered a classic AB paradigm, and found that in a single task condition in which participants were instructed to ignore T1, performance was equal across all three groups. However, in the dual-task condition the magnitude of the AB was significantly increased for participants in the two benzodiazepine groups, particularly the group taking Diazepam. These results were later replicated in a study using only Diazepam (Boucart, Waucquier, Michael, & Libersa, 2007).

In another study, researchers examined how Clonidine, a drug used to treat Tourette Syndrome and other hyperactive disorders, could enhance the AB effect (Nieuwenhuis, van Nieuwpoort, Veltman, & Drent, 2007). Clonidine use was expected to enhance the AB because it reduces attention and alertness in both humans and monkeys, and is thought to dampen the effects of norepinephrine---a neurotransmitter responsible for regulating arousal (Nieuwenhuis et al., 2007). Interestingly, Clonidine had no effect on the AB. The authors suggest that norepinephrine may not have as large a role in

selective attention as was previously thought, and that its effect on arousal may be indirect (Nieuwenhuis et al., 2007). Other studies of norepinephrine and the AB have yielded contradictory results (e.g. De Martino, Strange, & Dolan, 2008), but all point to a direct or indirect role of arousal in the AB. Other studies have investigated the role of arousal using nicotine dependence and the AB, and show that nicotine withdrawal in regular smokers leads to enlarged ABs (Heinz et al., 2007). It is possible that there is an optimal level of arousal for successful performance on the AB, and that consistent relationships of the AB and drug levels are difficult to observe given an inverted U-shape such as the one observed in the Yerkes-Dodson (1908) theory of arousal.

Non-Blinkers. Throughout the course of normal AB research, individuals also appear occasionally who seem to be immune to the AB effect. These individuals are typically better at the AB tasks than their counterparts, producing high T1 and T2 accuracy and T2 accuracy that is equal across T1-T2 lags (even when T2 performance is not at ceiling). Martens and colleagues have colloquially labeled these individuals as “non-blinkers” (Martens, Munneke, Smid & Johnson, 2006). Through the use of EEG, Martens et al. (2006) were able to show that participants with no discernable AB had an earlier onset for the T1-locked P3 ERP component than did participants showing a typical AB. As discussed above, some prominent models of the AB posit that the AB results from a bottleneck on attentional processing and/or working memory consolidation (e.g., Chun & Potter, 1995; Jolicoeur, 1998). If non-blinkers are able to process T1 at a faster pace than most individuals, a processing bottleneck may never form when completing an AB task, or may be very brief, such that the duration of T1 processing may never outlast the time T2 takes to decay. The non-blinkers also showed reduced EEG amplitude to

distractors across the RSVP stream, and greater frontal activation for T1 relative to distractors, which Martens et al. (2006) interpreted as evidence for a more efficient selection of targets from amongst distractors. These results are consistent with the Olivers and Nieuwenhuis overinvestment hypothesis in that non-blinkers may invest less in processing irrelevant distractors, enabling more efficient target processing. This study is particularly interesting because it is the first to examine individuals who were naturally immune to the AB.

Individual Differences Investigations of the AB

The recent focus on non-blinkers (e.g., Martens et al., 2006) has prompted researchers to begin to consider the full range of individual differences with respect to the AB effect, and examine what factors may predict the size of an individual's AB. If an individual demonstrates performance deficits on certain cognitive tasks relative to normal performance, and shows similar relative deficits on an AB task, it is possible that these tasks may share some underlying cognitive mechanism, through which we can better understand the AB. Similarly, if an individual has particularly good performance on a cognitive task relative to other participants, and a smaller-than-typical AB size, then again a similar underlying mechanism may be involved. Using this logic, a recent comprehensive study examined performance on a variety of cognitive tasks, and examined whether performance on these task was related to performance to various AB measures (Arnell, Howe, Joanisse & Klein, 2006).

Arnell et al. (2006) examined the performance of 64 undergraduate students on a classic AB task and measured the size of their individual ABs, overall T1 accuracy, and overall T2 accuracy. Participants also performed a single target RSVP detection task, and

a variety of cognitive tasks which all appeared to involve cognitive processes implicated in theoretical models of the AB. Participants performed vocal and manual reaction time (RT) tasks, in which speeded responses to single stimuli were examined and measured. These tasks were used as indicators of an individual's ability to rapidly process stimuli. A rapid naming task was also used in which participants named multiple items as quickly as possible, one after the other. Distracting information must be ignored, thus this task relates to one's ability to rapidly identify relevant information while ignoring irrelevant stimuli. A location probe task was also used, in which participants were required to report the identity of an item flashed at a subsequently cued location. Finally, a delayed speeded response task was used where an identification response was held until a tone was sounded in order to examine pure manual reaction time.

Interestingly, performance on all cognitive tasks, with the exception of the delayed RT task and the location probe task, significantly predicted T2 accuracy. T2 accuracy was higher for participants with faster multiple and single item naming times and faster manual RTs, and for participants with higher T1 accuracy in the AB task and better accuracy in the single-target detection task. None of the tasks, however, significantly predicted AB magnitude. This seems to indicate that while speed of information processing is important for overall T2 accuracy, the size of the actual blink is not necessarily determined by processing speed, and that other cognitive processes must be involved with the blink deficit other than simple processing speed.

Colzato, Spapé, Pannebakker, and Hommel (2007) were also interested in predicting individual differences in AB magnitude, and performed a study in which they examined working memory. Colzato et al. (2007) used Turner and Engle's (1989)

operation span task (OSPAN) to examine working memory capacity. The OSPAN requires participants to solve simple math problems while words are presented for later recall. The task calls for participants to read the math problems and their solution out loud, thus preventing verbal rehearsal of the to-be-remembered words. The active maintenance of words in memory without the benefit of rehearsal, while simultaneously working math problems in one's head is thought to be an excellent test of working memory ability. Colzato et al. (2007) found that working memory negatively predicted AB size, where individuals with a larger working memory had a smaller AB. This relationship was found to be significant over and above fluid intelligence as measured by the Raven's Standard Progressive Matrices (SPM). In contrast, Ravens score was not significantly related to AB magnitude, but higher fluid intelligence scores predicted higher overall T1 and T2 accuracy.

The finding that working memory scores predicted AB magnitude over and above fluid intelligence is important, as it allowed Colzato et al. (2007) to argue for the importance of working memory processes per se, as opposed to more general intellectual functioning. Colzato et al.'s study was the first individual differences study to provide evidence for performance on another cognitive task predicting AB magnitude. Colzato et al. (2007) argued that the executive control aspect of working memory was responsible for the relationship between OSPAN and AB performance. They suggest that executive control processes are related to the AB, such that AB deficits occur when an individual cannot effectively process, maintain, and manipulate multiple pieces of information at one time. However, Baddeley (1996) has posited that there are two separate components to WM: 1) a storage component that reflects the capacity of short-term memory, and 2) a

more dynamic executive control component that reflects the efficiency of handling information in working memory. It is not clear from the Colzato et al. (2007) study which aspect of working memory performance was related to AB size.

A study similar to Colzato et al.'s (2007) was recently completed in our own lab (Arnell, Stokes, Gicante & MacLean, in press). This study also used the OSPAN to examine working memory ability, Ravens SPM to examine fluid intelligence, and had individuals perform an AB task. In addition to these measures, Arnell and colleagues also administered digit-forward and digit-backwards digit span tasks from the WAIS to measure working memory capacity with a substantially reduced executive control component. These measures were included to test the hypothesis that the AB could simply be related to the storage capacity of the short term memory, rather than exclusively the working memory aspect, as indicated by Colzato et al. (2007). Arnell and colleagues again found that performance on the OSPAN task significantly predicted AB magnitude over and above general intelligence and forward and backward digit-span. Moreover, neither forward nor backward digit span predicted AB magnitude. These results support Colzato et al.'s (2007) conclusion that that short term memory capacity was not as important to the AB phenomenon as executive control of working memory.

Interestingly, a recent study on individual differences and the AB has revealed that participants' naturally occurring trait affect predicts AB magnitude (Maclean et al., accepted). Participants completed a trait affect questionnaire where they reported the degree to which an affective state (e.g., anger, happiness) was typical for them, and then completed a classic AB task. According to the Olivers and Nieuwenhuis (2006) overinvestment hypothesis, individuals who reported more positive dispositional affect

should be expected to have smaller ABs, as these individuals would be more likely to be in a diffuse attentional state. This hypothesis was supported such that greater positive trait affect significantly predicted smaller ABs, and greater negative trait affect significantly predicted larger ABs. This relationship occurred over and above T2 accuracy, indicating that affect modulates the AB per se, not just T2 performance overall. This is the first study on naturally occurring affect and the AB, and other similar studies in our lab have replicated these findings.

It is clear that individuals perform differently on a typical AB task, and that these differences can be modulated through the use of task manipulations. While we are beginning to understand that the differences in regular AB performance may be related to working memory ability, affect, or the amount of the attentional diffusion that is occurring during stimulus processing, we are still attempting to understand why individuals differ in AB magnitude. A recent set of studies examined a specialized group of individuals (video-game players) who have extremely efficient attentional processing on a variety of tasks (Green & Bavelier, 2003; 2006a; 2006b, 2007). A closer examination of some of the tasks used in these studies suggests a possible link between diffusion of attention and good attentional processing. The next section will examine these studies and measures in depth in order to further develop a link between diffusion of attention and individual differences in AB magnitude.

Video Game Players and Attentional Enhancement

Green and Bavelier: Video Game Experiments

When researchers examine distinct or specialized populations of individuals, they often look at groups of individuals with certain innate characteristics, such as age,

intelligence, or psychological disorders. However, individuals can also be grouped into distinct categories based on their life experiences or typical behaviours. A recent set of studies examined the attentional abilities of individuals who regularly play action video games (Green & Bavelier, 2003; 2006a, 2006b, 2007). These individuals were examined both because video game play is becoming quite prevalent in our society, and because frequent engagement in attentionally demanding tasks has previously been shown to alter attentional processing (Gopher, Weil, & Bareket, 1994). Green and Bavelier (2003) examined 8 action video game players (VGPs) and 8 non-video game players (NVGPs) on a variety of cognitive tasks which targeted various aspects of attentional ability. VGPs were defined as individuals who played action video games (e.g., first-person “shooter” games) for at least 4 days a week for a minimum of one hour per session over the past 6 months. NVGPs were individuals who had not played any action video games in the past year. The study had two purposes: to examine the attentional ability and efficiency of VGPs as compared to NVGPs, and to test whether or not these skills could be trained in NVGPs.

One of the cognitive tasks examined in Green and Bavelier’s (2003) first experiment was the flanker compatibility task. Their version of the flanker task required participants to press a key as quickly as possible indicating whether the target shape presented on each trial was a diamond or a square. This target was presented randomly in one of six placeholders that formed a ring. The other five placeholders were either empty (easy condition) or filled with various irrelevant distractor shapes (hard condition) which required a search of the placeholders (see Figure 5). A single large additional distractor was placed outside of the ring of distractors, and was either congruent with the target

(e.g., a square distractor with a square target) or incongruent with the target (e.g., a square distractor with a diamond target). Participants were instructed to ignore this additional distractor. The flanker task was designed to assess the interference of this irrelevant outside distractor on target detection reaction time (RT), by examining the difference in RT on congruent and incongruent trials (i.e. ‘the compatibility effect’). In typical individuals, easy trials with no inter-ring distractors demand little attention, thereby allowing the remaining attention to wander to the outside distractor, thus eliciting a large compatibility effect. On difficult trials, where there are many inter-ring distractors, participants are typically too busy trying to find the target to process the irrelevant distractor, thereby reducing interference from the outside distractor. Thus the flanker compatibility test is considered by many to be an excellent way to determine the amount of attentional resources at one’s disposal, because reductions in leftover attentional resources can be tracked with the reduction of the compatibility effect (e.g., Lavie, 1995).

Green and Bavelier’s (2003) study showed that for NVGPs the compatibility effect was present in the easy condition, but disappeared as the task became more difficult. This is the typical result that is found when using this task. For the VGPs, however, the compatibility effect was almost identical at both difficulty levels on the task, meaning that the outside distractor influenced target-detection RT regardless of task difficulty. Green and Bavelier concluded that VGPs had greater attentional capacity, showing that even when the task was very difficult and required much attention, the VGPs still had enough attention left over to process the irrelevant outside distractor. Alternately, VGPs may be able to take in more information across the display in an automatic and preattentive “first look” where automatic activations could be generated.

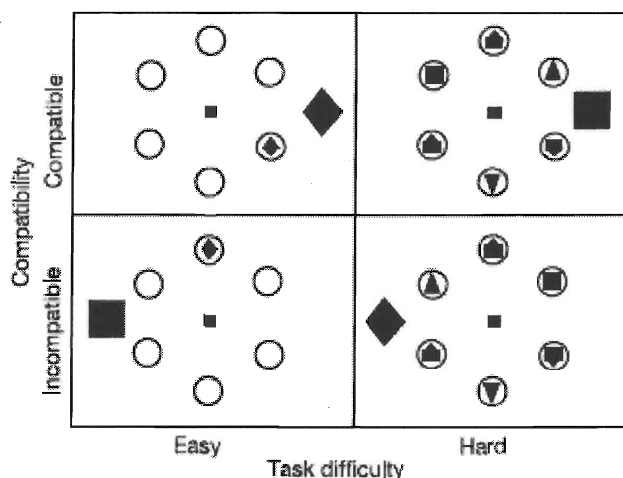


Figure 5: Modified Flanker Compatibility Task (from Green & Bavelier, 2003)

To test how much information the two groups could process in a glance, Green and Bavelier (2003) used an enumeration task. In this task 1 to 10 boxes are flashed on the screen for 50 ms, and participants are asked to indicate how many boxes were presented. When a small number of boxes are presented (1-3) most participants can automatically see how many boxes there are without having to count in their head (the ‘subitizing’ period – Beckwith & Restle, 1966). Typically participants have a low error rate at this level. However, once the number of boxes is increased to above 3, the error rate rapidly increases, indicating that the subitizing period has ended and that participants have now resorted to counting the number of boxes in their heads (the ‘counting’ period – Beckwith & Restle, 1966). In Green and Bavelier’s 2003 study, the NVGPs had near perfect accuracy until the number of boxes increased to an average of 3.3 and up. In contrast, the VGPs had extended subitizing periods which did not usually end until an average of 4.9 boxes was presented, and even thereafter had lower errors than the NVGPs (see Figure 6 for results). This indicates that VGPs were able to know almost instantly how many boxes were presented without having to actively count, even at display sizes of

4 or 5 items – about 2 items more than the NVGPs. As the enumeration task is thought to reflect the number of objects or items which can be immediately perceived, it appears that VGPs have better capacity for preattentively itemizing multiple objects.

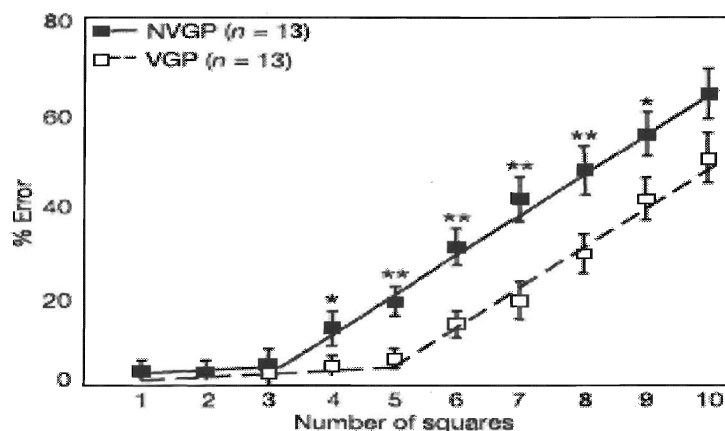


Figure 6: Performance of VGPs and NVGPs on an Enumeration Task (Green & Bavelier, 2003)

It is possible that VGPs may only have enhanced abilities for objects immediately within their line of sight. To examine this, a Useful Field of View (UFOV) task was administered which examines an individual's ability to perceive objects both centrally and peripherally. In this task, 8 "spokes" were presented on the screen and a target was briefly presented 10, 20 or 30 degrees from central fixation (eccentricity), after which the display immediately was masked by an assortment of shapes (see Figure 7 for example). Participants were asked to report on which numbered spoke the target was presented. This task is used to examine attentional efficiency for different spatial eccentricities. They found that the VGPs were not only able to detect the target about 80% of the time, but eccentricity did not influence reporting accuracy. In contrast, the NVGPs had extremely poor accuracy (about 30-40%) at all eccentricities. This indicates that not only are VGPs able to quickly localize a target, but their enhanced abilities appear both centrally and in the periphery.

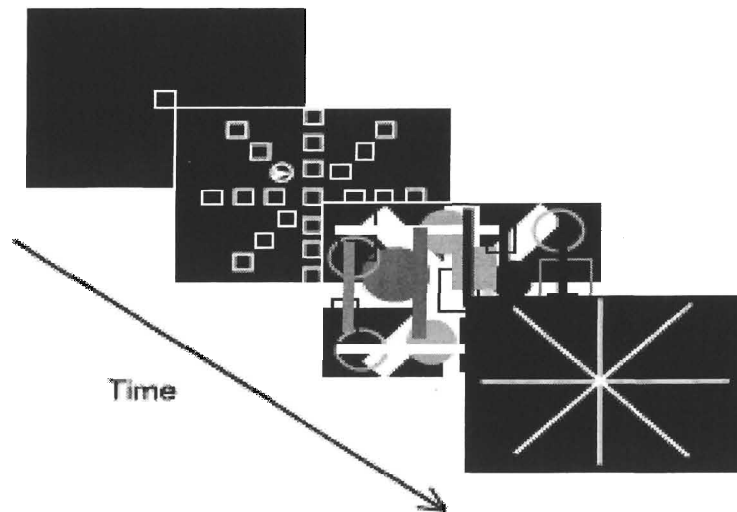


Figure 7: Sample UFOV Task (Green & Bavelier, 2003)

The previous three experiments all examined spatial attention abilities. Green and Bavelier (2003) also examined a test of temporal attention—the AB. They administered a standard AB task which involved the identification of a lone white T1 letter and the detection of T2 (a black X). Overall, VGPs had significantly better T2 detection accuracy than NVGPs, and a greatly attenuated AB. This result led Green and Bavelier to conclude that not only do VGPs have better spatial attention, they also have superior temporal attentional abilities. However, Green and Bavelier did not examine whether AB performance was related to performance on any of the other cognitive tasks.

The final experiment in Green and Bavelier’s 2003 study tested the extent to which participants could be trained on the tasks used in the above experiment. They took 17 NVGPs and divided them into an action video game training group (action) and a non-action video game training group (control). The action group was trained for 10 hours on an active first-person shooting game which involved active scanning of the screen and the ability to quickly react to both central and peripheral stimuli, whereas the control group trained for 10 hours on a non-active, focused puzzle game which required little

attentional switching or active scanning. When the two groups completed the four cognitive tasks previously mentioned, the action group consistently and significantly differed from the control group on all tasks. Indeed, their performance began to approximate that of the VGPs used in the previous experiments, indicating that limited training could influence spatial and temporal attention. This result is important both because it shows that these abilities can be trained, but also because they show that the VGPs used in the previous study were not a self-selecting group drawn to video games because of their cognitive abilities, but rather developed these abilities as a result of frequent game play.

To follow-up their previous results, Green and Bavelier (2006a) again examined the performance of VGPs and NVGPs on an enumeration task. As before, VGPs were significantly better at the task, with performance near ceiling for presentations of up to 5 squares, as compared to the NVGPs. To further examine this ability, a Multiple Object Tracking (MOT) test was used. This test requires participants to track multiple targets (typically circles) for several seconds as they move in unpredictable paths around the screen amidst identical moving distractors. At the end of the trial one circle is highlighted and participants indicate whether or not it was a target. The MOT test assesses the ability to allocate attention to multiple targets, and sustain this attention for several seconds under changing conditions. They found that VGPs were significantly more accurate than NVGPs at tracking up to 7 targets at once, and that their pattern of accuracy as the number of targets increased was similar to their pattern of accuracy on the enumeration task, with the greatest differences between the two experimental groups falling within the 3-5 target item range (when the subitizing period differs for the two groups). These

results conclusively show that VGPs not only show better automatic individuation of multiple objects, but also better sustaining and updating these for several seconds.

Green and Bavelier (2006b) also revisited the flanker compatibility task, changing it so that outside distractors were either presented centrally near the targets, or peripherally away from the targets. As expected, VGPs were still more influenced by the irrelevant distractors than NVGPs regardless of spatial location, suggesting that VGPs are also better at allocating attention to multiple spatial locations across a display even under conditions of high attentional load. In order to further investigate this finding, a UFOV test was once again administered. As before, VGPs were better at locating targets regardless of spatial eccentricity.

The previous three studies have demonstrated two main things: VGPs are significantly better at allocating attention to multiple stimuli, and that these enhanced abilities are not specific to central or peripheral regions of the visual field. However, it was still under debate whether these changes are strategic, meaning that for these specific types of tests the VGPs have developed good strategies, or if some underlying mechanism of spatial processing has actually been altered. To examine this, Green and Bavelier (2007) used a crowding paradigm. The crowding effect occurs when objects are spatially close to a target, therefore making it difficult to separate the target from the other stimuli. In the crowding paradigm, upside-down T-shaped targets are presented which are surrounded by right-side-up T-shaped distractors, with the distractors either presented very close to the target, or further away. Participant's individual "crowding zones" are then calculated, which measure the eccentricity at which target-distractor discrimination becomes difficult. This paradigm is essentially a test of spatial resolution,

meaning that it measures the ability to finely discriminate amongst multiple stimuli. Using this paradigm, Green and Bavelier (2007) were able to show that VGPs had much smaller crowding zones than did NVGPs, indicating that they have very high spatial resolution. While this is interesting in itself, it also demonstrates convincingly that the benefits enjoyed by VGPs are the result of real alterations to their visuo-spatial processing.

Related Video Gaming Studies

While the focus thus far has been on the studies conducted by Green and Bavelier, other researchers have found similar attentional benefits for VGPs. Castel, Pratt and Drummond (2005) administered a visual search task to VGPs and NVGPs which required them to quickly report the presence or absence of a target imbedded within an array of distractors. In a visual search task requiring serial search, as the number of distractors increases, RT to find the target increases. In addition, when distractors and targets are highly similar, therefore increasing task difficulty, the search slope becomes steeper (Castel et al., 2005; Wolfe, 1998). When action VGPs were administered the visual search task, their RT was significantly lower than NVGPs at all difficulty levels, although the RT slopes were similar for both groups. These results are consistent with Green and Bavelier's pattern of results in that they suggest that VGPs do not have better item-by-item serial attention than NVGPs (as revealed by the fact that VGP and NVGPs slopes are the same in both visual search and the counting phase of the enumeration task). However, VGPs do seem to take in more information than their NVGP counterparts in an automatic preattentive visual scan of the scene, and this information, although likely

implicit, appears to be able to direct attention to critical information at all eccentricities in the visual scene.

Trick, Jaspers-Fayer, and Sethi (2005) examined multiple-object tracking in four different groups of participants: VGPs, NVGPs, players of dynamic fast changing sports (e.g., soccer), and players of less dynamic more static sports (e.g., rowing). Participants were further divided into five age groups (6, 8, 10, 12, and 19 years of age). The participants completed a modified MOT test in which they were instructed to track the “spies” (targets) who had hidden in a field of “decoys” (distractors). As in Green and Bavelier (2006a), Trick et al. (2005) found that when age was controlled for, participants who played action video games were significantly better on the MOT test than NVGPs. In addition, they found that children who played active dynamic sports, particularly those who required a high degree of attentional awareness, were also significantly better on the MOT test than those who were not involved in active dynamic sports, although to a lesser degree. This is further evidence for enhanced visuo-spatial attention in groups who regularly need to keep track of multiple dynamic sources of information.

It is clear that individuals who engage in regular video game play have enhanced visuo-spatial attention and/or preattentive processing that effectively guides attention, and that this benefit can be observed using many different paradigms. Researchers are beginning to develop an understanding of the underlying mechanisms which may be involved with this improvement, as it appears that multiple aspects of visuo-spatial attention have been altered, but much work remains to fully understand this phenomenon. Across the range of tasks, VGPs appear to have a superior ability to automatically extract information across the whole display in a parallel preattentive processing stage.

Interestingly, this ability may result from the diffusion of attention, and the patterns shown by VGPs could be interpreted as reflecting diffuse attention.

As was discussed in the previous section, it has been hypothesised that during AB tasks, individuals overinvest their attentional resources on T1 or distractors (Olivers and Nieuwenhuis, 2005; 2006). This overinvestment is typically unnecessary, and prevents T2 from receiving adequate attention. When attention is diffused, only the necessary attentional resources are allocated to other items in the stream, and T2 performance improves. It is possible that these VGPs, through training, have successfully been able to diffuse their attention, preventing overinvestment of their attentional resources, thus allowing them to achieve maximum processing efficiency in the AB task as well as other attention tasks. This potential link between diffusion of attention and attentional performance benefits is discussed below for tasks used by Green and Bavelier, as well as three other attention tasks where the amount of attentional diffusion could influence task performance and could seemingly be measured.

Diffusion of Attention and Cognitive Tasks

Diffusion in VGP Tasks

Flanker Compatibility. The flanker compatibility task is often taken as a measure of cognitive or executive control where greater flanker interference is linked to a reduction of cognitive control (e.g., Heitz & Engle, 2007). However, results showing that perceptual load during the task can modulate the amount of flanker interference, with greater interference with lower perceptual loads, has led some researchers to suggest that flanker interference reflects the amount of attention left over after the primary task (perceptual load theory, e.g., Lavie, 1995). Green and Bavelier (2003; 2006b) have

shown that for VGPs an irrelevant distractor affects target identification RTs regardless of task difficulty. They interpret this to mean that their participants had greater attentional resources at their disposal, and thus had more resources remaining in the difficult condition to process the external distractor. Lavie (1995) first showed that when participants focus their attention, the external distractor tends to receive less processing, thus it does not affect their target RT. An easier, perhaps more diffused, approach leads to greater distractor processing, and thus more interference. Although perhaps not necessarily beneficial, VGPs may diffuse rather than focus their attention when performing a flanker task, leading to the distractor interference noted earlier.

Enumeration. Enumeration involves the ability to process how many items are presented in a display in a very brief period of time (Trick & Pylyshyn, 1993; 1994). Enumeration studies typically yield two different types of processing, depending on the number of targets presented in the task. When an average of 3-4 items are presented, participants typically know automatically how many items there were---a phase known as subitizing. During this phase participants generally make few if any estimation errors. It is thought that the subitizing period may reflect the capacity of preattentive, automatic processing (Tuholski, Engle & Baylis, 2001). When an average of 4 or more items are presented, participants can no longer 'know' how many items there were, and must resort to counting the items in their head---the counting phase. This phase is thought to be under conscious attentional control, and is characterized by a steady increase in estimation errors (Trick & Pylyshyn, 1994). Some studies have found that over-allocation of attention to small numbers of items can disrupt the subitizing phase, and lead to estimation errors (Trick & Pylyshyn, 1993). Trick and Pylyshyn (1993) found that when

participants focus on the features of items that are usually subitized, this automatic process is disrupted, thus leading to poor performance on the task. As the subitizing phase is thought to be preattentive, focussing attention in an enumeration task leads to greater costs than if targets were allowed to undergo automatic processing.

In past studies VGPs have been shown to have extended subitizing periods, and fewer estimation errors during the counting phase than NVGPs, but VGPs and NGVPs show the same slope across number of items once both groups are in the counting phase (Green & Bavelier, 2003). It is possible that with video game practice VGPs come to hone their diffusion of attention and the fast and preattentive processing stage that processes the array in parallel. This may effectively distribute their attentional resources, extending their subitizing period past that of average individuals and allowing them to better estimate overall item numbers based on the preattentive scan. However, once in the serial step-by-step counting phase, the efficiency of the counting appears to be the same for both groups. Of course, the extended subitizing period may be the result of some other altered cognitive process, but diffusion of attention may play a role. No known studies have examined this directly, but it is possible that the overinvestment hypothesis of attention may help explain the group performance differences on the enumeration task.

Useful Field of View (UFOV). The UFOV test, as previously noted, is designed to assess the ability to perceive stimuli both centrally and peripherally, and primarily tests spatial processing (Ball & Rebok, 1994). In recent years the UFOV task has been used extensively to examine driving performance in older adults in order to examine their ability to scan a large visual field and react to specific cues (Ball & Rebok, 1994). Ball and Rebok (1994) have found that above all other tests of visual acuity, the UFOV test is

the best predictor of driving performance. Ball and colleagues believe that the UFOV taps into preattentive processing, in which one automatically and passively scans the visual field for targets. In the studies conducted by Green and Bavelier (2003; 2006b) VGPs performed better than NVGPs on the UFOV task at all eccentricities, suggesting that VGPs had superior preattentive automatic scanning of the visual field. It is possible that this performance is a result of a more diffuse or passive attentional state, thereby allowing the VGPs to take in all areas of the visual field, rather than over-focusing on any one section. It seems that good performance on the UFOV task might reflect good diffusion of attention, as poor UFOV performance suggests an inability to effectively divide attention.

Diffusion in non-VGP Tasks

Visual Search. As briefly described earlier, in visual search tasks participants search for a pre-specified target from within an array of distractors. Reaction time to detect or identify the target is usually measured, as well as the number of detection errors that are incurred. Typically when the number of distractors increases, the RT is longer, thus the search slope across the number of distractors gives a measure of “search efficiency” (Wolfe, 1998). In addition, the slope becomes steeper when targets and distractors have similar features and are not highly distinguishable (Wolfe, 1998). Recent studies, however, are beginning to show that cognitive strategy while performing a visual search task is an excellent indicator of individual search efficiency (Smilek, Enns, Eastwood, & Merikle, 2006).

Smilek et al. (2006) instructed half of their participants to perform a typical visual search task using an active search strategy, which involved actively scanning for

the targets in the array. The other half of the participants were told to adopt a passive search style, in which they were told to “allow the target to come to them”. Interestingly, when the visual search task was made difficult, such that target-distractor independence was minimal, participants who adopted a passive search style had significantly flattened search slopes, as compared to the active group. Passive searchers also had less error than active searchers. Smilek et al. (2006) propose that diffusion of attention was responsible for the passive searcher’s performance, and relate their findings to Olivers and Nieuwenhuis’s 2005 study on additional task benefit and the AB discussed earlier. Given that efficient visual search appears to be related to attentional diffusion, and good AB performance appears to be related to attentional diffusion, it follows that performance on a visual search task may relate to performance on an AB task.

Posner Cueing Paradigm. Posner’s spatial cueing paradigm presents either endogenous (central) or exogenous (peripheral) cues to participants, which allow them to orient their attention to the likely location of a peripherally presented target (Posner, Snyder & Davidson, 1980; Prinzmetal, Presti & Posner, 1986). The cues are either valid (correctly directing the participant’s attention), neutral (not directing the participant’s attention), or invalid (misdirecting the participant’s attention). Reaction time to detect the target is measured. Typically, participants show faster RTs (benefits) from using the cues on valid trials as compared to neutral trials, and slower RTs (costs) from using the cues on invalid trials as compared to neutral trials (Posner et al., 1980). However, this only appears to be the case when participants focus attention in a specified area that is directed by the cues.

Past studies show that when participants are able to diffuse their attention across the display, thus effectively ignoring the cues, costs and benefits are reduced, and average RT is better than if the cues are actively used (Posner et al., 1980). Experts in visual attention, such as the VGPs in Green and Bavelier's studies, appear to use a more diffused attentional strategy when performing a spatial cueing task (Pesce & Bosel, 2001). For example, using elite volleyball players, Pesce and Bosel (2001) were able to show that RTs for the three different cue conditions were nearly identical, as compared to the control group, all of whom showed the classic pattern of significant costs and benefits. This seems to suggest that certain individuals with highly developed visuo-spatial skills can adopt a diffuse state of attention, which in many cases is beneficial. By not over-allocating their attentional resources to the cues, these experts are able to circumvent the pitfalls associated with invalid cues, and adopt a rather defensive strategy where they will not get the big benefits, but where they will avoid the big costs. Other studies have similarly shown that adopting this diffused state of attention is beneficial when performing a spatial cueing task (e.g. Prinzmetal et al., 1986; Goldsmith & Yeari, 2003).

Stroop. The classic Stroop paradigm requires participants to rapidly name the ink colour of presented words, while ignoring the word meaning and identity. On some proportion of trials, the words are colour names which are incongruent with their ink colour (e.g. the word red printed in green ink). As word reading is thought to be an automatic process, it is very difficult for individuals to avoid reading the colour name. Therefore, on incongruent trials RTs are considerably longer than neutral (e.g., the word table in green ink) or congruent (e.g., the word green in green ink) trials for most

individuals (Stroop, 1935; Macleod, 1991). Interestingly, a recent set of studies have shown that in individuals who are susceptible to hypnosis, the Stroop effect can be attenuated or eliminated simply by suggesting during hypnosis that they no longer have the ability to read (Raz, Shapiro, Fan & Posner, 2002; Macleod & Sheehan, 2003).

Raz et al. (2002) administered a classic ink naming Stroop task to 16 individuals who were deemed to be highly suggestible to hypnosis, and 16 non-suggestible participants. Participants were given the suggestion that they no longer could read and that presented words would be perceived as a jumble of symbols. Results showed that individuals who were high in hypnotic suggestibility had significantly less Stroop interference (difference between neutral and incongruent RTs) as compared to controls. The authors conclude that these highly suggestible individuals were able to modulate the presumably automatic process of reading, thus eliminating the Stroop effect. The authors suggest that hypnosis allows individuals to “tune” their attention to specific items in a task, therefore the participants in Raz et al.’s (2002) study were able to perform better on the Stroop task by focusing on not reading the words in the task. A study by Macleod and Sheehan (2003) were able to replicate this effect, and also suggest that focus of attention can aid in eliminating Stroop interference.

In terms of the AB, it would be interesting to see how Stroop performance relates to AB magnitude. If a focused strategy leads to better performance on the Stroop task, it would follow that less Stroop interference may predict larger AB size. Conversely, greater interference in the Stroop task may relate to diffusion of attention, and thus smaller ABs.

Global/Local Task. The global/local task is a classic paradigm used to examine focus and diffusion of attention (Navon, 1977). This task typically presents participants with Navon stimuli, large letters/shapes/objects made up of smaller letters/shapes/objects (see Figure 8 for sample), and asks the participants to report either the large global or the small local elements as rapidly as possible. Navon's global precedence hypothesis proposes that individuals will preferentially process the global stimuli in a scene, thus most individuals are particularly susceptible to intrusions of the global stimuli on trials in which they are to report local stimuli (Navon, 1977). However, some individuals show a more local bias, such as individuals from collectivist cultures (Davidoff, Fonteneau, & Fagot, 2008), musicians (Stoesz, Jakobson, Kilgour, & Lewycky, 2007), individuals with obsessive-compulsive disorder (Moritz, & Wendt, 2006) and individuals with autism (Scherf, Luna, Kimchi, Minshew, & Behrmann, 2008). As such, this task gives a good indication of participants' global or local bias.

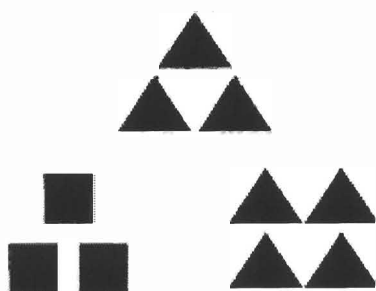


Figure 8. Sample Navon stimuli (from Frederickson & Branigan, 2005).

Recently, researchers have begun to examine individual differences in global/local processing and affect. Gasper and Clore (2002) examined whether naturally occurring affective state could influence participants bias towards global processing of stimuli. Participants were asked to report their current mood state, then were given a

target object and asked to report which of two sample figures most represented the presented target. The sample figures were Navon figures which consisted of both global and local parts. Gasper and Clore (2002) found that individuals who reported happier mood states were significantly more likely to compare the target figure to global aspects of the sample figures, and individuals who reported sad moods were significantly more likely to report local aspects of the sample figures. Frederickson and Branigan (2005) later replicated this result in a study which induced a spectrum of affective states in the participants (specifically amused, content, neutral, angry and anxious), and suggested that affect can influence the degree to which an individual focuses or diffuses their attention.

A recent study used the global/local task with the AB paradigm (Crewther, Lawson, & Crewther, 2007). This study used Navon stimuli as targets and distractors within the AB task, and asked participants to either attend to the global or local features of the targets. They found that the duration of the AB was significantly longer for trials in which participants were asked to focus on the local features as compared to global features, and proposed that individuals were able to process global stimuli more efficiently. This study did not examine dispositional focus or diffusion of attention, but it does provide evidence that a global or diffused attentional state could potentially help attenuate the AB. Thus individual diffusion or focus of attention as measured by the global/local task may relate to performance on the AB task.

Current Study

In an effort to understand the AB more completely, researchers have just begun to examine which variables can predict individual differences in AB magnitude. Thus far, only self-reported positive/negative trait affect and working memory score have been

predictive of the size of an individual's AB. Positive affect has been shown to predict smaller AB magnitude (MacLean et al., in press; Olivers & Nieuwenhuis, 2006), and has been suggested to result in a diffused attentional state (Fredrickson, 2001; Olivers & Nieuwenhuis, 2006). Diffusion of attention via an additional task (Olivers & Nieuwenhuis, 2005, 2006) or a concurrent diffusing perceptual display (Arend et al., 2006) has also been shown to reduce the AB. The overinvestment hypothesis of Olivers and Nieuwenhuis (2005, 2006) posits that diffusion of attention reduces the typical overinvestment of attention to T1 and distractors in the AB paradigm, leaving more attention for T2, thereby reducing the AB.

Green and Bavelier (2003, 2006a) showed that VGPs not only have a smaller AB than NVGPs, but that they perform better on several other cognitive tasks. This naturally lead to the question of whether individual differences in AB magnitude could be predicted by individual performance differences on these other tasks (UFOV, flanker compatibility, and enumeration). The pattern of performance shown by VGPs on these tasks is consistent with these individuals having greater diffusion of attention than NVGPs. Additional tasks not used in the Green and Bavelier studies also appear to be related to the ability to focus or diffuse attention, and have been linked to performance in video game players (e.g., Castle et al., 2005) or athletes in dynamic sports (e.g., Pesce & Bosel., 2001; Trick et al., 2005). As the ability to diffuse attention appears to be negatively related to AB magnitude (Arend et al., 2006; Olivers and Nieuwenhuis, 2005; 2006), it followed that individual performance differences on the above mentioned tasks may predict individual differences in the size of the AB.

Relationships between AB Performance and Performance on Other Cognitive Tasks

The main goal of the present study was to examine whether individual performance differences on the global/local, UFOV, enumeration, flanker, visual search, Stroop and Posner spatial cueing tasks could predict individual differences in AB magnitude, T2 accuracy, T1 accuracy and lag-1 sparing in the AB task. Specifically, the following relationships were hypothesized:

1. Globally biased processing has been associated with greater diffusion of attention, thus global interference (the amount of interference from global items while performing the local task) should negatively relate to AB magnitude, and local interference (the amount of interference from local items while performing the global task) should positively relate to AB magnitude. In addition, global precedence (global interference – local interference) should negatively relate to AB magnitude, such that greater global precedence scores should relate to smaller AB magnitude.

2. Diffusion of attention has been linked to greater processing of flankers in the flanker compatibility task, and reduced AB magnitude in the AB task, therefore the flanker compatibility effect (RT difference for incompatible minus compatible trials) should negatively relate to AB magnitude. All groups show a compatibility effect on easy trials. VGPs who may be proficient at diffusing attention show a large compatibility effect even on difficult trials, whereas non-VGPs individuals do not. Therefore, I also hypothesised that the difference in amount of flanker interference for easy minus difficult trials should positively relate to AB magnitude, such that individuals who were not as affected by task difficulty levels were expected to have smaller ABs.

3. On the enumeration task, AB magnitude should be negatively related both to overall accuracy in the counting phase, and to duration of the subitizing period.

Individuals who diffuse their attention may have the ability to preattentively and automatically individuate larger numbers of stimuli as compared to individuals who focus, because of superior automatic preattentive processing, as highlighted by the Trick and Pylyshyn (1993) study. This diffusion should allow better overall estimations in the counting period, and longer subitizing periods.

4. Overall accuracy on the UFOV task should negatively relate to AB magnitude as diffused individuals appear to have superior automatic preattentive processing that can be used to guide attention to relevant targets. Individuals who naturally use a diffused attentional strategy will not focus in at any one eccentricity, or spatial location, thus increasing their chances of correctly responding, regardless of eccentricity. Individuals who tend to over-focus usually have smaller UFOVs and thus larger eccentricity costs because they focus in on one area of the visual field, rather than scanning the entire field. Therefore the difference in accuracy for the furthest and closest eccentricities (eccentricity cost) should also relate to AB magnitude, but in a positive direction.

5. In the visual search paradigm, RT should be positively related to AB magnitude. Individuals who are able to diffuse their attention appear to be better at using preattentive information from across the display to guide their attention to target locations, as suggested by findings with VGPs in the UFOV and visual search tasks of Green and Bavelier (2003) and Castel et al. (2005). This should allow individuals with diffused attention to have faster target detection RTs in visual search, and smaller AB magnitudes. RT at the smallest distractor size was used here to avoid confounds with

search slope. The slope of the RTs across the number of distractors in the visual search task was hypothesised to positively relate to AB magnitude given that Smilek et al. (2005) observed shallower search slopes with diffuse instructions versus focus instructions, and diffuse attention predicts less AB. However, Castel et al. (2005) showed that although VGPs have faster overall RTs in a visual search task than NVGPs, the slope of the RT function across number of distractors did not differ. Smilek et al. observed the change in slope for the two groups only for difficult search arrays where targets and distractors were quite similar. Therefore, it was possible that visual search slopes would only be influenced by diffusion in difficult search conditions.

6. The magnitude of costs (invalid-neutral RTs) and benefits (neutral-valid RTs) on the Posner cueing task should positively relate to AB magnitude. Individuals with fewer costs and benefits tend to have not used, or been influenced by the cues, suggesting a diffused, unfocused attentional state which has been shown to be beneficial in reducing the AB.

7. For the Stroop task, Stroop interference (as measured by the RT difference between incongruent and neutral trials) was hypothesised to negatively relate to AB magnitude, such that individuals with greater Stroop interference would have smaller ABs. As shown with the hypnosis studies (Raz et al., 2002; Macleod & Sheehan, 2003), greater focus of attention is related to less Stroop interference, and as shown with the enumeration study, participants in a diffuse state may be more susceptible to the Stroop effect, because they are not focusing their attention on the colour and allow automatic processes to take over.

Predicting RSVP Target Accuracy

In addition to AB magnitude, it was also interesting to examine the relationships among the measures used in this experiment, and target (T1 and T2) accuracy in the AB task. Arnell et al. (2006) showed that many measures of cognitive processing speed are related significantly to target accuracy, but not to AB magnitude. There are three specific measures which I expected would relate to T1 and T2 accuracy in the AB task:

1. Both the enumeration task and the UFOV task present information for a very brief period, and accuracy of report is the dependent variable. Individuals who have faster processing speed and can take in the visual information more quickly would presumably perform better on such tasks. These individuals would then be expected to have longer subitizing periods, and higher accuracy in the counting phase for the enumeration task, and greater overall accuracy in the UFOV task. Performance on RSVP targets is similar in that targets are presented briefly and then masked by trailing distractors requiring rapid extraction of relevant visual information. Therefore, subitizing period duration, accuracy at the counting phase, and overall UFOV accuracy were hypothesized to be positively related to target accuracy in the AB task.

2. For many of the cognitive tasks I used derived RT measures, such as RT slope or RT difference scores, to examine relationships with AB magnitude. However, processing speed, in the form of the neutral, baseline, or overall RT for each task, was also examined for the global/local, flanker, visual search, Posner cueing, and Stroop tasks. In the study by Arnell et al. (2006), naming times and manual RTs to identify lone stimuli were significantly negatively related to target accuracy in RSVP, but not to AB magnitude. Thus it was hypothesized that processing speed, as measured by baseline or

overall RT on the above tasks, would also relate to T1 and T2 accuracy in the AB task, but not to AB magnitude.

I also examined the relationship for each of the cognitive performance measures with the amount of lag-1 sparing for each participant, but had no specific predictions about what relationships would be observed.

In addition to performing zero-order correlations to examine all of the relationships hypothesized above, correlations between predictor measures were also examined. Four simultaneous multiple regressions were also performed (with AB magnitude, T1 accuracy, T2 sensitivity, and lag-1 sparing as the four separate criterion measures). For each of the regressions all of the significant zero-order predictors of that criterion were examined together as simultaneous predictors in order to examine whether the predictors explain unique or overlapping variability in AB performance.

Relationships Among Cognitive Task Performance and Affect

This study also examined how state and trait affect could influence AB magnitude, lag-1 sparing, T1 and T2 accuracy in the AB task, and performance measures from the other cognitive tasks. Previous studies have shown that positive affect is related to smaller ABs (MacLean et al., in press ; Olivers and Nieuwenhuis, 2006), whereas negative affect is related to larger ABs (MacLean et al, in press; Rokke et al., 2002). These patterns were predicted here for both state and trait affect measures. More generally, positive affect has been linked to diffusion of attention (Fredrickson, 2001; Rowe et al., 2007) and negative affect to focusing of attention (Compton, 2000; Rowe et al., 2007). Correlations were examined between state and trait measures of positive affect and negative affect and each of the cognitive performance measures mentioned above. I

hypothesized that positive affect would be linked with cognitive performance patterns that reflect diffusion of attention (i.e., global interference or precedence on the global/local task, greater interference on flanker tasks, fewer costs and benefits on the Posner cueing task, shallower visual search slopes, and better UFOV and enumeration performance). I also hypothesized that negative affect would be associated with cognitive performance patterns that reflect focusing of attention (i.e., local interference on the global/local task, less interference on flanker tasks, more costs and benefits on the Posner cueing task, steeper visual search slopes, and lower UFOV and enumeration performance).

Relationships Among Cognitive Task Performance and Personality

The relationship between personality factors and the AB was also examined in this study. Individual personality differences may be related to the amount of attention one devotes to a task, as well as the participant's self-reported affect. Although all of the big-5 dimensions of personality (Costa & McCrae, 1992) were measured (extraversion, neuroticism, agreeableness, conscientiousness, and openness to experience), I was interested specifically in examining the personality dimensions of conscientiousness, neuroticism and extraversion. Previous research shows that conscientious individuals are more likely to be careful in their decisions, and more likely to focus on the task at hand (Costa & McCrae, 1992). Thus, it was expected that higher scores on the conscientiousness factor would be related to larger AB magnitude, simply because it is possible that conscientious individuals may focus too intensely on the AB task, when a diffused approach is typically more beneficial. Conscientiousness was also hypothesized to be positively related to cognitive performance patterns that reflect focusing of attention

(i.e., local interference on the global/local task, less interference on flanker tasks, more costs and benefits on the Posner cueing task, steeper visual search slopes, and lower UFOV and enumeration performance).

I expected individuals who scored highly on the neuroticism scale to have larger ABs, because I expected that they would be so concerned with missing targets that they would overinvest their attention to distractors and T1, thus causing T2 deficits at short lags. Neurotic individuals have a tendency to become anxious when presented with a challenge, and tend to over-think their strategies when performing difficult tasks (Costa & McCrae, 1992). Neuroticism has also been linked to negative affect (Costa & McCrae, 1992; Uziel, 2006) which is associated with larger AB magnitude (MacLean et al, in press; Rokke et al, 2002). As discussed previously, a diffused and open approach, in addition to positive affect is optimal for good AB performance, therefore I predicted that neurotic individuals would have larger ABs. Neuroticism was also hypothesized to be positively related to cognitive performance patterns that reflect focusing of attention (i.e., local interference on the global/local task, less interference on flanker tasks, more costs and benefits on the Posner cueing task, steeper visual search slopes, and lower UFOV and enumeration performance).

Extraversion has been found to relate to positive affect (Yik & Russell, 2001; Shiota, Keltner, & John, 2006; Uziel, 2006), therefore I expected a negative relationship between extraversion and AB magnitude. Extraversion was also hypothesized to be related to cognitive performance patterns that reflect diffusion of attention (i.e., global interference of global precedence on the global/local task, greater interference on flanker

tasks, fewer costs and benefits on the Posner cueing task, shallower visual search slopes, and better UFOV and enumeration performance).

Lastly, I also examined relationships between the “agreeableness” and “openness to experience” personality factors and AB magnitude, as well as each of the five personality dimensions and T1 and T2 accuracy and lag-1 sparing in the AB tasks. However, no specific hypotheses were made for these relationships. As well, I investigated how each of the personality dimensions related to positive and negative affect, and how each of the five personality dimensions related to performance measures on the other cognitive tasks.

Method

Participants

Ninety-eight undergraduate student volunteers from Brock University participated in this study. Participants were recruited through the Brock University psychology online experiment site. Participants were between the ages of 17 and 30 ($M = 19.9$, $SD = 1.91$), and 66 of the participants were female. Participants older than 30 tend to show age-related deficits on many of the tasks used in this study, and these deficits could potentially have interfered with the expected pattern of results (e.g. Georgiou-Karistianis et al., 2006; Lahar et al., 2001), thus participants older than 30 years of age were not permitted to participate in this study. Participants were to have learned English before the age of 8 as some tasks presented alphanumeric material that required early and consistent exposure to English in order to show the predicted pattern of results. All participants had normal or corrected-to-normal vision, no self-reported colour blindness, and no motor movement problems with the fingers of either hand. Visual acuity was measured using a

standard Snellen eye chart. Participants were required to successfully read the letters on the eye chart to the 20/20 vision line with less than 3 mistakes. If participants had more than three mistakes, they received a half-hour's worth of pay (\$5) and did not continue with the experiment. Participants were individually tested, and testing took approximately 2 hours per participant. Participants were remunerated either \$20 for their participation, or up to 2 hours of research participation hours towards a participating psychology course at Brock University.

Apparatus and Materials

All computer tasks were presented using E-Prime software (Schneider, Eschman, & Zuccolotto, 2002) on a Dell desktop computer with a 17-inch CRT monitor. All responses in the computer tasks were made via button press on the computer keyboard. Participants performed all tasks in a small dimly-lit testing room within the Attention Laboratory at Brock University with minimal outside distractions.

Personality Questionnaire: Modified NEO-PI. A modified version of the NEO-PI personality questionnaire (Costa & McCrae 1992) was used to assess all five dimensions of the Big-5 model of personality (see Appendix A). This questionnaire is paper-based, and contains 50 questions, 10 for each of the five personality factors (openness to experience, conscientiousness, extraversion, agreeableness, and neuroticism). Half of the questions are reverse keyed in order to prevent acquiescence bias. Participants answered each question using a 5-point likert scale, based on the degree to which they feel each item in the questionnaire corresponded to their own behaviours (1= very inaccurate; 5 = very accurate).

To score the personality questionnaire, all reverse keyed items were first transposed, after which the scores on questions for each personality factor were added individually for each participant. Thus each participant had five different scores, one for each of the five personality factors assessed by this measure. Personality was assessed on a continuum, with higher scores on a factor indicating higher levels of that trait.

Trait Affect Measure. The trait affect questionnaire was a modified version of the Positive and Negative Affect Schedule (PANAS) (Watson, Clark & Tellegen, 1988; see Appendix A). The PANAS consists of a list of 20 adjectives used to describe different affective states (e.g., happy, angry, bored, etc.). Ten of the items are part of the positive affect subscale and ten are part of the negative affect subscale. In the version used here an additional focus item (“focused”), and three additional diffusion items (“bored”, “relaxed”, and “sleepy”) also appeared on the PANAS. Participants were asked to rate the extent to which they generally experience each mood using a 9-point likert scale (0 = not at all; 8 = very much).

State Affect Measure. The Emotion Report Form (ERF) (Fredrickson, 2001, see Appendix A) was used to measure state affect. The ERF traditionally consists of 5 positive affect items and 5 negative affect items. In the version used here, an additional 3 focus items (“focused”, “attentive”, and “interest”) and 3 diffusion items (“bored”, “relaxed”, and “sleepiness”) also appeared on the ERF. Participants were asked to rate each item on a scale from 1 (“not at all”) to 8 (“a great deal”) depending on how they felt at that moment.

Both affect questionnaires yielded scores of positive affect and negative affect. Each of these were calculated by adding the ratings for adjectives from the given affect

category individually for each participant. For the PANAS, positive items included “interested”, “excited”, “strong”, “enthusiastic”, “proud”, “alert”, “inspired”, “determined”, “attentive”, and “active”. Negative items included “distressed”, “upset”, “guilty”, “scared”, “hostile”, “irritable”, “ashamed”, “nervous”, “jittery”, and “afraid”. For the ERF, positive affect items included “amusement”, “contentment”, “happiness”, “joy”, and “serenity”. The negative items included “anger”, “anxiety”, “disgust”, “fear”, and “sadness”. Thus each participant had a total of four affect scores (a state and a trait score for positive affect and negative affect). Each participant’s positive affect score was also added to their negative affect score to give a measure of total emotional activation for both trait and state affect. There is no pre-determined cutoff for high or low scores, thus scores on these measures were examined on a continuum.

Stimuli and Design

AB. In the AB task, participants viewed a series of letters presented rapidly one at a time in the center of a computer screen. Participants were asked to identify a lone white letter (T1) from within the stream and detect the presence or absence of a black X (T2). There were 19 letters in each stimulus stream, and T1 and T2 were separated by a lag of 1-8 items. T1 appeared at either position 7 or position 10 in the stream. T2 was present on 67% of trials, and absent on 33% of trials, and each combination of T1 position and lag was presented 5 times each; thus T2 was present on 80 trials, and absent on 40 trials for a total of 120 trials. Each trial began with a 1000 ms wait period, followed by a 500 ms central fixation cross. After 500 ms, the cross was replaced by the first letter in the stream. Each letter was presented individually on the screen for 110 ms with no blank interstimulus interval (ISI) between letters. All distractors were presented in black New

Courier 18 point font on a grey background. T1 appeared in white font to distinguish it from the other stimuli. For each trial, each distractor and T1 was randomly drawn from all letters of the alphabet except X. After the stream was complete, participants were asked to type in the letter corresponding to T1 on the keypad, and make a decision regarding the presence or absence of T2 (press the 'k' key for present and the 'l' key for absent). Participants were instructed to say the X was absent unless they thought it was probably presented on that trial. Responses were not speeded and accuracy was examined. This task took approximately 20 minutes to complete.

T2 hits (saying “yes” to a present T2 on T1 correct trials) were calculated separately for each participant at each lag. To control for individual differences in bias to say “present” to the X, each participant’s false alarm rate (saying “yes” to an absent T2 on T1 correct trials) was subtracted from their hits at each lag to give a T2 sensitivity score for each lag. To estimate AB magnitude, T2 sensitivity at short lags (1 to 3) was subtracted from T2 accuracy at long lags (7 to 8), such that a larger difference reflects a greater effect of T1-T2 lag and more AB. The sum of each participant’s T2 sensitivities at the long lags (lags 6 to 8) was used as a measure of their T2 accuracy. Overall percent correct T1 identification accuracy was also calculated across all trials for each participant. To estimate lag-1 sparing, mean T2 accuracy for lag 2 was subtracted from mean T2 accuracy at lag 1. Larger numbers reflect more lag-1 sparing.

Stroop. In the Stroop task, coloured words were presented on the computer screen, and participants were asked to indicate as quickly and accurately as possible the font (“ink”) colour of each word via button press while ignoring the identity of the word. There were three conditions in this experiment: neutral, congruent, and incongruent. In

the neutral word condition, one of four neutral words was presented (box, lamp, truck, or stereo) in one of four different font colours (red, green, yellow, or blue). In the congruent word condition, one of four colour words (red, green, yellow, or blue) was presented in the font colour that corresponded with the word identity, thus the word “red” was presented in red ink etc. In the incongruent word condition, one of four colour names was presented (red, green, yellow, or blue) in one of four font colours (red, green, yellow, or blue), but the word identity did not match the font colour; therefore the word “green” could be presented in red ink, but not the word “red” in red ink. Each trial began with a 1000 ms central fixation point, after which a coloured word from one of the three conditions appeared on a grey computer screen.

Participants responded with a keyboard press as quickly as possible to identify the font colour of the presented word. The button responses were as follows: The ‘a’ key for red, the ‘s’ key for blue, the ‘k’ key for green, and the ‘l’ key for yellow. Keys were labeled with appropriate stickers. Reaction time (RT) and accuracy of the responses were recorded. After each response, there was a 1000 ms wait, and then the next trial would begin. There were 32 different word type/font colour combinations, 16 from the neutral condition, 12 from the incongruent condition, and 4 from the congruent condition. All combinations were presented 3 times each for a total of 96 trials. Condition, word identity and colour were randomly intermixed within the block. The Stroop task took approximately 5-10 minutes to complete.

The three conditions of the Stroop task allow for estimates of Stroop interference, and facilitation. Interference was measured by subtracting each participant’s mean RT on neutral trials from their mean RT on incongruent trials. Facilitation was measured by

subtracting each participant's mean RT on congruent trials from their mean RT on neutral trials. Note that greater interference and greater facilitation are both represented by larger positive values. Baseline RT was estimated using the average RT for the neutral condition.

Enumeration. In the enumeration task, participants were asked to report the number of boxes briefly flashed on a computer screen. Each trial began with a 500 ms central fixation period, after which 1-10 filled black boxes were flashed simultaneously on the white background of a computer screen for 50 ms. After the boxes were flashed, there was a 500 ms blank interval, following which the participant made a key press indicating the number of boxes shown. Participants used the number pad on the keyboard to indicate how many boxes they thought were flashed on the screen, using 1-9 to indicate 1-9 boxes, and the 0 key to indicate 10 boxes. Participants made their responses without speed pressure, and accuracy was recorded. The boxes appeared in a pseudorandom pattern in the central portion of the computer screen. The maximum horizontal or vertical distance between boxes was 3 cm and the minimum horizontal or vertical distance between boxes was 0.3 cm. There were ten different arrays (patterns) for each set size, and each was presented twice for a total of 200 trials. The number of boxes varied randomly trial to trial with the above constraints. The enumeration task took approximately 10-15 minutes to complete.

There were two main measures derived from the enumeration task. First, the length of the subitizing period was examined. The length of the subitizing period was determined by finding the lowest number of boxes at which accuracy begins to drop off and becomes less than perfect. In the present study the subitizing period was estimated

separately for each individual and operationalized as the number of boxes at which accuracy first dips below 90% minus 1. For example, if a participant scored 100, 100, 95, 90, and 85 for set sizes 1 to 5 respectively, then their subitizing period score would be $5^{\text{th}} \text{ box} - 1 = 4$. Average overall accuracy was also measured by examining mean accuracy across all 10 box conditions (sum of the accuracy of 1-10 boxes/10).

Visual Search. In the visual search task, participants searched for a target presented within a field of distractors that were presented simultaneously at various locations on the screen, and made a speeded target present/ absent decision. In this computerized test, there were two different factors: the number of stimuli (2, 16, 32, or 64) and the target presence/absence. The eight different conditions were presented randomly 16 times each, for a total of 128 trials. Target and distractor locations were pseudo-randomly selected within a 9 cm by 11.5 cm frame. Each trial began with a 1000 ms wait and then a 500 ms central fixation cross on the screen, after which the stimulus array appeared on the screen and remained on until a response. Targets were right-side-up “T” shapes presented within upside-down “T” distractors. All shapes appeared in black font on a white background. Participants used the keyboard to respond whether the target was present (by pressing the “t” key) or absent (by pressing the “y” key). RT and accuracy were recorded. This task took approximately 10-15 minutes to complete.

Four measures were examined for this task: search slope for target present trials, search slope for target absent trials, the slope difference between target-present and target-absent trials, and RT at the smallest set size. The search slopes are a measure of search efficiency or the cost per item during serial deployment of attention. Search slopes were estimated individually for each participant by subtracting the RT at the smallest set

size (2) from the RT the largest set size (64). The difference in slope on target-present and target-absent trials was also examined to determine how participants react to not detecting the target. In past studies, search slope is approximately twice as large on target-absent trials as on target-present trials (Treisman & Gelade, 1980). Slope ratios larger than 2:1 could therefore suggest extra careful search perseverance, and ratios smaller than 2:1 could suggest that the individual gave up search prematurely, but only if accompanied by larger errors at larger set sizes on target present trials. Finally, RT at the smallest set size (2) was used to obtain an estimate of target detection response speed without serial search.

UFOV. In the UFOV task, participants were required to determine on which of eight spokes a target was briefly flashed. There were two factors in this experiment: The spoke on which the target was presented (8 different spokes, one at every 45 degrees on a clock face) and the eccentricity of the target on the spoke (close to the center, further from the center, or on the periphery). Thus there were 24 different combinations of target location in this experiment, each of which was presented three times in random order, for a total of 72 trials. At the beginning of each trial, eight blank white spokes were presented on a black screen for 1000 ms, after which a target flashed for 15ms on one of the spokes. The entire display was then immediately masked by a grey and white assortment of shapes for 400 ms, after which the blank white numbered spokes were presented, and the participant was prompted to indicate on which spoke the target appeared. Responses were completed using the number keypad, and participants were asked to press the number that corresponded to the spoke number on which they believed the target appeared.

Participants were aware that accuracy, but not response speed was recorded. This task took approximately 10 minutes to complete.

For the UFOV task two measures were obtained: the difference in accuracy from closest to furthest eccentricity, and overall accuracy. Given that there were three different eccentricities at which targets can appear in this task, any declines in accuracy with eccentricity can be measured, with greater declines reflecting smaller useful fields of view. UFOV accuracy fall-off from closest to furthest eccentricity was measured for each individual by subtracting their accuracy at the eccentricity furthest from fixation from accuracy at the eccentricity closest to fixation. Overall accuracy was determined by examining the average accuracy for each individual across all trials.

Posner Cueing. In the Posner cueing task, participants were presented with central symbol cues (< >) and a subsequent target. The task was to determine as quickly as possible on which side of the computer screen the target appeared. There were three different cue conditions in this experiment: valid (an arrow which points to the correct target location), invalid (an arrow which points to the incorrect target location) or neutral (a double-headed arrow which points to both potential target locations). Combinations of cue condition and target side (left or right) were randomly presented, with the constraints that valid cues occurred 55% of the time, neutral cues occurred 30% of the time, and invalid cues occurred 15% of the time and the target occurred on each side equally often for every cue condition. There were 122 trials in total. Each trial began with 2000 ms wait period, followed by the presentation of a centrally placed cue for 200 ms. There was a 400 ms blank interstimulus interval before the target appeared on either the left or right side of the computer screen (horizontal distance from left target side to right target side

equaled 30cm). All stimuli appeared in black font with a white background. Participants responded as quickly as possible to the location of the target by pressing the 'd' key if the target appeared on the left, and the 'j' key if the target appeared on the right. Speed and accuracy of responding was stressed. This experiment took approximately 10 minutes to complete.

For this task, the magnitude of the RT costs (invalid trial RT minus neutral RT) and benefits (neutral trial RT minus valid RT) was isolated for each individual so that larger positive numbers indicated greater costs and greater benefits. The sum of the costs and benefits was also calculated. Each of these measures allows for the determination of the degree to which participants used the cues and were affected by them. Finally, baseline RTs for trials where there was no cue (neutral condition) were also examined in order to determine the general processing speed of participants.

Flanker Compatibility. In the flanker compatibility task, participants were asked to quickly identify which of two targets (a square or a diamond) was presented in a placeholder on a 10.5cm diameter ring of six visible circle placeholders centered on the computer screen. Each circle of placeholders contained either 0 or 5 distractors (distractors consisted of up-pointing and down-pointing arrows, triangles, and stars). An additional square or diamond distractor which was twice the size of the other stimuli was always presented just outside the ring of stimuli on either the right or left side of the screen. On half of the trials the large distractor was the same shape as the target (congruent), and on half of the trials it was different from the target (incongruent). Therefore, there were four different ways in which the targets could be presented: 0 ring distractors and a congruent external distractor, 0 ring distractors and an incongruent

external distractor, 5 ring distractors and a congruent external distractor, or 5 ring distractors with an incongruent external distractor. The factors of number of distractors and congruent/incongruent was fully crossed with the two target types (square/diamond), and six possible target positions within the ring, for a total of 48 conditions. Each combination was presented twice for a total of 96 trials. All conditions were intermixed, and drawn at random.

Each trial began with a 1000 ms wait period, after which 6 unfilled circles forming a ring appeared on the screen (fixation). These circles remained blank for 500 ms, after which the target appeared in one of the circles with either 0 or five distractors in the other circles, and an incongruent or congruent distractor placed just outside the ring of circles. All stimuli appeared in black font on a white background. After the stimuli appeared on the screen, participants were asked to quickly determine which target was presented via button press (press the 'g' key for diamond targets and the 'h' key for square targets). The stimuli remained on the screen until the participant responded. Response speed and accuracy were examined. This task took approximately 10 minutes to complete.

The flanker compatibility effect (incompatible RT minus compatible RT) was calculated separately for each number of distractors for each participant, and provided an estimate of interference. An overall interference score (average of the compatibility effect for 0 and 5 distractors) was also calculated. The change in the amount of interference from easy to difficult trials (compatibility effect with 5 distractors minus the compatibility effect with 0 distractors) was also calculated for each participant and this was used as an estimate of how much the participant's distractor processing was

influenced by load. Overall RT in the flanker task was estimated using the mean RT for each participant for correct trials across all task conditions. This gave an estimate of processing speed. Overall RT scores for both 0 and 5 distractors were also calculated separately across conditions. Lastly, the change in RT from easy to difficult trials (overall RT for 5 distractors minus the overall RT for 0 distractors) was calculated in order to estimate how RT was influenced by distractor load.

Global/Local. On each trial of the global/local task, participants were presented with a Navon stimulus (a large letter that was constructed of smaller letters; e.g. an “H” made out of “T”s) in the center of the screen. Global letters (60 x 45 mm) were 10 times as large as the smaller local letters (6 x 4.5 mm), and the viewing distance was approximately 75cm from the computer screen for all participants. Participants were required to quickly report either the identity of the smaller letters (local trials) or the identity of the large letter (global trials) by pressing the corresponding key on the keyboard. The letters that were presented could only be “H” or “T”. Half of the trials in each condition were letter congruent (an “H” made of small H’s or a “T” made of small T’s) and half were letter incongruent (an “H” made of small T’s or a T made of small H’s). Global and local trials were presented in alternating blocks, with 24 trials in each of 4 blocks for a total of 96 trials. All participants began with the global block. Each trial began with a 500 ms central fixation cross on the screen, after which the Navon stimulus appeared on the screen and remained until the participant made a button response indicating the identity of the target. All letters appeared in black font on a white background, and the task took approximately 5-10 minutes to complete.

For this task, global and local interference, global precedence, and mean global and local RT were all calculated for each participant. Local interference was measured as the degree to which local features on the global incongruent trials interfered with RT (global incongruent RT – global congruent RT) and global interference was measured as the degree to which global features on the local incongruent trials interfered with RT (local incongruent – local congruent). Global precedence was measured for each participant by subtracting their RT estimate for local interference from their RT estimate for global interference. This allowed me to determine whether individuals were more affected by global or local stimuli in this task, and is an indicator of overall global bias. Overall global and local RTs were also measured for each participant by averaging their RTs for the global incongruent and congruent conditions, and their local incongruent and congruent conditions respectively.

Procedure

After each participant provided informed consent to participate in the study, and the vision test indicated they had normal or corrected-to-normal vision, they were provided with the PANAS trait affect questionnaire, and were asked to complete it as detailed above. Participants then completed a short medical history questionnaire that asked them about mood-altering medications, psychological disorders, and stimulant use.¹ Participants then completed the NEO-PI personality questionnaire, followed by the ERF state affect questionnaire and then the eight computerized cognitive tasks. At the beginning of each computerized task, the experimenter fully explained the instructions,

¹ No participant was removed from the data set on the basis of their responses to the questionnaire, and analyses showed the pattern of results was the same whether or not some participants were removed on the basis of their responses to medications, disorders or stimulant use.

observed 5-10 practice trials, and then left the room in order for the participant to complete each task alone (see Appendix C for verbal script). Each participant completed all eight cognitive tasks sequentially in this manner, receiving breaks between each task block and each cognitive task.

In order to remove unwanted variability due to order effects, the cognitive tasks were completed in the following order for all participants: AB, Stroop, enumeration, visual search, UFOV, Posner cueing, flanker, and global/local. Keeping task order constant was appropriate here as I was examining individual differences, not comparing performance across tasks, and different task orders would contribute order variability that could obscure relationships between tasks. The ERF was presented directly before the AB task as I am particularly interested in state affect while performing an AB task. To have measured state affect earlier would potentially give an inaccurate picture of participants' mood state during the AB task, and if it had been measured after the AB task, then performance on the AB task may have influenced affect, complicating interpretation of the possible relationship between AB performance measures and state affect. After completion of the final computerized task, participants completed a short questionnaire which asked them about their video game experience (see Appendix A). It was important that participants complete this questionnaire because, based on the studies conducted by Green and Bavelier (2003; 2005; 2006), video gamers perform differently on the cognitive tasks used in this experiment. As this experiment is examining the normal range of performance, it is important to ensure that any results that are found are not due to a

select population of individuals who are extremely proficient at the tasks.² This measure was administered at the end of the study to prevent participant suspicion, as no other portion of the study appeared to relate to video game play. At this time the participant was debriefed, compensated, and received a more detailed feedback form which described the purpose of the experiment.

Results

Outlier Removal

Participants. A total of 13 participants were removed from the final analysis for having mean long-lag (6, 7, and 8) accuracy on the AB task that was less than .50. Long lag accuracy represents baseline levels of performance in the AB task. A score of less than .50 means that the participant was able to detect less than half of the T2s. Participants with accuracy this low at the long lags were potentially not completing the task correctly. It is also difficult to assess AB magnitude when long lag accuracy is so low, as it makes it likely that short lag accuracy shows a floor effect, which would lead to a misrepresentation of AB magnitude. One additional participant was removed from the experiment for failing to complete all of the cognitive tasks due to illness. Therefore the total number of participants in the final analysis was 84.

Trials. All measures that yielded RT scores were examined for trial outliers. An outlier elimination procedure using a +/- three standard deviation cut-off was applied to RT data from the Stroop, Posner cueing, visual search, flanker, and global/local tasks prior to analysis. This procedure was performed individually for every combination of

² Only 11 participants reported playing action video games, only one of whom played on a regular basis. No participant was removed from the data set on the basis of their responses to this questionnaire, and analyses showed the pattern of results was the same whether or not these participants were removed.

participant, task, and condition. Only RTs from correct trials were included in the outlier elimination procedures and the calculation of RTs for each condition.

Performance Patterns in Each of the Cognitive Tasks

For some of the following ANOVAs, Mauchley's test indicated a violation of sphericity. In all such cases, a Greenhouse-Geisser correction was implemented and the corrected df and p values are reported.

AB. For the AB task, mean first target (T1) accuracy was .95 ($SD=.052$) with a range of .72 to 1.0. Second target (T2) hits averaged across all 8 lags was .67 ($SD=.12$) with a range of .43 to .92, and overall T2 sensitivity (T2 hits corrected for false alarms) averaged across all 8 lags was .58 ($SD=.122$) with a range of .29 to .90. T2 sensitivity was conditionalized on T1 correct in all cases, as is typical for AB studies. The mean percentage of T2 false alarms was .09 ($SD=.079$) with a range of .0 to .35. Mean T2 sensitivity for individual lags can be seen in Figure 9. A repeated measures Analysis of Variance (ANOVA) with lag as the within subjects factor showed a significant main effect of lag, such that sensitivity was poorer for short versus long lags, $F(4.8, 395) = 122.04, p < .001$. A series of Bonferroni corrected t-tests comparing lags 1, 2, 3, 4, and 5 individually with the average of the long lags (6-8) showed that sensitivity for all of the short lags ($M=.56, SD=.16$) was significantly lower than sensitivity for the long lags ($M=.86, SD=.09$) (p 's $< .001$). This pattern of results is consistent with typical AB results found in the literature, and provides evidence that the AB task worked as expected.

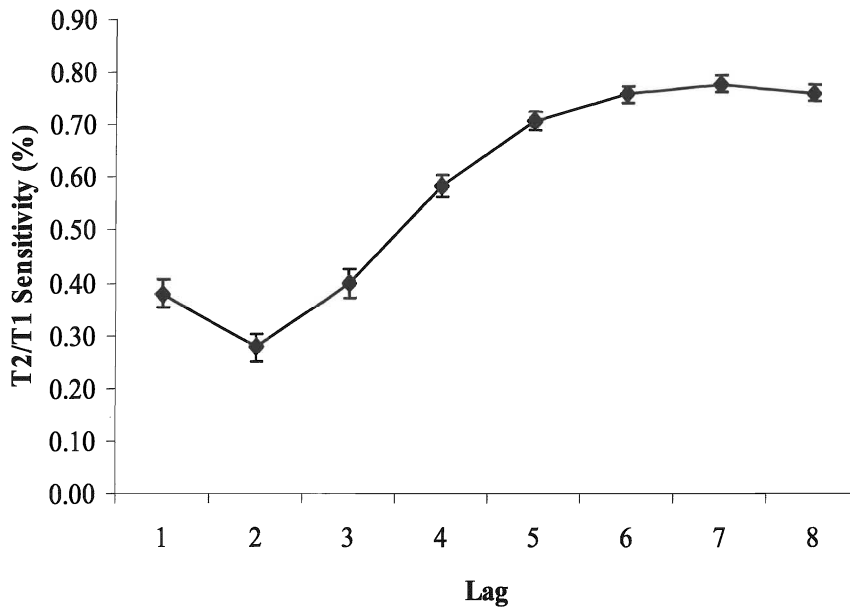


Figure 9. T2 sensitivity (proportion hits – proportion false alarms) given T1 correct as a function of lag in the AB task. Error bars represent the standard error for each condition mean (SD/\sqrt{N}).

Stroop. For the Stroop task, mean RTs for the neutral, congruent and incongruent conditions are shown in Figure 10. RTs on neutral, congruent, and incongruent trials were analyzed using a repeated measures ANOVA. A significant main effect of condition was found, showing that the condition influenced colour naming RTs, $F(1.6, 133.6) = 85.89$, $p < .001$. Paired-samples t-tests, with a Bonferroni correction showed a statistically significant difference between the neutral and incongruent condition, $t(82) = -8.84$, $p < .001$, neutral and congruent condition, $t(82) = 4.62$, $p < .001$, and the incongruent and congruent condition, $t(82) = 10.87$, $p < .001$, indicating that RT was fastest in the congruent condition, and slowest in the incongruent condition as expected based on typical Stroop findings.

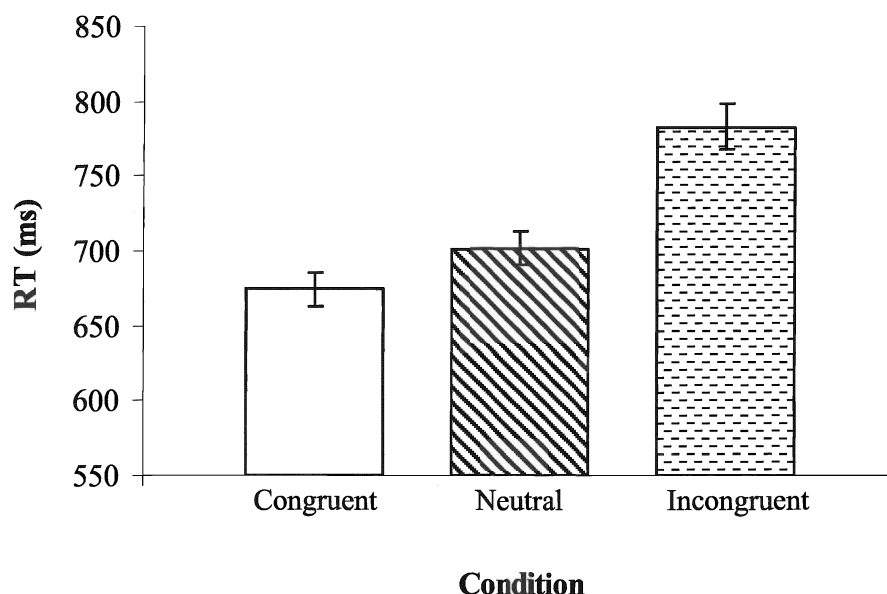


Figure 10. Mean RT in ms as a function of condition in the Stroop task. Error bars represent the standard error for each condition mean.

The proportion of response errors was also examined as a function of Stroop condition. The mean proportion of errors were .04 ($SD=.06$) in the neutral condition, .06 ($SD=.08$) for the incongruent condition, and .03 ($SD=.03$) for the congruent condition. A repeated measures ANOVA showed that the mean proportion of errors differed across conditions, $F(1.5, 118.84)=11.68, p<.001$. To correct for multiple comparisons, a series of Bonferroni corrected paired-samples t-tests showed a statistically significant difference between the neutral and incongruent condition, $t(83)=-2.96, p=.004$, and the incongruent and congruent condition, $t(83)=4.18, p<.001$, but no significant difference between the neutral and congruent condition, $t(83)=1.89, p=.06$. Overall, these analyses indicate that errors were greatest for the incongruent condition, and lesser for the neutral and congruent conditions, providing no evidence for a speed/accuracy trade-off.

Enumeration. Mean accuracy on the enumeration task ranged from .85 to 1.0 at the smallest number of boxes (1) and ranged from .00 to .80 at the largest number of boxes (10: see Figure 11 for mean accuracy for each number of boxes). The mean subitizing period, as measured by the point at which accuracy falls below .90, was 3.8 boxes ($SD=1.6$, with a range of 1 to 7 boxes). This approximates the mean subitizing period observed in previous studies (e.g., Trick & Pylyshyn, 1993; 1994). Mean accuracy for the counting period (the period after which accuracy drops below .90) was .67 ($SD=.21$). Overall performance on the enumeration task was analyzed using a repeated measures ANOVA with number of boxes as the within subjects factor. There was a significant main effect of number of boxes, such that as the number of boxes presented on the screen increased, performance decreased, $F(4.19, 347.5)=323.96, p<.001$. To further test this, a series of Bonferroni corrected t-tests comparing accuracy for each number of boxes to accuracy for one fewer box (e.g., comparing the 1 to 2 box condition, 2 to 3, etc.) were completed. Accuracy for detecting the boxes was significantly reduced as the number of boxes increased (all p 's $<.001$), except for in the 1-2 and 2-3, and the 6-7 box comparisons. This is consistent with the idea that during the subitizing period accuracy is consistently high, but rapidly declines during the counting period.

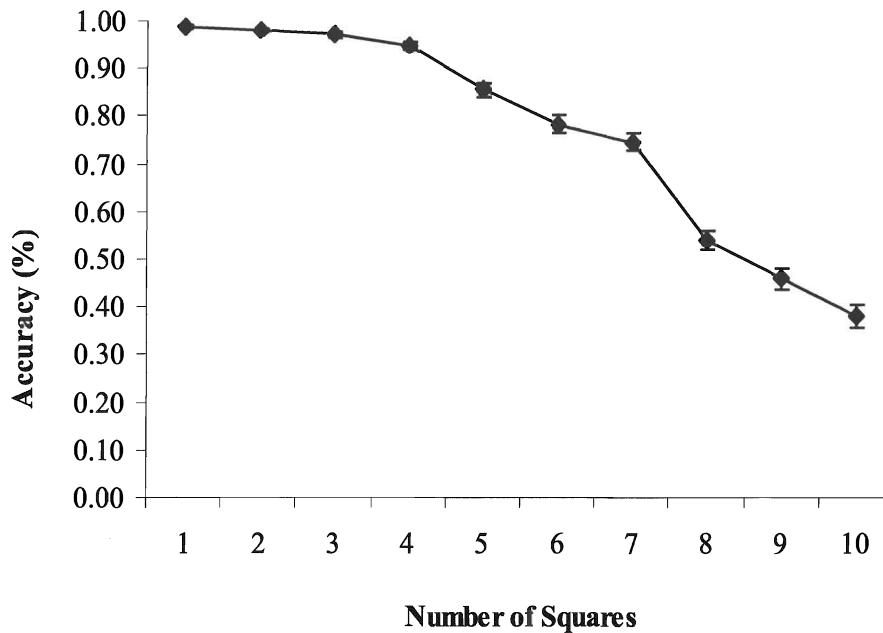


Figure 11. Mean proportion correct on the enumeration task as a function of number of boxes presented. Error bars represent the standard error for each condition mean.

Visual Search. Mean RTs for target present and target absent trials are shown in Figure 12a as a function of number of distractors. A 2 x 4 repeated measures ANOVA (presence/absence of target by number of distractors) revealed a significant main effect of number of distractors, $F(1, 83)=178, p<.001$, and for the presence/absence of the target, $F(1.3, 104.98)=224.8, p<.001$. There was also a significant interaction between number of distractors and presence/absence of the target, reflecting the greater effect of number of distractors for the target absent condition compared to the target present condition, $F(1.77, 146.6)=94.1, p<.001$. Indeed, the slope across number of distractors RT for target absent trials was approximately twice as large as for target present trials. This 2:1 slope ratio was expected in this visual search task, and is indicative of self-terminating search.

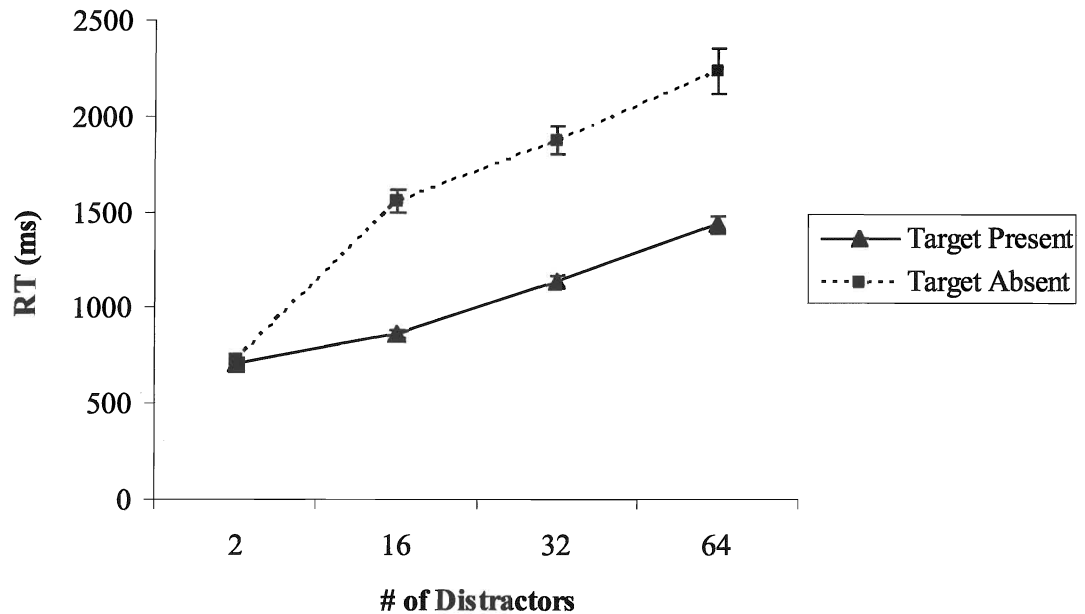


Figure 12a. Mean visual search RTs as a function of target presence/absence and number of distractors. Error bars represent the standard error for each condition mean.

Mean visual search errors are presented in Figure 12b as a function of target presence/absence and number of distractors. A 2 x 4 repeated measures ANOVA (presence/absence of target by number of distractors) performed on the error data showed a significant main effect of target presence/absence, $F(1, 83)=209.09, p<.001$, and a significant main effect of the number of distractors, $F(3, 249)=104.83, p<.001$. The interaction between target presence/absence and number of distractors was also significant, $F(3, 249)=128.75, p<.001$, suggesting that as the number of distractors increased, the number of errors increased, but only in the target present condition. There does appear to be a speed/accuracy trade-off in the target present condition given that the slope for errors on target present trials was significantly steeper than the slope for errors on the target absent trials, whereas the RT slope was significantly steeper for the target absent as compared to the target present condition. This implies a speed/accuracy trade-

off for the target present condition, wherein participants appeared to give up more easily and incorrectly indicate that the target was absent.

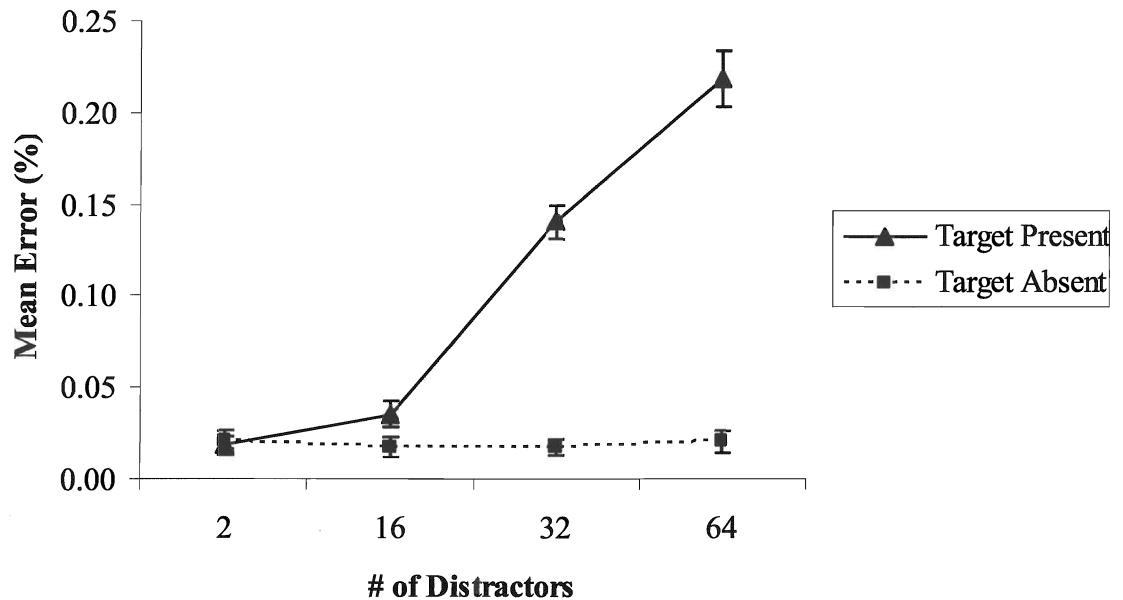


Figure 12b. Proportion of mean visual search errors as a function of target presence/absence and number of distractors. Error bars represent the standard error for each condition mean.

UFOV. Overall accuracy for the UFOV task was .74 ($SD=.22$). Mean accuracy for the close, middle and far eccentricities are shown in Figure 13. Accuracy on the UFOV task was analyzed using a repeated measures ANOVA with the three different target eccentricities as the within subjects factor. There was a significant main effect of eccentricity, showing that accuracy differed depending on how far the target was from central fixation, $F(1.69, 140.4)=60.72, p<.001$. Paired samples t-tests with a Bonferroni correction showed that accuracy for close and middle eccentricities did not differ significantly, $t(83)=.289, p=.773$; but accuracy for the farthest eccentricity was significantly lower than accuracy in the near, $t(83)=8.13, p<.001$, or middle, $t(83)=9.97,$

$p < .001$, eccentricities. Thus, as expected, there was a significant drop-off in accuracy at the farthest eccentricity from fixation.

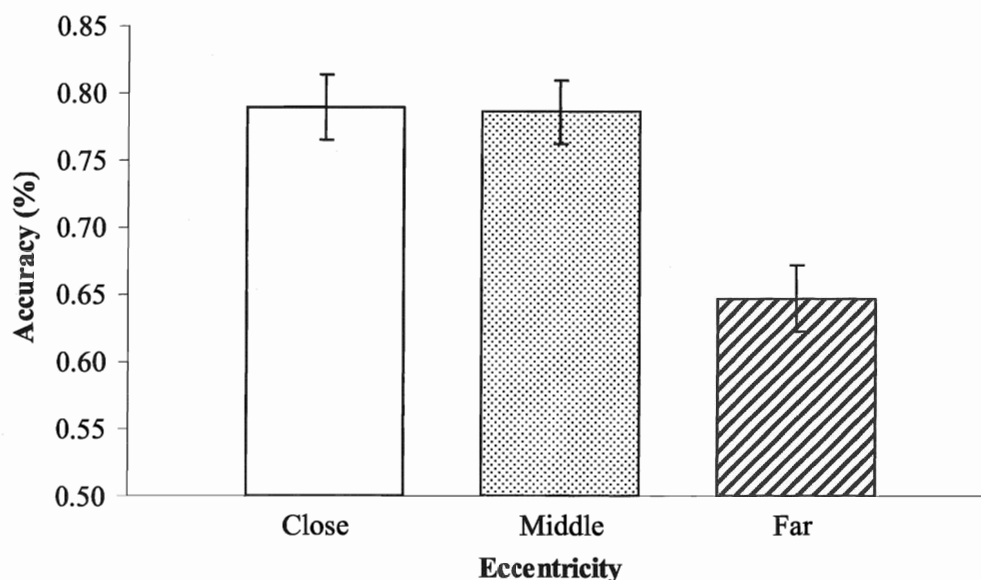


Figure 13. Mean proportion correct on UFOV task as a function of target eccentricity. Error bars represent the standard error for each condition mean.

Posner Cueing. Mean RTs for the neutral, congruent and incongruent conditions are shown in Figure 14. Mean RTs on the Posner cueing task were analyzed as a function of cue condition using a repeated measures ANOVA. There was a significant main effect of cue condition, $F(2, 166) = 58.39, p < .001$, illustrating that cue type affected RT on this task. Paired samples t-tests, with a Bonferroni correction, were conducted to compare RT for each pair of conditions. Mean RT was significantly longer for invalid compared to neutral cues, $t(83) = 9.64, p < .001$, and significantly shorter for valid cues as compared to neutral cues, $t(83) = -2.31, p = .02$. A significant difference was also found between invalid and valid cues, $t(83) = -8.91, p < .001$. The pattern of results indicates that invalid cues indeed increased RTs, and valid cues reduced RTs as expected.

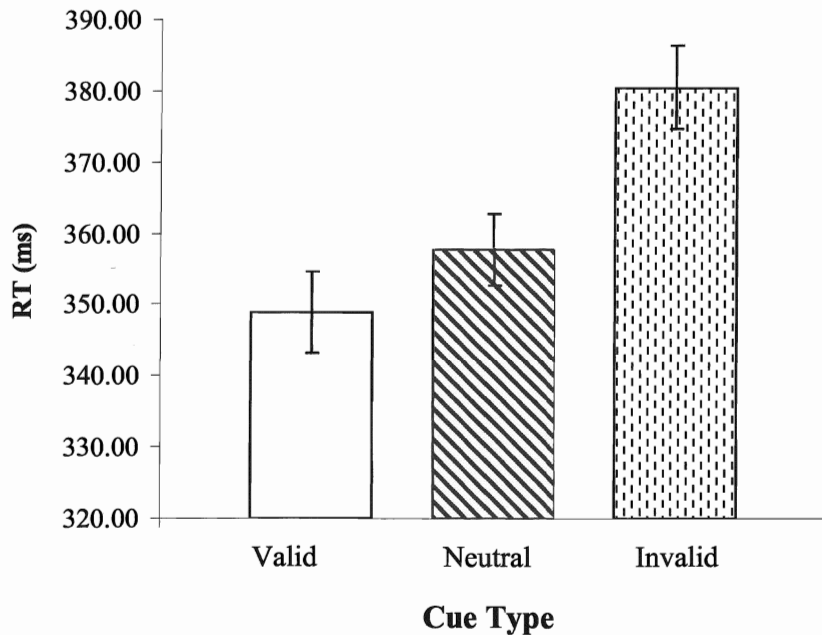


Figure 14. Mean RT for Posner cueing task as a function of cue type. Error bars represent the standard error for each condition mean.

The mean percentage error was .01 ($SD=.02$) for the neutral condition, .02 ($SD=.05$) for the invalid condition, and .003 ($SD=.01$) for the valid condition. These means were analyzed using a repeated measures ANOVA. There was a significant main effect of condition, such that the number of errors changed depending on the type of cue presented, $F(2, 166)=9.56, p<.001$. A series of Bonferroni corrected paired-samples t -tests were conducted in order to further examine this pattern of results. The invalid condition differed significantly from the neutral condition, $t(83)=2.89, p=.005$, and from the valid condition, $t(83)=-3.47, p<.001$, but the valid and neutral condition did not differ significantly, $t(83)=-1.67, p=.10$. This indicates that errors were highest in the invalid condition, which parallels the increase in RT also seen for this condition.

Flanker Compatibility. Mean target identification RTs are presented in Figure 15a as a function of the number of distractors (0 or 5) and whether the flanker was compatible/incompatible with the target identity. A 2 x 2 (compatibility by number of

distractors) repeated measures ANOVA showed a significant main effect of compatibility, $F(1, 82)=332.04, p<.001$, where RTs were 26 ms longer overall for incompatible trials than for compatible trials. There was also a significant main effect of number of distractors, $F(1, 82)=13.78, p<.001$, where RTs to identify the target were 30.14 ms longer overall with five distractors than with no distractors. The interaction between compatibility and number of distractors did not reach significance indicating that flanker interference was equally large regardless of the number of distractors, $F(1, 82)=.268, p=.61$.

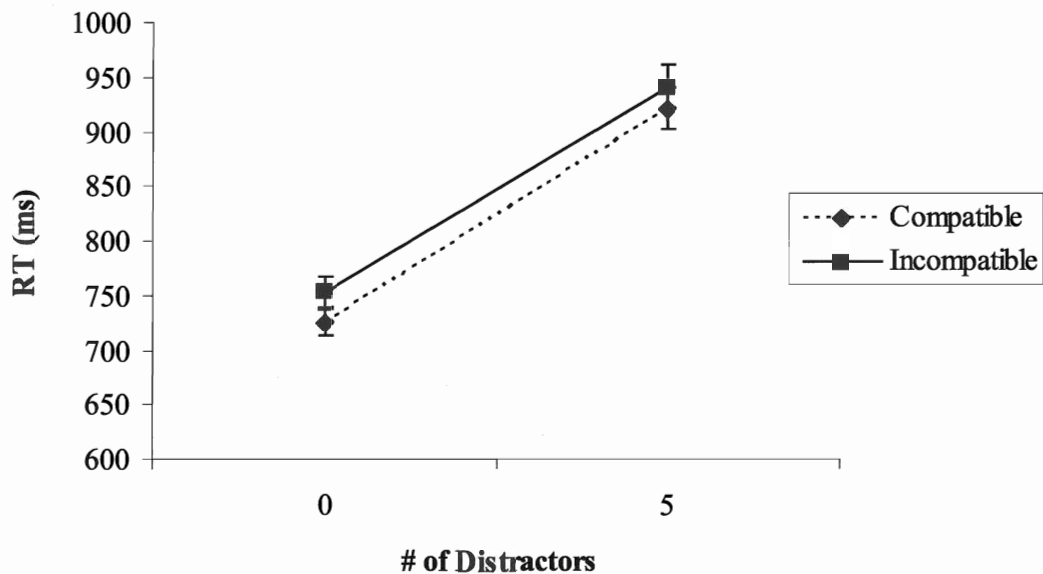


Figure 15a. Mean flanker task RTs as a function of target/flanker compatibility and number of distractors. Error bars represent the standard error for each condition mean.

The mean error data for this task were also examined, and are presented in Figure 15b as a function of number of distractors (0 or 5) and whether the flanker was target compatible or incompatible. A 2 x 2 (compatibility by number of distractors) repeated measures ANOVA showed a significant main effect of compatibility, $F(1, 82)=6.52, p=.012$, reflecting the increase in number of errors for incompatible trials compared to

compatible trials. There was no significant main effect of the number of distractors presented, $F(1, 82)=1.64$, $p=.20$, and no congruency by distractors interaction, $F(1, 82)=.012$, $p=.91$. Therefore, while the RTs did not show the expected pattern of a reduced flanker effect with additional distractors (the flanker effect was equal for 0 and 5 distractors), no speed/accuracy trade-off was observed for this task.

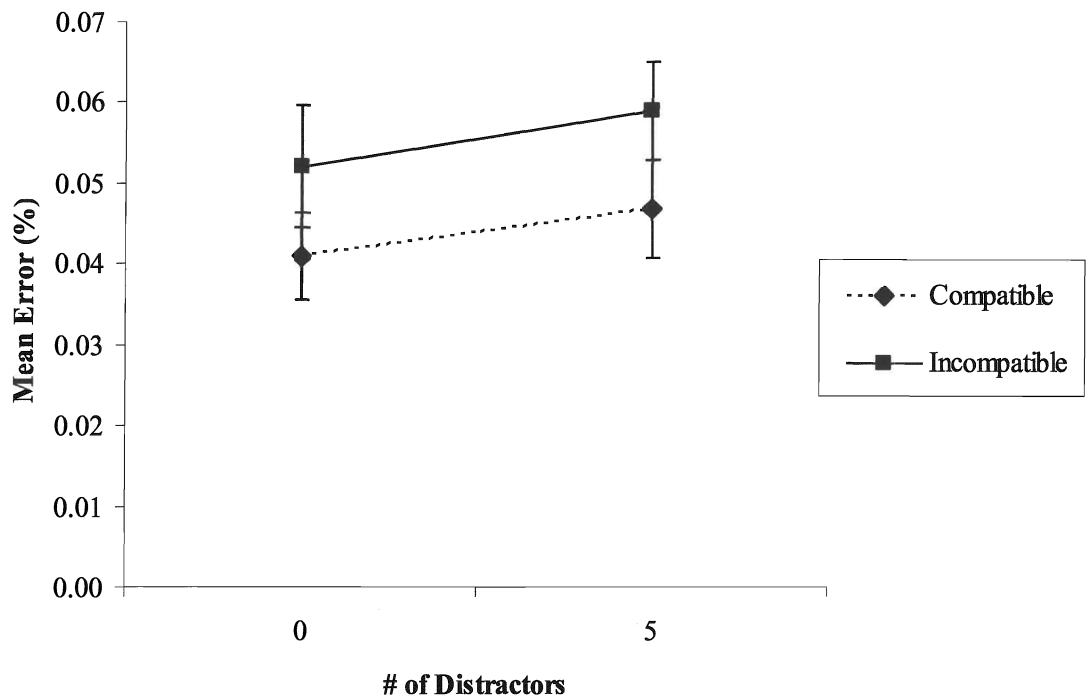


Figure 15b. Mean proportion errors in the flanker task as a function of target/flanker compatibility and number of distractors. Error bars represent the standard error for each condition mean.

Global/Local. Mean letter identification RTs for the global/local task are presented in Figure 16a as a function of whether participants performed the global or local task and whether the information across global/local levels was congruent or incongruent. Mean RTs were analyzed using a 2 x 2 (global/local task by congruency) repeated measures ANOVA. There was a significant main effect of global/local task where RTs were faster for global trials as compared to local trials, $F(1, 83)=34.61$,

$p < .001$. There was also a significant main effect of congruency, indicating that RTs on congruent trials were significantly faster than on incongruent trials, $F(1, 83) = 132.78$, $p < .001$. The interaction between feature size and congruency was not significant indicating that local interference was equal in magnitude to global interference, $F(1, 83) = .487$, $p = .49$.

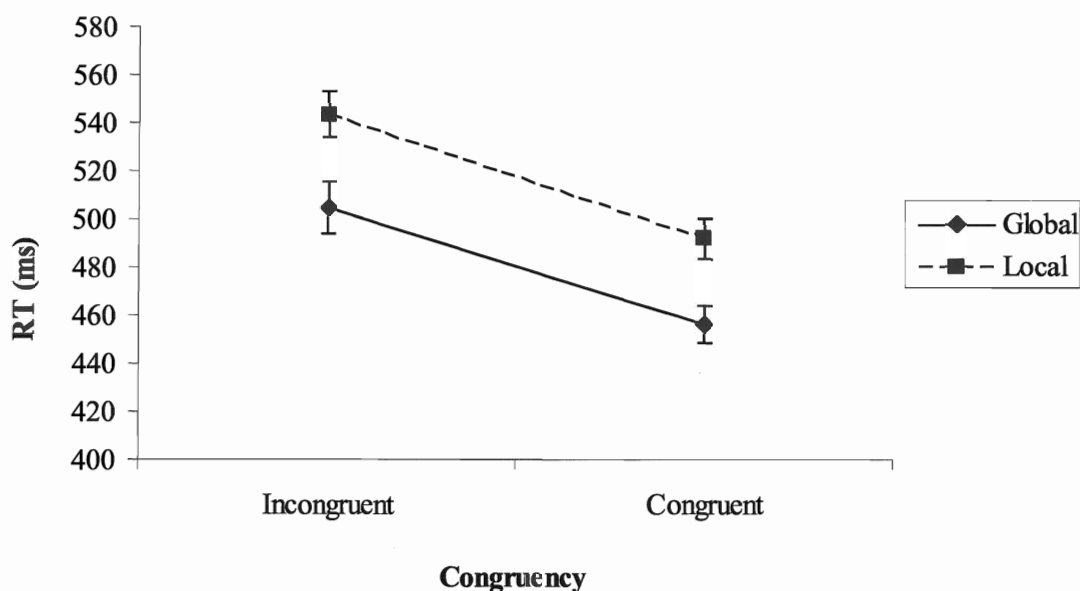


Figure 16a. Mean RT on global and local tasks as a function of target congruency. Error bars represent the standard error for each condition mean.

The mean error data were also examined for this task, and are presented in Figure 16b as a function of congruency and global/local task. A 2 x 2 (congruency by global/local task) repeated measures ANOVA was conducted on these means. There was significant main effect of congruency, $F(1, 83) = 80.39$, $p < .001$, a significant main effect of task, $F(1, 83) = 19.59$, $p < .001$, and a significant interaction of compatibility and task, such that congruency had more effect on global trials than local trials, $F(1, 83) = 8.71$, $p = .004$. The faster RTs observed on global trials were also accompanied by more errors,

thus the main effect of global/local shows a speed/accuracy trade-off. The RT data also suggested equal amounts of global and local interference, however, the error data suggest more local interference than global interference, so the RT data may slightly underestimate the amount of local interference in this task. The overall congruency effect shows no speed/accuracy trade-off.

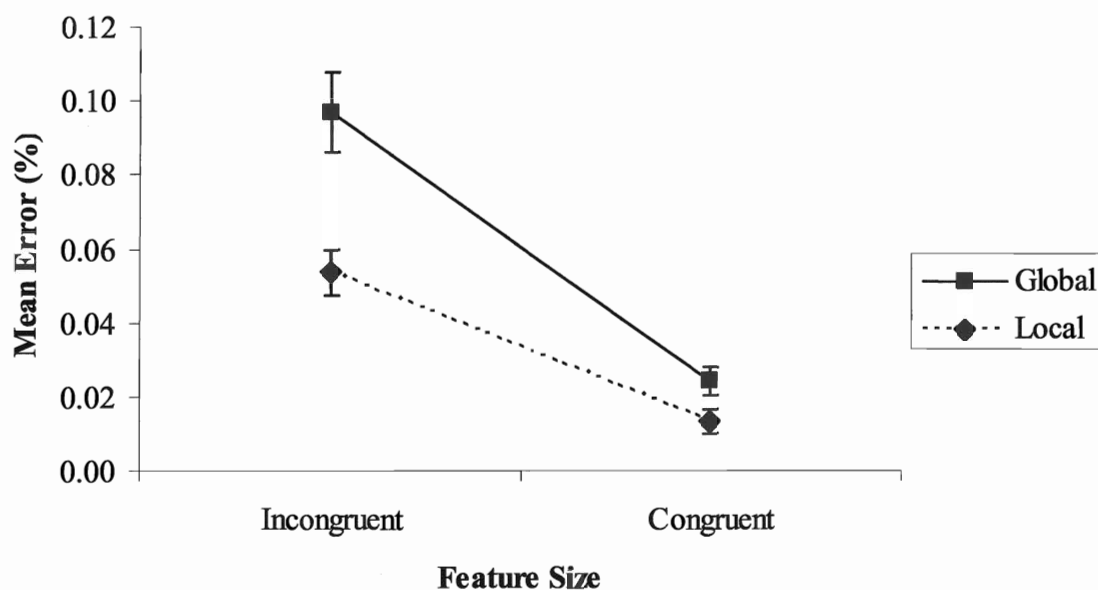


Figure 16b. Mean proportion errors on global and local tasks as a function of target congruency. Error bars represent the standard error for each condition mean.

Relationship between AB Magnitude and Cognitive Measures

AB Magnitude. Correlational analyses were conducted in order to examine the relationship between AB magnitude and the cognitive performance measures from the seven other cognitive tasks used in this experiment (see Table 1 for all zero-order correlation values). There were only a few cognitive performance measures that were significant predictors of AB magnitude.

Table 1.

Correlations among measures of the AB and cognitive performance.

	AB Size	T1	T2	Lag-1
Stroop Neutral	.11	.06	-.13	.06
Stroop Interference	.05	-.05	.15	.05
Stroop Facilitation	.28**	.16	-.18	-.03
Enumeration Subitizing Period	.01	-.05	.10	.18
Overall Enumeration Accuracy	-.01	.26*	.30**	.04
Visual Search Baseline RT	-.04	.02	-.19	-.12
Visual Search Slope Target Present	-.15	.06	.05	-.14
Visual Search Slope Target Absent	-.30**	.02	.04	-.10
Visual Search Slope Ratio	-.25*	.01	.09	-.09
UFOV Fall-off	.03	-.22*	-.12	.05
Overall UFOV Accuracy	.05	.22*	.18	.01
Posner Neutral	-.01	-.26*	-.19	.01
Posner Cost	<.01	.14	.01	.08
Posner Benefit	-.11	-.05	-.07	<.01
Posner Costs + Benefits	-.07	.07	-.04	.06
Overall Flanker RT 0 Distractors	.09	.01	-.26*	.21
Overall Flanker RT 5 Distractors	.05	.01	-.22	.32**
Flanker Interference 0 Distractors	-.04	-.21	-.20	.17
Flanker Interference 5 Distractors	.05	.05	-.14	.35**
Overall Flanker Interference	.01	-.09	-.20	.31**
Difference in Flanker Interference	-.08	-.18	-.05	-.17
Difference in Flanker RT	-.08	-.01	.09	.27*
Global Overall RT	.04	-.12	-.17	.22*
Local Overall RT	-.09	-.12	-.11	.12
Global Interference	-.07	.04	.02	.02
Local Interference	.26*	-.01	-.11	.05
Global Precedence	-.27*	.03	.11	-.04

Note: * indicates $p < .05$, ** indicates $p < .01$.

One of these relationships was a significant negative correlation between AB magnitude and visual search slope on absent trials, such that steeper slopes on target absent visual search trials were related to smaller AB magnitude (see Figure 17) which is opposite to the positive relationship that was hypothesized. The relationship between AB magnitude and visual search slope on target present trials fell short of conventional levels of statistical significance ($p = .167$). There was also a significant negative correlation between visual search slope ratio and AB magnitude. That is, the steeper the slope for absent trials relative to present trials, the more likely the AB would appear attenuated suggesting that the time taken to find the target did not predict AB magnitude as much as the time taken to give up on searching for the target, where prolonged search was associated with smaller ABs. Indeed, the relationship between AB magnitude and the number of errors (misses) at the largest distractor size on target absent trials approached significance ($r = .21, p = .052$) where a smaller number of target misses predicted smaller ABs. Together these results suggest that individuals who were more likely to prolong search and find the targets in dense arrays had smaller ABs while individuals prone to prematurely give-up searching dense arrays, thereby missing the target, had larger ABs.

Secondly, in opposition to the hypothesized results, a significant positive correlation was observed between AB magnitude and Stroop facilitation (see Figure 18) suggesting that a larger AB appears to relate to paying more attention to irrelevant word identity. However, Stroop facilitation and Stroop interference are both essentially measures of how influenced a participant was by the irrelevant written words during the Stroop task, and there was no relationship between Stroop interference and AB magnitude. This will be examined further in the Discussion.

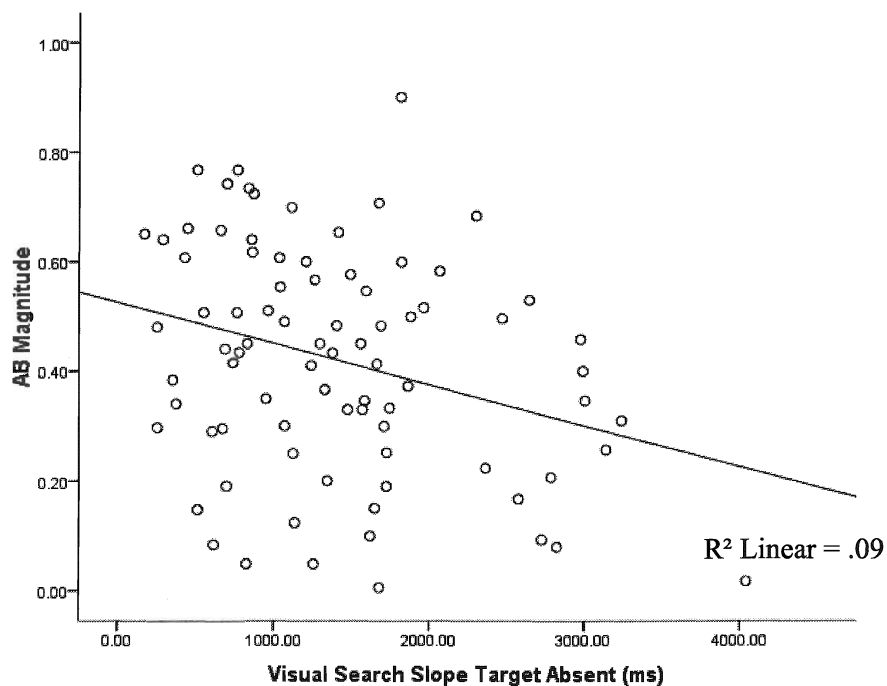


Figure 17. Correlation between AB magnitude and visual search slope (RT with 64 distractors – RT with 2 distractors) on target absent trials such that greater positive values reflect steeper visual search slopes.

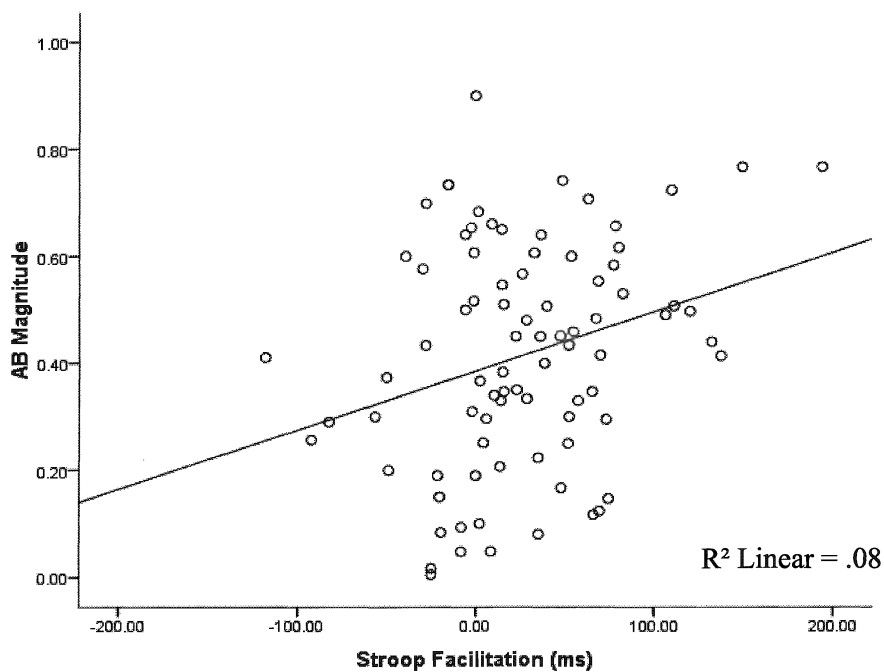


Figure 18. Correlation between AB magnitude and Stroop facilitation (neutral RT – congruent RT) such that greater positive numbers represent greater Stroop facilitation.

Lastly, AB magnitude related to two different measures of global/local performance. There was a significant positive relationship between AB magnitude and local interference, meaning that the more participants were influenced by local features on global trials (thus suggesting a more local bias) the larger the AB tended to be (see Figure 19). This relates well to previous hypotheses that a local or focused state of attention should contribute to a larger AB magnitude. Also, in line with these predictions, global precedence and AB magnitude were significantly negatively correlated (see Figure 20). Higher global precedence scores reflect a global bias where there is greater interference of global information when performing the local task compared to the amount of local interference when performing the global task, thus this relationship indicates that a larger global bias is related to a smaller AB.

When either long lag accuracy or overall T2 sensitivity were covaried out of the AB magnitude measure, the above correlations remained significant, and the magnitude of the relationships changed very little³. No other significant correlations between AB magnitude and cognitive performance were found.

³ As AB magnitude is calculated by taking the average T2 accuracy at long lags and subtracting the average T2 accuracy at short lags, higher T2 accuracy at long lags affords a greater opportunity for a mathematically larger AB than does lower accuracy at long lags. Also, an AB may be larger because T2 accuracy was reduced more at short lags (reflecting a true increase in the AB), because T2 accuracy increased at the long lags, or both. Long lag accuracy and overall T2 sensitivity were covaried out in order to show that the relationship between AB magnitude and cognitive performance was a true reflection of the dip in accuracy for the AB period, and not simply a function of better long lag or T2 accuracy.

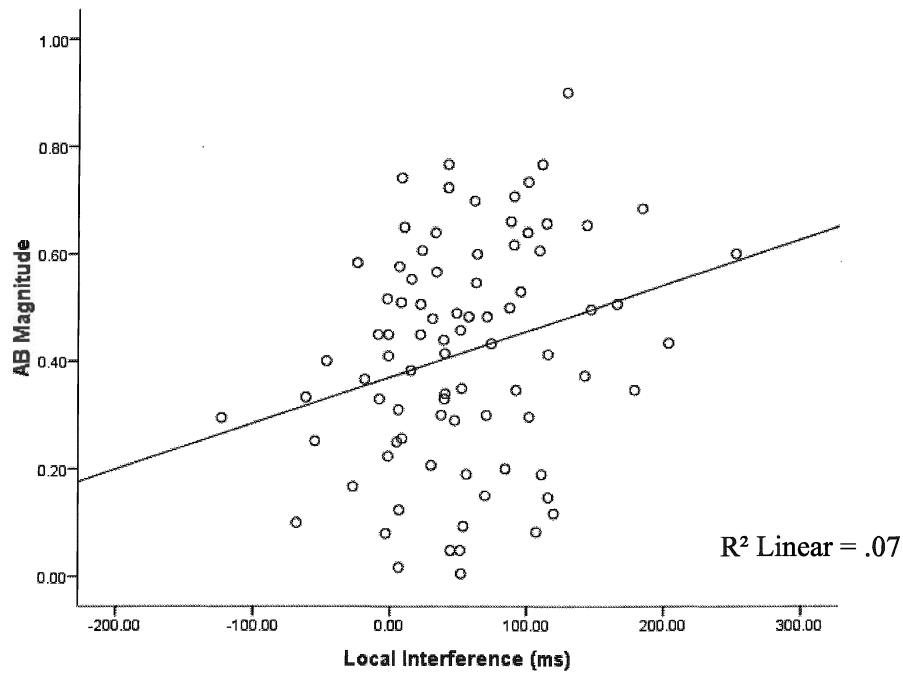


Figure 19. Correlation between AB magnitude and local interference (global task & incongruent – global task & congruent) such that higher scores reflect more interference from local features on global incongruent trials.

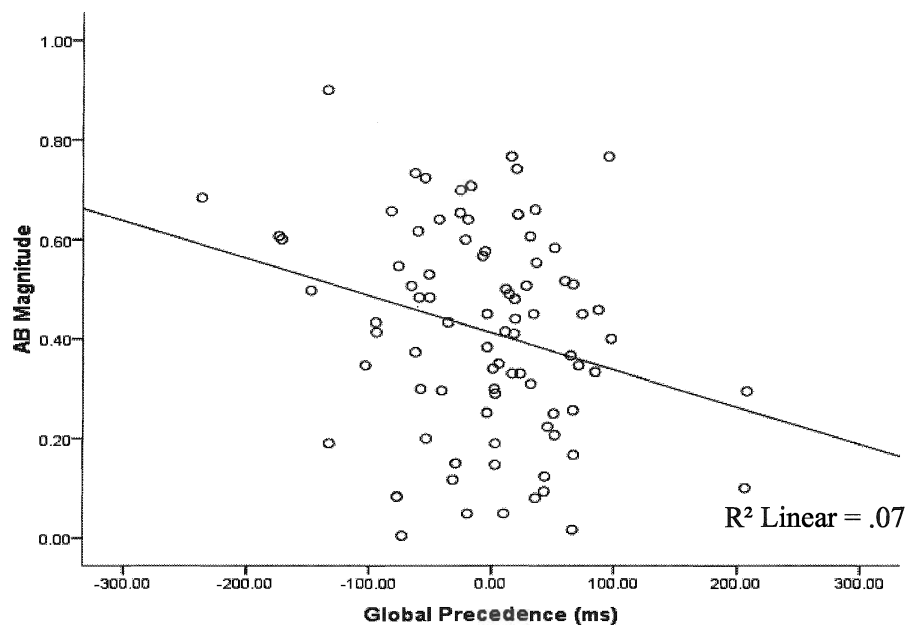


Figure 20. Correlation between AB magnitude and global precedence (global interference – local interference) such that higher global precedence scores reflect greater global bias (i.e., greater interference of global on local relative to interference of local on global).

A simultaneous multiple regression analysis was conducted to examine whether the variables that were significant predictors of the AB each explained unique variability in AB magnitude, or whether they were essentially redundant predictors that explained common (shared) variability. AB magnitude was the criterion variable, and global precedence, visual search slope target absent, and Stroop facilitation were included as the predictors (see Table 2 for regression results). Only these three variables were included in the analysis as the other two variables which significantly correlated with AB magnitude were mathematically created using one of these three variables. Overall, the three variable regression model was able to explain a significant 19% of the variability in AB magnitude, $F(3, 78)=7.15, p<.001$, and all three predictors explained significant unique variability in AB magnitude. Therefore, the results of the regression suggest that the relationship among AB magnitude and these predictors is not explained by a common construct, and that these variables contribute uniquely to AB magnitude.

Table 2.

Summary of Simultaneous Multiple Regression for Variables Predicting AB Magnitude (N=82).

Variable	β	Semi-partial r	p
Global Precedence	-.24	-.24	.019
Visual Search Slope Absent	-.23	-.23	.024
Stroop Facilitation	.26	.26	.011

Note: $R^2 = .185, p<.001$

Target Accuracy. In order to determine if RSVP target accuracy (T1 and T2) was related to any of the cognitive measures used in this experiment, correlational analyses

were performed to examine the relationships among T1 and T2 accuracy and the cognitive performance measures (see Table 1 for zero-order correlation values). As predicted, there was a positive correlation between T1 accuracy and overall UFOV accuracy (see Figure 21) where higher overall accuracy on the UFOV task was related to higher AB T1 accuracy. There was also a significant negative relationship between T1 accuracy and accuracy fall-off from near to far UFOV eccentricities (see Figure 22). This relationship illustrates that participants who were better at identifying T1 in the AB task also showed less decrease in accuracy in the UFOV task as the target moved further from fixation.

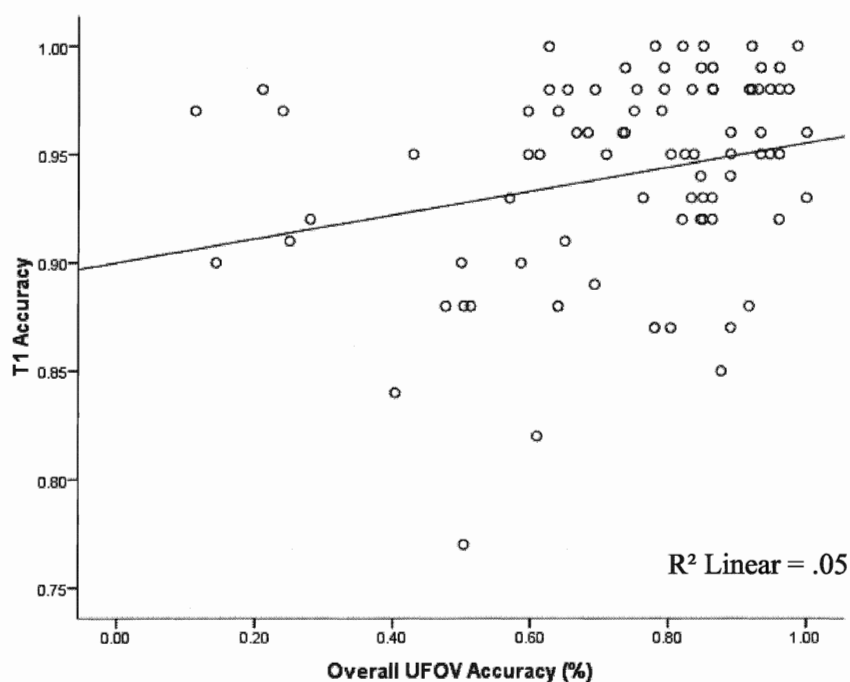


Figure 21. Correlation between T1 accuracy during the AB task and overall UFOV accuracy.

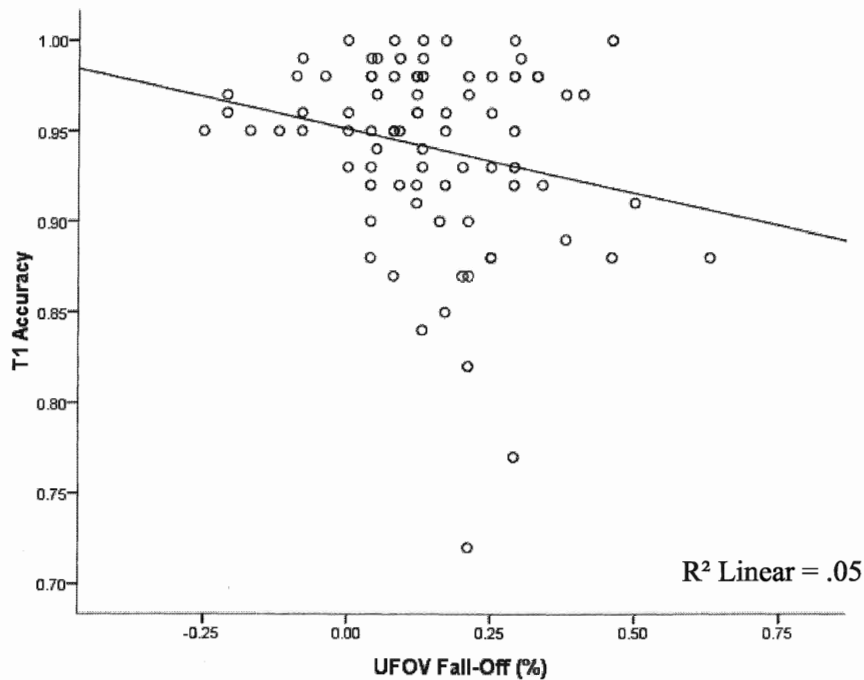


Figure 22. Correlation between T1 accuracy during the AB task and fall-off in UFOV accuracy (accuracy for far eccentricity – accuracy for close eccentricity).

T1 accuracy was also significantly negatively related to RT on the Posner cueing task for the neutral condition (see Figure 23). The neutral condition is essentially a baseline RT condition, thus this relationship suggests that, as RT on the Posner task increases, accuracy for detecting T1 in the AB task decreases. Essentially, this means that individuals who were better at identifying T1 in the AB task were also faster to process targets in the Posner task when spatial cues were not informative. Similarly, T2 sensitivity was negatively correlated with overall flanker RT for 0 distractors, suggesting that faster RTs on the flanker task with no distractors were related to greater T2 sensitivity (see Figure 24). Again, this suggests that individuals who are better able to detect the targets in the AB task were faster to detect targets in the flanker task.

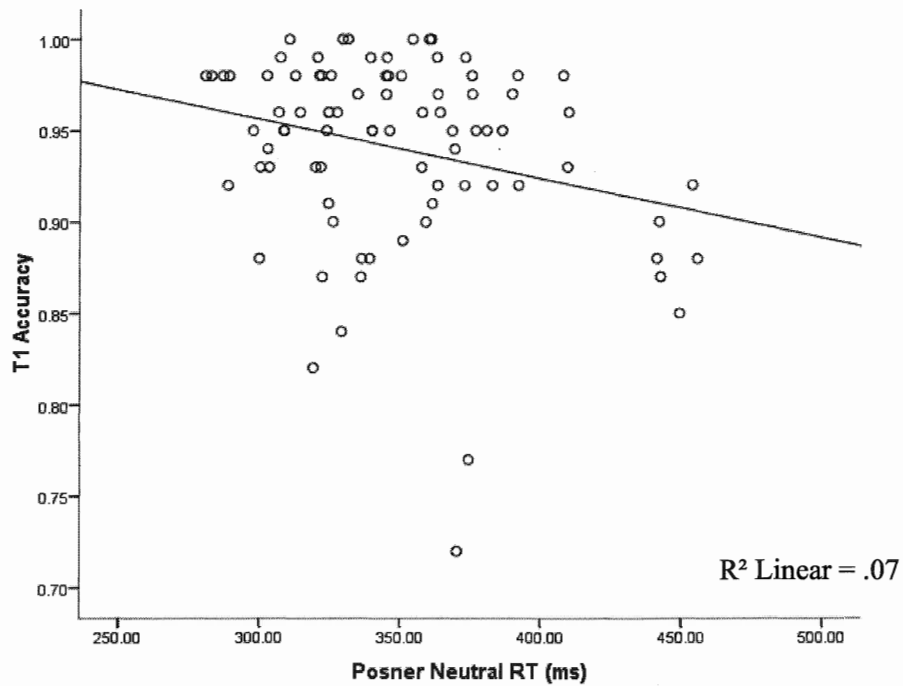


Figure 23. Correlation between T1 accuracy during the AB task and RT on Posner neutral trials.

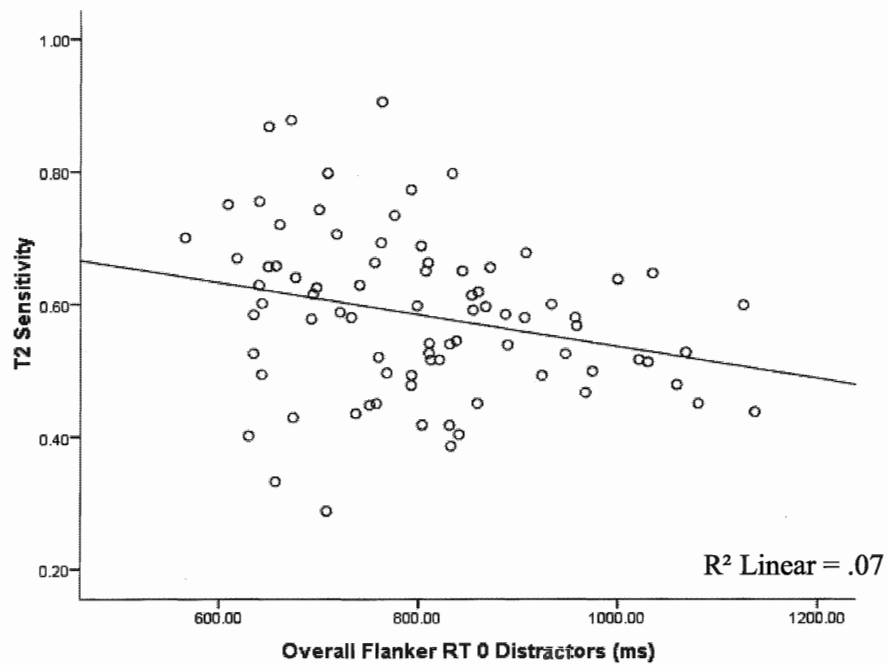


Figure 24. Correlation between T2 sensitivity on the AB task and overall mean RT for the 0 distractor condition in the flanker task.

Finally, as predicted, both T1 accuracy and T2 sensitivity showed a significant positive correlation with overall enumeration accuracy, such that individuals with better accuracy on the enumeration task tended to have better accuracy for both the first and second target in the AB task (see Figure 25ab). No other cognitive measures showed significant relationships with T1 or T2 accuracy.

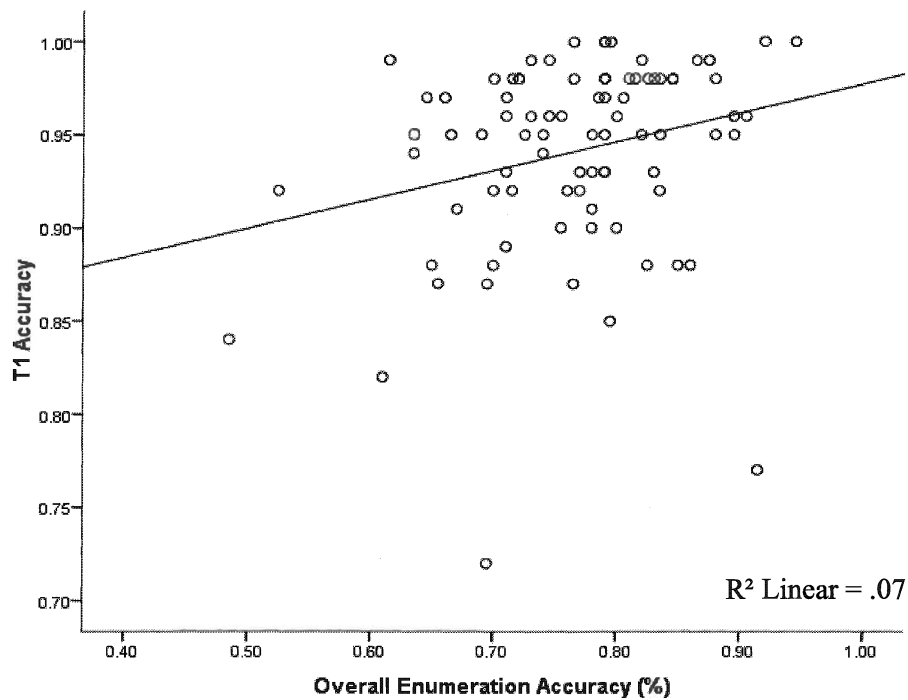


Figure 25a. Correlation between T1 accuracy from the AB task and overall accuracy on the enumeration task.

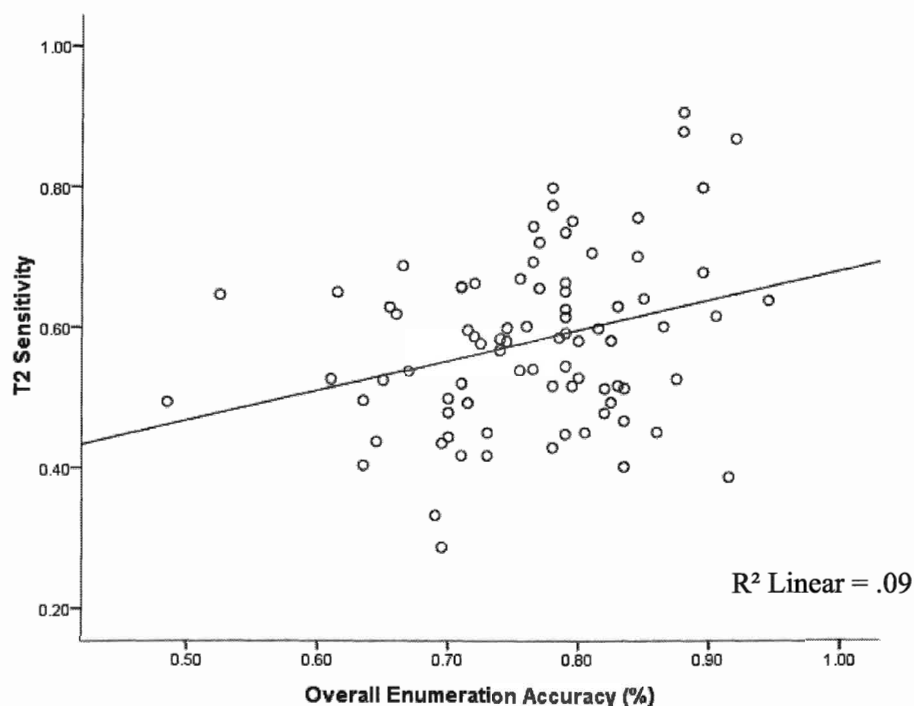


Figure 25b. Correlation between T2 sensitivity from the AB task and overall accuracy on the enumeration task.

A simultaneous multiple regression analysis was conducted using T1 accuracy as the criterion variable, and the significant predictors of T1 accuracy (overall UFOV performance, UFOV fall-off, overall enumeration accuracy, and Posner neutral RT) as the predictors (see Table 3 for regression results). Overall, this model explained a significant 13.7% of the variability in T1 accuracy, $F(4, 77)=4.23$, $p=.004$, and UFOV fall-off explained a significant proportion of unique variability in T1 accuracy.

Table 3.

Summary of Simultaneous Multiple Regression for Variables Predicting T1 Accuracy (N=81).

Variable	β	Semi-partial r	p
Overall UFOV	.17	.16	.130
UFOV fall-off	-.21	-.21	.050
Overall Enumeration Accuracy	.22	.20	.053
Posner Neutral	-.13	-.13	.231

Note: $R^2 = .137$, $p = .004$

A simultaneous multiple regression analysis was also conducted using T2 sensitivity as the criterion variable with overall enumeration accuracy and overall flanker RT for 0 distractors as the predictors (see Table 4 for regression results). Overall, the model explained a significant 11.9% of the variability in T2 sensitivity, $F(2, 79) = 6.45$, $p = .003$. Both enumeration accuracy and flanker RT for 0 distractors explained a significant proportion of unique variability in T1 accuracy, suggesting that the relationship between T2 sensitivity and these cognitive measures is not explained by a common construct.

Table 4.

Summary of Simultaneous Multiple Regression for Variables Predicting T2 Sensitivity (N=82).

Variable	β	Semi-partial r	p
Overall Enumeration Accuracy	.27	.27	.012
Overall Flanker RT 0 Distractors	-.23	-.23	.032

Note: $R^2 = .119$, $p = .003$

Lag-1 Sparing. Lag-1 sparing refers to the increase in detection accuracy for T2 when it is presented immediately after T1 (in the lag-1 position) in the AB task. Lag-1 sparing is measured as the difference in accuracy for lag 2 and lag 1, and a greater positive number indicates greater lag-1 sparing. A correlational analysis was conducted in order to examine the relationship between lag-1 sparing and the other cognitive measures used in this study (see Table 1 for zero-order correlation values). There was a significant positive relationship between lag-1 sparing and overall flanker interference and flanker interference with 5 distractors, such that the greater the interference from external flankers on the flanker task, the greater the lag-1 sparing (see Figure 26 for relationship with overall flanker interference). In addition, lag-1 sparing correlated positively with flanker RTs with 5 distractors, indicating that the ability to locate the target quickly in the presence of distractors in the flanker task was related to less lag-1 sparing (see Figure 27). There was also a significant positive correlation between lag-1 sparing and the overall RT difference for 0 and 5 distractors in the flanker task, suggesting that individuals whose target detection time was more influenced by the additional distractors had larger lag-1 sparing (see Figure 28). Lastly, there was a significant positive correlation between lag-1 sparing and overall global RT on the global/local task (see Figure 29) where longer RTs on global trials were related to greater lag-1 sparing. No other correlations between lag-1 sparing and cognitive performance measures reached significance.

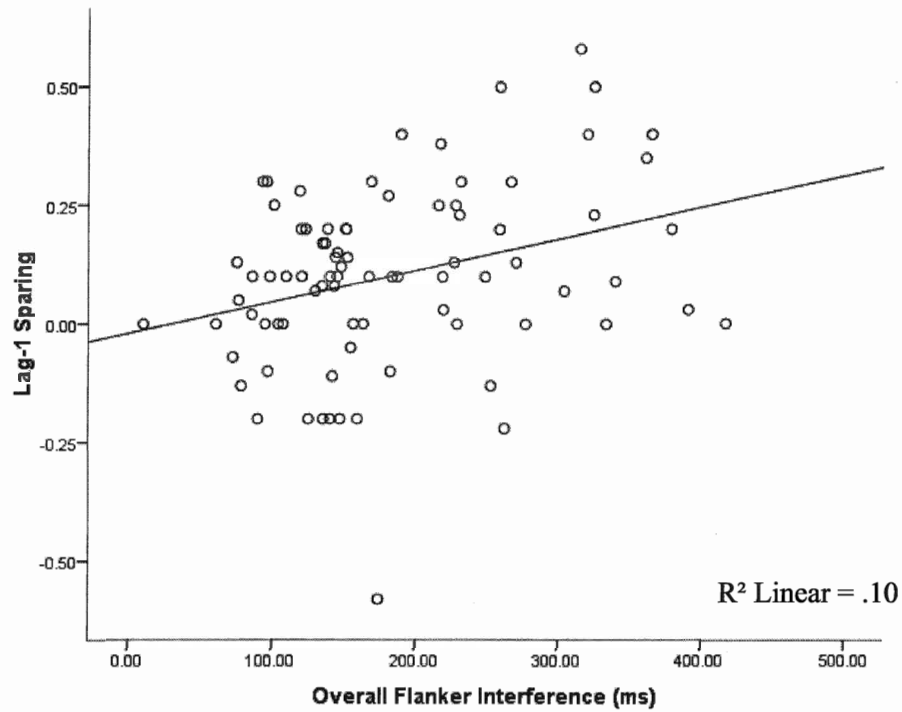


Figure 26. Correlation between lag-1 sparing in the AB task and overall interference on the flanker task.

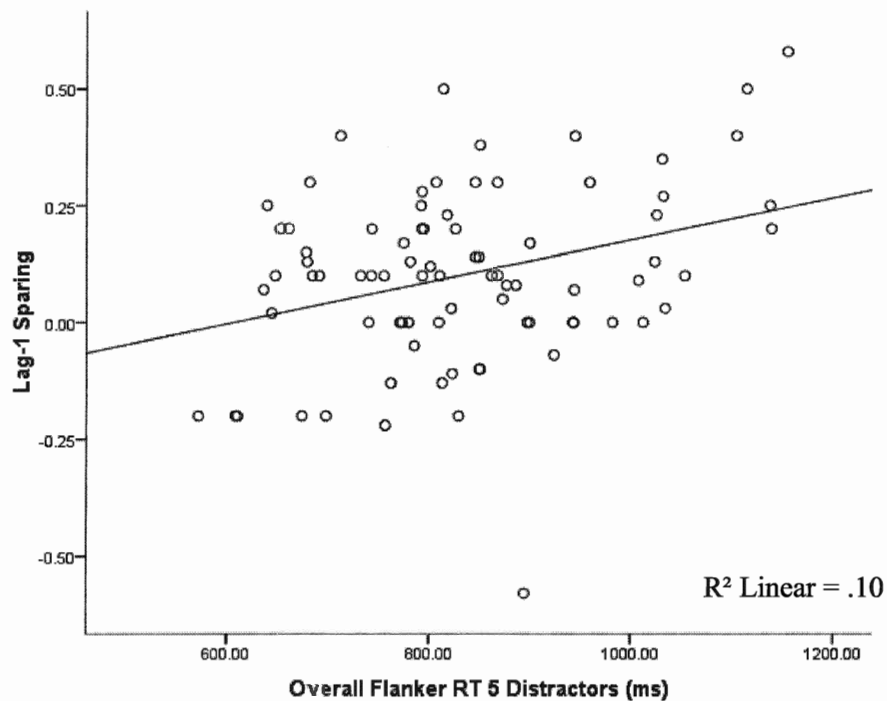


Figure 27. Correlation between lag-1 sparing in the AB task and RT on the flanker task for 5 distractors.

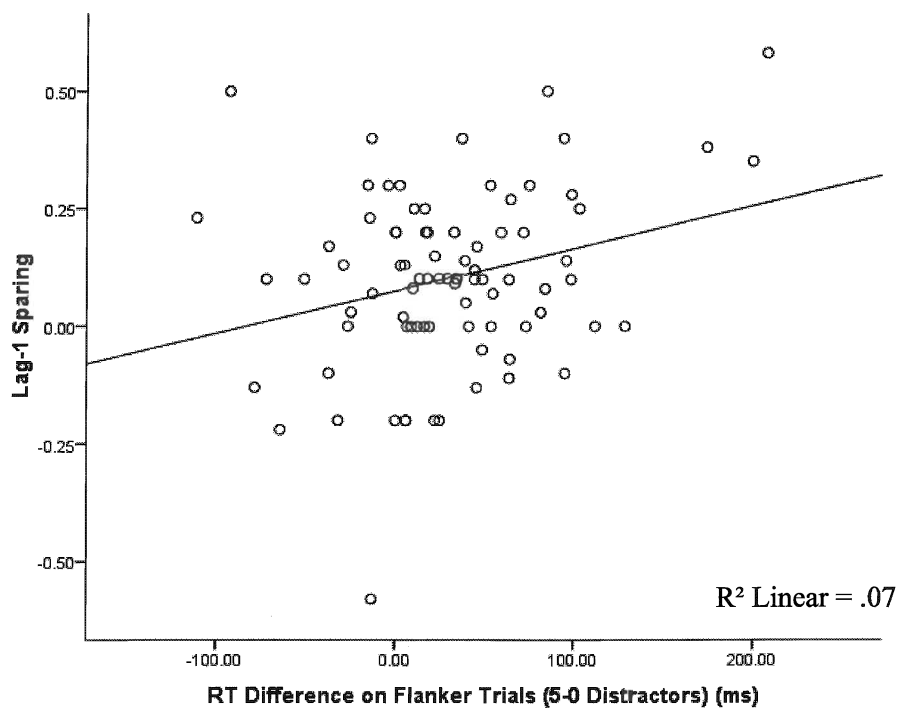


Figure 28. Correlation between lag-1 sparing in the AB task and the overall difference in mean RT for 5 and 0 distractors in the flanker task such that larger positive numbers represent a greater increase in RT when distractors were present in the circle array.

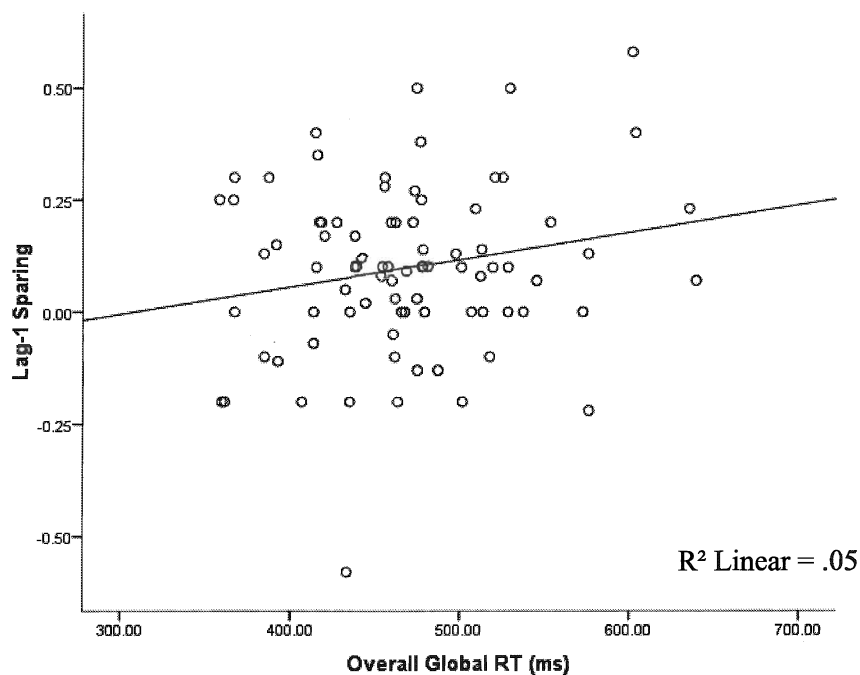


Figure 29. Correlation between lag-1 sparing in the AB task and overall global RT for the global/local task.

A simultaneous multiple regression analysis was conducted using lag-1 sparing as the criterion variable, and overall global RT, overall flanker interference, overall flanker RT difference for 0 and 5 distractors, and overall flanker RT for 5 distractors as individual predictors (see Table 5 for regression results). The overall model explained a significant 13.1% of the variability in lag-1 sparing, $F(4, 77)=4.06, p=.005$, and only overall flanker RT difference from 0 to 5 explained a significant proportion of unique variability in lag-1 sparing.

Table 5.

Summary of Simultaneous Multiple Regression for Variables Predicting Lag-1 Sparing (N=82).

Variable	β	Semi-partial r	p
Overall Global RT	.13	.10	.346
Overall Flanker RT Difference	.25	.23	.031
Overall Flanker Interference	.18	.13	.210
Overall Flanker RT 5 Distractors	.07	.05	.632

Note: $R^2 = .131, p=.005$

Relationships among Affect Measures

Four different measures of affect were calculated for each participant: trait positive affect (PA), trait negative affect (NA), state PA, and state NA (explanation for how variables were derived can be found in the methods section) (see Table 6 for M s, SD s, and range). A correlational analysis was conducted in order to examine the intercorrelations amongst these four variables (see bold section of Table 7 for zero-order correlational values). As expected, trait NA positively correlated with state NA.

However, the relationship between trait PA and state PA only approached significance

($p = .08$). According to some models of affect, PA and NA should be negatively related, however, no significant relationship was observed between state PA and state NA, or between trait NA and trait PA. Trait NA was negatively related to state PA however.

Table 6.

Means, SDs, and Range for All Affect Measures.

	<i>M</i>	<i>SD</i>	<i>Min</i>	<i>Max</i>
Trait Positive Affect	3.44	.48	2.3	4.9
Trait Negative Affect	1.81	.54	1.0	3.7
State Positive Affect	4.78	1.24	1.2	7.0
State Negative Affect	.70	.71	0.0	3.0

Note: The scale ranged from 1 to 5 for trait measures and from 0 to 8 for state measures. In both cases higher scores indicate greater affect.

Relationships between Affect and the AB

A correlational analysis was conducted in order to examine relationships among the four measures of AB performance previously described, and the four measures of affect discussed in this section (see Table 7 for zero-order correlational values). Unfortunately, no measures of state or trait affect correlated significantly with any measures of the AB. The implications of this finding are examined in the Discussion section below.

Relationships between Affect and Other Cognitive Performance Measures

Finally, a correlational analysis was completed in order to examine the relationships among the four affect measures and measures from the other cognitive tasks used in this experiment (see Table 8 for zero-order correlation values).

Table 7.

Correlations between Affect and Measures of the AB.

	1	2	3	4	5	6	7	8
1. Trait Positive Affect	-	.01	.19	-.06	-.01	.02	.01	.06
2. Trait Negative Affect		-	-.22*	.39**	.04	.04	.02	-.05
3. State Positive Affect			-	-.13	.04	-.08	.03	-.19
4. State Negative Affect				-	-.10	-.15	-.02	.14
5. AB Magnitude					-	.04	-.43**	.04
6. T1 Accuracy						-	.38**	-.08
7. T2 Sensitivity							-	-.15
8. Lag-1 Sparing								-

Note: * indicates $p < .05$, ** indicates $p < .01$.

Table 8.

Correlations among Affect and Cognitive Performance Measures.

	Trait PA	Trait NA	State PA	State NA
Stroop Neutral	-.13	-.13	-.17	.03
Stroop Interference	-.03	.18	-.06	.11
Stroop Facilitation	-.03	-.13	.02	-.03
Enumeration Subitizing Period	.04	.06	.07	.03
Overall Enumeration Accuracy	.02	.03	-.03	-.14
Visual Search Baseline RT	-.01	-.02	-.13	-.16
Visual Search Slope Target Present	-.15	-.10	-.05	-.05
Visual Search Slope Target Absent	-.24*	-.16	-.07	-.12
Visual Search Slope Ratio	-.13	-.09	-.02	-.17
UFOV Fall-off	-.09	.05	.04	.14
Overall UFOV Accuracy	.02	.08	-.04	-.02
Posner Neutral	-.22*	-.09	-.17	-.20
Posner Cost	-.12	.09	-.01	.23*
Posner Benefit	.17	-.04	.14	-.07
Posner Costs + Benefits	.02	.04	.09	.12
Overall Flanker RT 0 Distractors	-.27*	-.14	-.22*	-.07
Overall Flanker RT 5 Distractors	-.27*	-.14	-.22*	-.07
Flanker Interference 0 Distractors	-.24*	-.06	-.16	.01
Flanker Interference 5 Distractors	-.26*	.03	-.30**	.16
Overall Flanker Interference	-.29**	-.02	-.27*	.10
Difference in Flanker Interference	.03	-.08	.14	-.14
Difference in Flanker RT	-.09	.17	-.08	.15
Global Overall RT	-.27*	-.19	-.04	.06
Local Overall RT	-.22*	-.24*	-.02	-.06
Global Interference	.01	.10	-.10	.04
Local Interference	-.04	.04	.07	.04
Global Precedence	.04	.02	-.12	-.01

Note: * indicates $p < .05$, ** indicates $p < .01$.

Trait PA was negatively correlated with overall RT on the flanker task for both 0 and 5 distractors. This suggests that individuals with greater trait PA were faster to detect targets in the flanker task, regardless of distractor load. In addition, trait PA negatively correlated with flanker interference for trials in which both 0 and 5 distractors were presented, as well as negatively with overall flanker interference. This suggests that individuals with greater trait PA tend to show less interference from the flanker even for difficult levels of the flanker task, which is opposite to what one might predict if PA leads to diffusion of attention and therefore more processing of irrelevant distractors. Each of these relationships was also observed for state PA, although the negative relationship between state PA and overall flanker interference for 0 distractors was not significant ($p = .153$). Furthermore, the relationships between these flanker variables and trait and state NA measures were non-significant. This indicates that the significant relationships observed between these flanker measures and PA were not simply due to high overall emotional activation, but were specific to PA per se.

In addition to relationships between PA and flanker performance, a negative correlation between trait PA and visual search slope on target absent trials was found. This indicates that individuals with greater trait PA tended to have shallower search slopes when the target was absent, meaning that PA was related to less RT cost per distractor on the visual search task. However, this relationship was not observed for state PA, and both trait and state NA also showed non-significant trends toward a negative relationship with target absent visual search slope, suggesting that the relationship, if real, may be due to overall emotional activation more than PA per se. Indeed, when PA and NA were summed together providing a measure of affect activation, the relationship

between trait activation and visual search slope on target absent trials was significant ($r = -.28, p = .011$), but this was not true for state activation ($p = .27$).

Trait PA was significantly negatively related to overall RT on both global and local trials of the global/local task, such that individuals with greater trait PA were likely to detect the targets in the global/local task more quickly, regardless of target congruency. However, trait NA also correlated negatively with overall local RTs for the global/local task (and just missed significance with the global task RTs, $p = .09$). The finding that greater levels of both trait PA and NA are related to faster RTs on the global/local task suggests that this relationship may be explained by activation, rather than strictly positive or negative affect. As such, trait activation (trait PA + trait NA) was calculated to examine this possibility. Interestingly, trait activation was significantly negatively correlated with both global RT ($r = -.32, p = .003$) and local RT ($r = -.32, p = .002$), indicating that high emotional activation, rather than PA or NA, predicted decreased in RT on this task.

Trait PA was negatively related to the RT for Posner neutral trials, such that greater trait PA scores were related to faster RTs on the Posner task when a neutral cue was presented. In addition, state NA was positively related to Posner costs, such that greater state NA scores predicted more costs on trials in which an invalid cue was presented which follows from the idea that high NA should be associated with greater focusing of attention at cued locations. Again, trait (trait PA + trait NA) and state activation (state PA + state NA) were calculated to examine the possibility that the correlations between affect and Posner neutral were explained by activation. State activation and Posner neutral were significantly correlated ($r = -.26, p = .017$) suggesting

that high emotional activation was related to the decrease in RT for this task. Trait activation narrowly missed reaching significance ($p = .055$) but a similar explanation for the decrease in RT on the Posner task can be seen here.

In general, greater emotional activation was associated with faster overall RTs on three separate tasks (global/local, visual search, and Posner cueing). Furthermore, greater PA (both trait and state) was associated with faster RTs and reduced interference in the flanker task in the absence on any effects of NA. Lastly, state NA was related to more costs on invalid Posner trials.

Relationships among Personality Factors and Affect Measures

Five different personality variables were calculated for each participant: conscientiousness, openness to experience, neuroticism, agreeableness, and extraversion (explanation for how variables were derived can be found in the methods section) (see Table 9 for *Ms*, *SDs*, and range). A correlational analysis was conducted in order to examine the intercorrelations amongst the five personality variables (see bold section of Table 10 for zero-order correlational values). Agreeableness was positively correlated with conscientiousness and extraversion. Both agreeableness and extraversion negatively correlated with neuroticism. This is the expected pattern of results that is often found in the literature (e.g. Costa & McCrae, 1992). In addition to the intercorrelations among personality measures, a variety of significant correlations were found among the personality facets and the four affect measures discussed in the previous section (see Table 10 for zero-order correlational values)

Table 9.

Means, SDs, and Range for All Personality Measures.

	<i>M</i>	<i>SD</i>	<i>Min</i>	<i>Max</i>
Conscientiousness	3.42	.54	2.3	4.8
Openness	3.68	.59	2.2	4.9
Neuroticism	2.49	.69	1.2	4.3
Agreeableness	3.80	.50	2.0	4.7
Extraversion	3.59	.71	2.1	4.9

Note: The scale ranged from 1 to 5 with higher scores indicating higher levels of the personality facet.

Both trait and state PA correlated positively with scores of extraversion such that higher PA was related to greater extraversion. Trait PA also correlated negatively with neuroticism, such that individuals who scored higher on trait PA reported less neuroticism. Trait NA was correlated with neuroticism as well, but positively, such that individuals who scored higher on trait NA tended to report more neuroticism. Both trait and state NA were significantly negatively correlated with agreeableness, where lower levels of NA were associated with greater agreeableness. Openness to experience was positively related to state PA but negatively related to trait NA, such that more agreeable individuals reported greater state PA and less trait NA. There were no significant relationships with conscientiousness. All of the relationships between affect and personality found here have been previously reported in the literature (e.g. Shiota et al., 2006; Yik & Russell, 2001; Uziel, 2006) thus these results provide evidence that the affect and personality measures were performing as expected.

Table 10.

Correlations between Personality and Affect.

	1	2	3	4	5	6	7	8	9
1. Conscientiousness	-	.16	-.16	.24*	.02	.21	-.13	.01	-.07
2. Openness to Experience		-	.12	.08	-.03	.04	-.27*	.23*	-.11
3. Neuroticism			-	-.43**	-.42**	-.39**	.35**	-.12	.21
4. Agreeableness				-	.35**	.12	-.34**	.17	-.34**
5. Extraversion					-	.44**	-.08	.25*	-.19
6. Trait Positive Affect						-	.01	.19	-.06
7. Trait Negative Affect							-	-.22*	.39**
8. State Positive Affect								-	-.13
9. State Negative Affect									-

Note: * indicates $p < .05$, ** indicates $p < .01$.

Relationships among Personality and Cognitive Performance Measures

As AB performance is central to this study, a correlational analysis was conducted in order to examine the relationship between the four measures of the AB and 5 facets of personality (see bolded section of Table 11 for zero-order correlational values).

Unfortunately, no significant correlations were found among AB performance and personality. This finding was surprising, and the implications will be addressed in the Discussion section. Personality measures, however, were significantly correlated with a variety of other cognitive measures (see Table 12 for zero-order correlational values).

Openness to- Experience. Consistent with predictions from the diffusion hypothesis, openness to experience was significantly negatively correlated with local interference on the global/local task. Local interference is calculated as the degree to which local features interfere with RT on global trials, therefore this relationship suggests that individuals who score higher on the openness to experience personality factor are less influenced by local features in the global/local task; that is they are less locally biased. In addition, a significant negative correlation was found between openness to experience and Stroop interference. As Stroop interference is a measure of how much the colour words on incongruent Stroop trials affect RT, this relationship suggests that individuals who score higher on the openness personality factor are less susceptible to the Stroop effect. However, openness to experience was positively correlated with Stroop facilitation, which is a measure of how much the colour words on congruent Stroop trials can affect RT. This relationship suggests that individuals who score higher on openness can effectively use the colour words on congruent trials to aid their responses. Therefore it is unclear why individuals who are more open to experience would be influenced by the

Table 11.

Correlations between Measures of the AB and Personality.

	1	2	3	4	5	6	7	8	9
1. AB Magnitude	-	.04	-.43**	.04	-.04	.03	.01	.08	.06
2. T1 Accuracy		-	.38**	-.08	.13	.10	.17	-.07	-.13
3. T2 Sensitivity			-	-.15	.14	.01	.02	-.13	-.06
4. Lag-1 Sparing				-	-.03	.04	-.07	-.05	.03
5. Conscientiousness					-	.16	-.16	.24*	.02
6. Openness to Experience						-	.12	.08	-.03
7. Neuroticism							-	-.43**	-.42**
8. Agreeableness								-	.35**
9. Extraversion									-

Note: * indicates $p < .05$, ** indicates $p < .01$.

Table 12.

Correlations among Personality and Cognitive Performance Measures.

	Conscientious	Openness	Neurotic	Agreeable	Extraverted
Stroop Neutral	-.15	-.20	.10	-.01	.08
Stroop Interference	-.16	-.29**	-.12	-.14	.04
Stroop Facilitation	.11	.24*	.22*	.05	-.02
Enumeration Subitizing Period	.06	.09	-.01	-.17	.02
Overall Enumeration Accuracy	-.06	-.01	.09	-.18	-.23*
Visual Search Baseline RT	-.08	.01	.08	.12	.20
Visual Search Slope Target Present	.07	-.04	.17	.01	-.01
Visual Search Slope Target Absent	-.06	.04	.04	.11	-.08
Visual Search Slope Ratio	-.16	.05	-.06	.05	-.08
UFOV Fall-off	.01	.01	.10	-.01	-.26*
Overall UFOV Accuracy	.05	.01	-.01	-.01	.02
Posner Neutral	-.11	-.08	-.08	.15	.08
Posner Cost	-.04	.11	.10	.17	.07
Posner Benefit	.01	-.06	.15	.22*	.29**
Posner Costs + Benefits	-.03	.04	-.03	.27*	.25*
Overall Flanker RT 0 Distractors	-.15	-.11	.19	-.04	-.02
Overall Flanker RT 5 Distractors	-.09	-.07	.20	-.02	-.01
Flanker Interference 0 Distractors	-.21	-.11	.22	-.13	-.07
Flanker Interference 5 Distractors	-.02	-.09	.24*	-.02	.13
Overall Flanker Interference	-.13	-.12	.27*	-.09	.12
Difference in Flanker Interference	-.18	-.02	-.03	-.11	.07
Difference in Flanker RT	.13	.08	.02	.05	.01
Global Overall RT	-.12	-.19	.13	.01	-.07
Local Overall RT	-.11	-.04	.09	.14	-.02
Global Interference	-.01	-.19	.05	.02	.18
Local Interference	-.19	-.22*	.16	-.07	-.05
Global Precedence	.16	.08	-.11	.08	.15

Note: * indicates $p < .05$, ** indicates $p < .01$.

words in the Stroop task on facilitation trials only. These relationships are further explored in the Discussion section.

Extraversion. Consistent with diffusion related predictions, extraversion was significantly negatively correlated with UFOV fall-off, such that individuals who scored higher in extraversion had less of an accuracy drop off from close to far target eccentricities on the UFOV task. However, in opposition to diffusion predictions, extraversion also negatively correlated with overall enumeration accuracy, suggesting that high scores on extraversion are related to poorer accuracy on the enumeration task. Extraversion was also significantly positively related to Posner benefits, and Posner costs plus benefits (but not Posner costs), suggesting that individuals who scored higher in extraversion were more likely to benefit from the valid cues in the Posner task, and were more likely to use the cues in general. No other measures of cognitive performance correlated with extraversion.

Agreeableness. As with extraversion, agreeableness was positively correlated with both Posner benefit, and Posner costs plus benefits (but the relationship with Posner cost failed to reach significance). These two measures of Posner cueing performance reflect the tendency of participants to use the cues presented in this task. Thus these two relationships suggest that individuals who score higher in agreeableness tend to be more influenced by the cues in the Posner task. No other measures of cognitive performance significantly correlated with agreeableness.

Neuroticism. Scores on the neuroticism personality factor positively correlated with Stroop facilitation. This suggests that individuals who were more neurotic were more likely to be influenced by the word meaning in the Stroop task, and thus benefited

from reading the words on congruent Stroop trials. However, the relationship between neuroticism and Stroop interference was not significant, suggesting that while neurotic individuals may be influenced by the words on congruent trials, they were not influenced by them on incongruent trials. This makes this relationship somewhat unclear, and is further investigated in the Discussion section. Lastly, neuroticism positively correlated with flanker interference at 5 distractors, as well as overall flanker interference. This suggests that individuals who displayed higher levels of neuroticism were more likely to suffer interference from the flanker distractor. Conscientiousness did not correlate significantly with any of the cognitive measures used in this experiment.

Intercorrelations among Cognitive Measures

A large variety of significant intercorrelations were observed among the cognitive measures used in this study (see Table 13 for a more detailed summary of the significant correlations). Many of the relationships were as expected, such as the 17 large positive relationships amongst RT measures such as Stroop neutral RT, Posner neutral, global RT, local RT, and baseline visual search RT. There were also 21 positive relationships between a measure of interference/facilitation and a separate RT measure (e.g., Stroop neutral RT and overall flanker interference) suggesting that individuals with longer RTs (even in baseline conditions) were more likely to show interference from irrelevant stimulus information. Also, accuracy-based performance on the enumeration and UFOV tasks were positively related to each other and negatively related to some RT measures, suggesting that individuals with accurate target detection accuracy showed faster RTs on at least some tasks. These relationships show that the performance measures worked as expected. A few additional relationships appear more arbitrary and, given the number of correlations, some may reflect Type 1 errors.

Table 13.

Significant Intercorrelations among Cognitive Measures.

Variable 1	Variable 2	<i>r</i>	<i>p</i>
Enumeration Subitizing Period	Stroop Neutral	-.35	.001
Enumeration Subitizing Period	Overall UFOV Accuracy	.23	.038
Enumeration Subitizing Period	Overall Local RT	.28	.009
Overall Enumeration Accuracy	Stroop Neutral	-.28	.012
Overall Enumeration Accuracy	Overall UFOV Accuracy	.33	.002
Overall Enumeration Accuracy	Visual Search Slope Ratio	.29	.009
Overall Enumeration Accuracy	Global Interference	-.24	.030
Overall Enumeration Accuracy	Global Precedence	-.22	.040
Overall Enumeration Accuracy	Overall Local RT	-.31	.005
Stroop Neutral RT	Overall Flanker RT 0	.58	<.001
Stroop Neutral RT	Overall Flanker RT 5	.55	<.001
Stroop Neutral RT	Overall Flanker Interference	.39	<.001
Stroop Neutral RT	Flanker Interference Distractors	.24	.029
Stroop Neutral RT	Flanker Interference No Distractors	.42	<.001
Stroop Neutral RT	Posner Neutral	.39	<.001
Stroop Neutral RT	Visual Search Baseline RT	.40	<.001
Stroop Neutral RT	Local Interference	.31	.005
Stroop Neutral RT	Overall Global RT	.51	<.001
Stroop Neutral RT	Overall Local RT	.57	<.001
Stroop Interference	Overall Flanker RT 0	.24	.032
Stroop Interference	Overall Flanker RT 5	.26	.019
Stroop Interference	Posner Neutral	.31	.004
Stroop Interference	UFOV fall-off	.27	.012
Stroop Facilitation	Overall Flanker RT 0	.29	.008
Stroop Facilitation	Difference in Flanker RT	-.36	.001
Stroop Facilitation	Overall Global RT	.25	.012

Variable 1	Variable 2	<i>r</i>	<i>p</i>
Posner Neutral	Overall Flanker RT 0	.47	<.001
Posner Neutral	Overall Flanker RT 5	.47	<.001
Posner Neutral	Flanker Interference No Distractors	.39	<.001
Posner Neutral	Overall Flanker Interference	.34	.002
Posner Neutral	Visual Search Baseline RT	.45	<.001
Posner Neutral	Overall Global RT	.42	<.001
Posner Neutral	Overall Local RT	.53	<.001
Posner Cost	Overall Local RT	.27	.015
Visual Search Baseline RT	Overall Flanker RT 0	.58	<.001
Visual Search Baseline RT	Overall Flanker RT 5	.52	<.001
Visual Search Baseline RT	Flanker Interference No Distractors	.32	.004
Visual Search Baseline RT	Overall Flanker Interference	.26	.020
Overall Global RT	Overall Flanker RT 0	.61	<.001
Overall Global RT	Overall Flanker RT 5	.54	<.001
Overall Global RT	Flanker Interference Distractors	.31	.004
Overall Global RT	Flanker Interference No Distractors	.53	<.001
Overall Local RT	Overall Flanker RT 0	.59	<.001
Overall Local RT	Overall Flanker RT 5	.52	<.001
Overall Local RT	Flanker Interference Distractors	.32	.004
Overall Local RT	Flanker Interference No Distractors	.46	<.001
Overall Local RT	Overall Flanker Interference	.46	<.001
Local Interference	Difference in Flanker RT	.22	.046
Global Precedence	Visual Search Slope Target Present	.22	.044
Global Precedence	Visual Search Slope Ratio	-.22	.045
Global Precedence	Difference in Flanker RT	-.23	.040

Reliability of the Measures

Due to the fact the fact that some of the predicted relationships in this thesis were either not observed, or were significant but in an unexpected direction, it was necessary to examine the reliabilities of the measures used in this study. To examine the reliability of the cognitive task measures, a split-half correlation with a Spearman-Brown correction was completed for all of the cognitive variables (see Table 14) (Rosenthal & Rosnow, 1991; Wilmer, 2008). Each of the 7 cognitive tasks were split by even or odd trials, and each of the measures were calculated separately for even and odd trials. A simple Pearson correlation was then conducted to test the degree to which measures derived from even and odd trials were related (see value under “r” heading in Table 14). The Spearman-Brown correction was then applied to adjust each correlation upwards to account for the fact that the measures were computed using only half of the trials (see last column of Table 14). A corrected value of at least .70 was required in order to claim good reliability.

Importantly, the three main AB measures (AB magnitude, T1 accuracy, and T2 sensitivity) were found to be acceptably reliable with corrected values greater than .70. The reliability estimate of .72 observed here for the AB was similar to the test-retest reliability of .66 that McLaughlin, Shore and Klein (2001) obtained for the AB despite the fact that their study used two different AB tasks with testing sessions separated by 6 weeks. All of the raw variables for each of the cognitive measures were also found to be acceptably reliable, such that all but one of the measures of overall accuracy or mean RT showed corrected values greater than .80. None of these raw variables were related to AB magnitude. The good reliability estimates for AB magnitude and for these raw variables suggest that these null relationships were not the result of too much measurement error, but that these variables are simply unrelated to AB magnitude.

Table 14.

Split-half Reliability Estimates for all Cognitive Performance Measures.

	r	Spearman-Brown Corrected r
AB Magnitude	.56	.72
T1 Accuracy	.61	.76
T2 Sensitivity	.56	.72
Lag-1 Sparing	-.05	-.08
Global Congruent RT	.74	.85
Global Incongruent RT	.75	.86
Local Congruent RT	.75	.86
Local Incongruent RT	.76	.86
Global Interference	.07	.13
Local Interference	.32	.48
Global Precedence	.18	.31
Stroop Neutral RT	.80	.89
Stroop Congruent RT	.82	.90
Stroop Incongruent RT	.68	.81
Stroop Interference	.12	.21
Stroop Facilitation	.16	.28
Overall UFOV Accuracy	.89	.94
UFOV Fall-Off	.46	.63
Overall Enumeration Accuracy	.79	.88
Visual Search Baseline RT Present	.68	.81
Visual Search Baseline RT Absent	.49	.66
Visual Search Slope Present	.45	.62
Visual Search Slope Absent	.73	.84
Visual Search Slope Ratio	.00	.00
Posner Neutral RT	.85	.92
Posner Valid RT	.93	.96

	r	Spearman-Brown Corrected r
Posner Invalid RT	.49	.66
Flanker Congruent RT 0 Distractors	.76	.86
Flanker Congruent RT 5 Distractors	.69	.82
Flanker Incongruent RT 0 Distractors	.72	.84
Flanker Incongruent RT 5 Distractors	.69	.82
Flanker Interference 0 Distractors	-.21	.00
Flanker Interference 5 Distractors	-.07	.00
Difference in Flanker Interference	-.08	.00
Difference in Flanker RT	.27	.43

In contrast to the raw measures, in many cases the derived or subtracted measures, such as global precedence or Stroop facilitation, had very poor reliability. This was somewhat troubling for two reasons: 1) it means that it is possible that some of these variables really are related to AB magnitude, but that the relationships could not be observed here due to measurement error, and 2) it could indicate that the significant relationships found between some of the cognitive performance measures and the AB may be spurious. To further explore the nature of the relationship between AB magnitude and three measures that showed significant relationships with AB magnitude yet had low reliability, a series of regression analyses were conducted.

To examine the relationship between global/local processing and the AB, the four raw measures of global/local processing (RT for global and local congruent and incongruent) were entered as simultaneous predictors into a regression with AB magnitude as the criterion. RT for the global incongruent condition explained a significant proportion of the unique variability in AB magnitude ($p = .01$), with semi-partial $r = .29$. Interestingly, the strength of this relationship between two variables with good reliability is almost the same as the variability explained by the derived local

interference ($r = .22$), and global precedence ($r = -.24$) measures that had low reliability. Although the zero-order correlation between AB magnitude and global incongruent was not significant, the semi-partial was. This suggests that when variability common to all of the global/local RT measures was removed (e.g., response execution speed, participant's desire to be careful in the accuracy of the response), the remaining variability specific to the amount that local information interfered while performing global trials was related to AB magnitude. Local interference is calculated by subtracting the RT for global congruent from global incongruent. The present results suggest that local interference predicts AB magnitude because of variability on the incongruent trials, not the congruent trials, as one might expect if this variable was reflecting local interference.

In a subsequent regression both local interference and global interference were included as simultaneous predictors of AB magnitude. Local interference was a significant predictor of AB magnitude over and above global interference (semi-partial $r = .27, p < .01$) which was not significant (semi-partial $r = -.09, p = .397$), and the overall amount of variability explained was similar to that observed for global precedence alone and for global incongruent RT in the regression above. Global precedence is calculated by subtracting local interference from global interference. The results of this regression suggest that global precedence predicts AB magnitude because of local interference, without any contribution from global interference.

In sum, because the highly reliable measure of global incongruent RT explained nearly the same amount of variance as measures derived from this variable, it can be concluded that the lack of reliability for the subtracted measures did not produce spurious relationships. Indeed, the fact that the single measure of global precedence predicted almost as much variability ($r^2 = .06$) in AB magnitude as the four RT predictors

combined ($R^2 = .09$) suggests that the variability in this measure that is reliable is quite highly related to AB magnitude.

Similarly, the raw measures from the Stroop task (neutral, congruent, and incongruent RT) were entered into a simultaneous regression with AB magnitude as the criterion variable, resulting in a multiple- R^2 of .09. Congruent RT significantly explained a unique proportion of the variability in AB magnitude ($p = .01$) and neutral RT approached significance (semi-partial $r = .19$, $p = .08$). The semi-partial correlation coefficient for congruent RT and AB magnitude ($r = -.28$) was similar in size to the zero-order correlation for Stroop facilitation and AB magnitude ($r = .26$), indicating that this highly reliable raw measure explained nearly the same amount of variance as did the less reliable derived Stroop facilitation measure. As Stroop facilitation, which was previously shown to relate to AB magnitude, is calculated by subtracting neutral RTs from congruent RTs, the present results suggest that Stroop facilitation predicts AB magnitude because large ABs are associated with faster congruent RTs and somewhat slower neutral RTs. Therefore, as was the case with the global/local task, while the derived or subtracted variable of Stroop facilitation did not have high reliability, the raw variables used to create these derived variables did, and explained nearly the same amount of variability in AB magnitude as the derived measures. As such, this allows us to conclude that the relationships between AB magnitude and these cognitive measures are real, rather than spurious relationships brought about by error.

While the above analyses suggest that the observed relationships between AB magnitude and local interference, global precedence, and Stroop facilitation were real, it remains possible that the null relationships observed between measures from other tasks and AB magnitude were the result of poor reliability of the measures. Indeed, the derived

flanker variables showed a reliability of 0, indicating that they were extremely unreliable and may not be useful individual difference measures. Therefore the flanker results should be treated with extreme caution. However, it is also worth noting that when regressions using the raw variables were performed for each of the other tasks, no raw variables were found to be unique significant predictors.

While the three main measures of the AB were found to be reliable, the measure of lag-1 sparing showed a reliability of 0 (see Table 14), indicating that it too is an extremely unreliable measure. As such, the lag-1 sparing results must be interpreted with caution, as the relationships found may be simply due to error. As lag-1 sparing was related almost exclusively to performance on the flanker compatibility task, which also showed a reliability of 0, it is even more likely that these relationships were due to simple measurement error. This will further explored in the General Discussion section.

In addition to examining the reliabilities of the cognitive measures, the internal consistency values were calculated for both the state and trait affect measures (ERF and PANAS receptively) as well as the personality measure (NEO-Pi). Internal consistency was measured here using Chronbach's alpha to examine the NA and PA facets of the affect scales, and all five facets of the NEO-Pi. Consistent with past research examining these scales (e.g., Crawford & Henry, 2004; Costa & McCrae, 1992), Chronbach's alpha for all of these scales was acceptably high (see Table 15 for values) indicating that these measures were reliable. As mentioned earlier, the AB measures were also found to be reliable, thus the null relationships reported earlier between affect measures and the AB, and personality measures and the AB cannot be explained by measurement error. This will be discussed further in the General Discussion section.

Branigan, 2005; Gasper & Clore, 2002). The hypothesis was based on the assumption that individuals who have a bias to diffuse their attention on the global/local task may also do so on the AB task. This hypothesis was supported by the results. Global precedence and local interference scores did significantly correlate with AB magnitude in the expected directions thereby providing evidence that dispositional diffusion can predict AB magnitude. This finding is particularly interesting because it is the first to show that individual differences in cognitive performance patterns indicative of diffusion can predict individual differences in AB performance.

Unlike previous studies of the AB where focus/diffusion was manipulated by task instructions, the addition of an extra task, the induction of positive affect (Olivers & Nieuwenhuis, 2005, 2006), or stimulus display (Arend et al., 2006), participants in the present study were not given any manipulation or instruction to focus or diffuse during the AB task. Global interference, however, did not significantly relate to AB magnitude, suggesting that it is mainly the preoccupation with local features, or a local precedence, that contributes meaningful variability to the global precedence score, allowing it to relate to AB magnitude. This supports the overinvestment hypothesis of Olivers and Nieuwenhuis (2005, 2006), which states that the AB occurs when individuals over-focus their attention to the items in the AB stream, thus overinvesting valuable attentional resources and creating more competition for further processing. When individuals diffuse their attention, they invest less in each item and are better able to distribute their attentional resources, thus reducing the competition for attentional resources and improving T2 accuracy.

It is clear from Figures 16a and 20 that on average there was no bias toward global or local features on the global/local task, but that there were large individual

differences in global/local bias (as evidenced by the large distribution of global precedence scores). Navon (1977; 1981). Others (e.g., Cassia, Simion, Milani, & Umlità, 2002) have typically reported a generalized bias toward global precedence in the global/local task (i.e., on average greater interference from global information than from local information), but the degree of general global bias can be modulated by changing the relative and absolute visual angle of the global and local information (Kinchla & Wolfe, 1979). The fact that as a group the participants in the present study showed no bias toward either global or local information suggested that each individual's bias toward global or local was the result of their dispositional processing style rather than any bias dictated by the stimuli.

In addition to the relationship between AB magnitude and performance on the global/local task, AB magnitude was also significantly related to Stroop facilitation. In the Stroop task, word reading is an automatic process that is difficult, if not impossible, to override. Previous studies show that individuals who diffuse their attention are more likely to allow automatic processes to take over, thus it seemed likely that they would be more susceptible to the Stroop effect (see Trick & Pylyshyn, 1993). However, contrary to the hypothesis, here Stroop facilitation was significantly positively related to AB magnitude, suggesting that individuals who were more influenced by the words in the Stroop task on congruent trials were more likely to have larger ABs. It is important to note, however, that Stroop interference, which should also relate to being influenced by the words in the Stroop task, was not at all related to AB magnitude.

There are two reasons for why this pattern may have emerged. First, given that Stroop interference and facilitation are derived by subtracting RT for incongruent or congruent trials from neutral trial RT, it is possible that individuals who over-focus may

have a different “neutral” or baseline point than do individuals who diffuse. If participants prone to over-focusing had longer Stroop neutral RTs, then the difference between neutral and congruent (i.e., Stroop facilitation) would be larger than for diffusers, not because they had more facilitation but because they had longer neutral RTs. Indeed there was a large significant positive correlation between Stroop neutral RT and local interference, such that individuals who were more focused and experienced more interference from local features on the global/local task also had longer RTs on in the Stroop baseline condition (see Table 13).

The second reason is that while many people conceptualize both facilitation and interference as the result of the influence of word reading on colour naming times, evidence exists to suggest that they are dissociable processes that may exist for different reasons. A review paper by MacLeod and MacDonald (2000) examined this evidence, and discussed a study in which no correlation was found between individual Stroop facilitation and Stroop interference. Indeed facilitation and interference were not significantly correlated in the current study ($p=.10$), providing support for the idea that facilitation and interference represent two unrelated processes. MacLeod and MacDonald (2000) suggest that Stroop facilitation may be attributed to inadvertent reading errors in the congruent condition, whereby participants simply read the words, and do not respond to the ink colour. As word reading is faster than colour naming, a facilitative effect seems to emerge (i.e., it is not that word reading facilitates colour naming, it is that word naming beats colour naming). Dunbar and MacLeod (1984) showed that when the words in a congruent condition were semantically related to the ink colour (i.e. the word “lemon” written in yellow ink) the facilitation effect disappeared, although incongruent trials using the same type of stimuli (the word “lemon” written in red ink) still showed an

interference effect. Therefore, Stroop facilitation and Stroop interference appear to be two distinct phenomena. When entered in the regression model, Stroop facilitation explained a significant unique proportion of the variability in AB magnitude over and above global precedence and visual search absent slope. If global precedence really does reflect diffusion as argued above, then this suggests that something other than diffusion in the Stroop facilitation scores relates to AB magnitude. It is currently unclear what cognitive process underlies the relationship between Stroop facilitation and AB magnitude, or even if this relationship is simply a Type I error. Presently, I can simply conclude that the relationship between Stroop performance and the AB magnitude requires further investigation, perhaps using experiments that include a semantic incongruency condition (e.g., lemon in red ink) as mentioned above.

Lastly, it was predicted that visual search slopes would positively relate to AB magnitude, such that individuals with steeper slopes would show larger ABs given that individuals who overinvest attention during RSVP trials would be likely to invest more attention in each item in the visual search array and therefore show a larger cost per distractor, creating steeper visual search slopes. Indeed, Smilek et al. (2005) observed shallower search slopes on a visual search task when participants received instructions to diffuse their attention, as compared to individuals who received instructions to focus on the task. As diffusion is related to smaller AB magnitude, it followed that shallow search slopes might also be related to smaller ABs. Interestingly, the opposite relationship was found in this study, such that visual search slope ratio, and slope on absent trials was significantly negatively related to AB magnitude. That is, individuals who had larger RT costs per distractor item (steeper search slopes) on target absent trials showed smaller ABs. It is important to note that while the participants in the Smilek et al. (2005) study

who were given diffuse instructions did have shallower search slopes, this pattern was seen only on difficult trials, in which the targets and distractors were very similar. In their study, there was no difference between the diffused and focus instruction groups on easy trials. Therefore in this current study it is possible that the expected relationship between AB magnitude and visual search slope was not found due to the nature of the visual search task used. Perhaps if the task had been more difficult, the hypothesized pattern would have emerged, but this seems less likely given that the present relationship would have to completely reverse directions to match the results of Smilek et al. (2005) and the hypothesis.

While visual search slope on target absent trials significantly predicted AB magnitude, visual search slope on target present trials did not, and the slope ratio was a significant predictor. This suggests that it is not necessarily the time to detect targets in the visual search task that predicts the AB, but rather the time to give up searching for the target on target absent trials. In other words, individuals who are more likely to “give up” searching and are faster to say that the target is absent are more likely to have larger ABs. The fact that errors increase substantially for target absent trials with a large number of distractors suggests that individuals are sometimes stopping search prematurely, and that a shallow visual search slope on absent trials may reflect that the individual engaged in sloppy search rather than efficient search. Recall that MacLeod and MacDonald (2000) suggested that Stroop facilitation occurs because individuals simply read the word instead of the font colour. If Stroop facilitation reflects the degree of word reading, then individuals who took the easier route on the Stroop task and simply read the words on congruent trials had larger ABs. Similarly, individuals who give up prematurely in the visual search task also had larger ABs. Together these results suggest that a more sloppy

or carefree approach to the tasks may be related to larger ABs. However, when entered into a regression, visual search slope for absent trials explained a significant proportion of unique variability in AB performance over and above Stroop facilitation and global precedence, suggesting that the processing that underlies this relationship is different from than that measured by global precedence or Stroop facilitation.

Unfortunately no measures from the other four tasks were related to AB magnitude. The magnitude of costs and benefits on the Posner task were expected to positively correlate with AB magnitude, as it was hypothesized that individuals who diffuse their attention would be less likely to use the cues in the Posner task, and thus show less benefits and costs (e.g. Pesce & Bosel, 2001). However, there was no relationship among any of the Posner measures and AB magnitude. AB magnitude was hypothesized to negatively relate to the flanker compatibility effect, as previous studies seemed to suggest that diffusion of attention was related to more interference from flankers on difficult trials due to the abundance of resources available to process these flankers, even at high cognitive loads (Green & Bavelier, 2003; 2006a). However, no correlation was found between flanker performance and AB magnitude. AB magnitude was also hypothesized to negatively correlate with both overall enumeration accuracy, and the length of the subitizing period. Past studies showed that individuals with a diffused attentional state had better accuracy on the enumeration task, and longer subitizing periods, thus it was expected that such a pattern of performance would negatively relate to AB magnitude (Green & Bavelier, 2003; Trick & Pylyshyn, 1993). Once again, these two measures did not correlate with AB magnitude. Lastly, UFOV accuracy was hypothesized to relate negatively to AB magnitude, as diffused individuals in past studies had been shown to have larger fields of view, and thus performed better on

the UFOV task (Green & Bavelier, 2003; 2006a). Again, no correlation was found between these measures. While none of these four measures related to AB magnitude, three of the four (not Posner cueing performance) did significantly relate to target accuracy - a possibility that was raised in the hypothesis section. This will be further discussed in the target accuracy section below.

It is important to note that of the tasks which did not predict AB magnitude, all four (Posner, flanker, enumeration and UFOV) required the participant to diffuse or direct their attention across space, whereas the tasks which did predict AB magnitude (global/local, Stroop) required participants to attend to a central location in order to process the relevant information. Although the visual search task does require participants to attend to a large array of stimuli over space, it was not the ability to detect the target, but rather the tendency to “give up” searching which predicted AB magnitude. This might suggest that diffusion of attention across space is not related to the AB, but that the more your attention is focused on irrelevant local information within the same stimulus (the word in the Stroop task or the local features in global/local task), the greater the AB. In other words, AB magnitude may be related to the ability to overcome local interference in a task via diffusion. This supports the overinvestment hypothesis (Olivers & Nieuwenhuis, 2006) because it shows that AB performance suffers when individuals over focus their attention and unnecessarily attend to irrelevant local details. When participants are able to diffuse their attention, thus broadening their attentional span, they are better able to avoid interference from irrelevant local features.

Interestingly, of the four hypotheses that were not supported, three were derived from examining the Green and Bavelier (2006) video-gamer studies. It was thought that because action VGPs are required to attend to multiple items in the games that they play

that this leads to an ability to divide their attention effectively, or diffuse their attention. None of the tasks on which they excelled however were related to AB magnitude in this experiment. Therefore, it is possible that the VGPs in Green and Bavelier's (2003) studies were not necessarily diffusing their attention, but rather engaging in some other form of attentional allocation that was beneficial for the AB task and for the other cognitive tasks used in their experiment. It is possible that some tasks included in the present study, such as global/local and Stroop, measure diffusion of attention, but that other tasks used here and in Green and Bavelier's (2003) studies measured some aspect of "hypervigilance" or effective division of attention rather than diffusion.

Hypervigilance is simply the ability to successfully divide attention and attend to a number of different stimuli within a short span of time (Greenfield, deWinstanley, Kilpatrick & Kaye, 1994). Indeed past studies on action VGPs have shown that participants who were "expert" VGPs performed significantly better on tasks of divided attention than did novice VGPs, suggesting that these VGPs possess a better than average ability to rapidly scan a stimulus array, and correctly report multiple target locations (Greenfield et al., 1994). Hypervigilance or an increased ability to divide attention is likely different than diffusion of attention as it is a less passive strategy than simply allowing targets to "hit you", therefore the difference between VGPs in their study and diffusers in ours is potentially reasonable, although this does not explain why the VGPs in their study also performed better on the AB task as compared to NVGPs. While information on video game play was collected for this study, unfortunately only a small number of participants reported having ever played an action video game ($N=11$), and only one participant reported playing action video games frequently. This prevents

further exploration of this potentially interesting finding, but does lend itself to ideas for future research.

The finding that dispositional diffusion of attention can lead to better performance on the AB task appears to support not only the Olivers and Nieuwenhuis (2006) overinvestment hypothesis, but also some other existing models of the AB. For example, the late selection interference model of the AB (Shapiro et al., 1994) suggests that items in the RSVP stream are processed first for semantics, and then high-level visual and semantic representations are formed and placed into a pre-consolidation buffer. Relevant items are then bound into object files and consolidated into VSTM. As immediate post-target distractors are admitted to this buffer, T2 suffers from interference from these distractors while waiting for consolidation, and thus an AB occurs.

The overinvestment hypothesis and the dispositional diffusion findings from this thesis appear to support this model of the AB because they suggest that if you focus your attention and allow distractors to cross the threshold for entry into the VSTM buffer, T2 is more likely to receive interference and thus the chance of an AB occurring is larger. On the other hand, if an individual were to diffuse their attentional resources, thereby preventing distractors from entering the VSTM buffer, there would be less items to interfere with the representation of T2, thus giving T2 a better chance to be reported. In order for this model to fit, however, one would have to assume that distractors enter the pre-consolidation buffer because they have not been inhibited, and not that they enter regardless of the amount of attention that has been allocated to them. If the distractors immediately preceding T1 and T2 enter into the pre-consolidation buffer regardless of the amount of attention they receive, then the interference with T2 would occur regardless of whether attention was diffused or focused, and this model would not be supported.

The diffusion hypothesis can also support the early selection model of the AB (Raymond et al., 1992). The Raymond et al. (1992) model suggests that the distractor immediately following T1 causes interference with T1 processing, which initiates a suppression of high-level feature gathering until T1 processing is complete and the suppression removed. If we assume that the T1+1 item interferes with T1 because it has not been properly inhibited, or has crossed some activation threshold which allows it to enter the same attentional window as T1, then it would follow that diffusion of attention would reduce the AB because it would prevent this distractor from interfering with T1 processing time, thus shortening the wait for T2 and preventing an AB from occurring. However, this model also seems to suggest that the T1+1 item would enter the same attentional gate regardless of the amount of attention it receives, in which case diffusion would not prevent an AB from occurring.

Similarly, bottleneck models of the AB such as the two-stage model posited by Chun and Potter (1995), the short term consolidation model of Joliceour (1998, 1999), and the computational serial token model of Bowman and Wyble (2007) suggest that the AB occurs because T2 receives interference from distractors while waiting in a theoretical attentional “bottleneck” which causes the representation of T2 to decay or degrade, preventing it from reaching conscious awareness. Potentially, diffusion could reduce the AB in these models by preventing distractors from entering the bottleneck with T2, thus reducing the amount of interference that T2 receives, and leaving the T2 representation more intact. This in turn would allow T2 to eventually receive higher level processing and have a better chance of coming into awareness because the representation of T2 was subjected to less decay. Again, it is unknown whether items enter the bottleneck because they have crossed some sort of activation threshold, or whether every

item that is perceived enters the bottleneck. Therefore, it is possible that these models in fact are not supported by the diffusion hypothesis. In addition, the finding in this thesis that none of the cognitive measures of processing speed predicted AB magnitude argues against a bottleneck model, as faster processing speed should allow T1 to clear the bottleneck sooner, thus allowing T2 to receive processing before decaying and thus attenuating the AB. Therefore, this model is less supported by the data in this thesis.

In summary, depending on the interpretation of both the findings from this thesis, and of previous AB models, the diffusion hypothesis does appear in some ways to support existing models of the AB. However, further research is required in order to understand what is meant by the term “diffusion” and how exactly this state can effect attention before stating support for one model over another based on the findings in this thesis. Additionally, the role of processing speed and the fact that it does not relate to AB magnitude should be taken into consideration when assessing whether existing models of the AB are supported by the data in this thesis.

Target Accuracy

Past research on individual differences and AB performance has shown that target accuracy on the AB task is related to measures of processing speed. For example, Arnell et al. (2006) found that individual differences on manual choice response time tasks and speeded vocal naming predicted individual differences in RSVP target accuracy, but not in AB magnitude. Similar results were found here for a subset of RT measures, in that individuals with faster RTs on Posner neutral trials, and faster RTs to respond to the target in the flanker task were significantly related to better T1 and T2 accuracy respectively, but not to AB magnitude. This lends support to Arnell et al. (2006) who concluded that the ability to respond accurately to targets in the AB task is related to

information processing speed. Individuals who can quickly isolate targets from distractors in RSVP will be able to extract target information prior to the target's visual representation being overwritten by the subsequent item in the RSVP stream and should have better report accuracy for those targets. The present finding that different sets of predictors are related to AB magnitude (the slope of the T2 accuracy line across lags) and target accuracy (the height of the T2 accuracy line averaged across lags) also supports the dissociation between target accuracy and AB magnitude first reported in Arnell et al. (2006), and also observed by Colzato et al. (2007) and Arnell et al. (in press). In these studies measures of processing speed and fluid intelligence were related to target accuracy, but not AB size, while measures of executive control of WM were related to AB magnitude, but not target accuracy. Similarly, in this study performance consistent with processing speed was related to target accuracy but not AB magnitude, and measures related to control over irrelevant information were related to AB magnitude but not target accuracy.

It was hypothesized that performance on measures such as UFOV and enumeration may relate to diffusion of attention and predict the AB. This was because it was presumed that the individuals in the Green and Bavelier (2003) study were diffusing their attention, which is why they were performing well on these tasks. However, neither of these measures related to AB magnitude and enumeration accuracy was actually correlated negatively and significantly with global interference and global precedence providing evidence that higher enumeration accuracy was associated with less diffusion of attention, not more. Another way to think about the enumeration and UFOV tasks is in terms of processing speed. In both the UFOV and enumerations tasks stimuli are presented briefly to the participant, and are then removed. The dependent variable is the

accuracy of reporting the display (number of boxes for enumeration or the “spoke” that held the target in UFOV). In RSVP, targets are also presented briefly, followed by a trailing mask, and accuracy of report is the dependent variable. Given these similarities one might expect overall UFOV and enumeration accuracy to be sensitive to processing speed and for there to be positive relationships between UFOV accuracy, enumeration accuracy, and RSVP target accuracy. On the other hand, while these tasks share similarities with the AB task, they differ in that in the enumeration task there are no competing stimuli or mask, and in each of the paradigms there is only a single task and goal, not two as in the AB. Therefore the ability to quickly process items is paramount to these tasks, yet there is no requirement to manage multiple important targets.

Despite these differences, enumeration accuracy was found to significantly positively relate to both T1 and T2 accuracy, such that individuals with better target accuracy on the AB task also had better accuracy for reporting the number of boxes presented in the enumeration task. Overall UFOV accuracy was also positively related to T1 accuracy (the relationship with T2 sensitivity fell just short of significance), demonstrating that the ability to quickly locate the target in the UFOV array was related to how well individuals can process target items in the AB task. Overall UFOV accuracy and overall enumeration accuracy were also significantly and positively related to each other (see Table 13). To further support the idea that UFOV accuracy and enumeration accuracy are related to processing speed, overall enumeration accuracy was negatively related to Stroop neutral, and overall local RT (see Table 13). Overall, results from the enumeration and UFOV tasks suggest that performance on these tasks is mainly dependent on how fast individuals can process information, but not necessarily how diffused or focused their attention might be.

Lag-1 Sparing

Lag-1 sparing in the AB task is explained in terms of both T1 and T2 often being processed together into the same attentional window if they are presented one after the other with no intervening distractor items (e.g., Chun & Potter, 1995). While no specific hypotheses were proposed for how lag-1 sparing would relate to cognitive performance, a variety of flanker measures were found to significantly relate to lag-1 sparing (see Table 1). Flanker interference for the 5 distractor condition and overall flanker interference were both positively related to lag-1 sparing, such that individuals who exhibited larger lag-1 sparing had more interference in the flanker task. Additionally, individuals with greater lag-1 sparing also showed slower RTs on the flanker trials where 5 distractors were presented, and a greater difference in flanker RTs for 0 and 5 distractors. Lastly, individuals with greater lag-1 sparing had slower RTs on global trials of the global/local task. Thus, it appears that lag-1 sparing is not only related to slower RTs, but also to more interference on the flanker task, particularly for the more difficult 5 distractor condition. This indicates that individuals who are slightly slower to process target/distractor items, and who are more susceptible to interference from distractors are more likely to show greater lag-1 sparing. When entered into a regression, only the difference in flanker RT for 0 and 5 distractors explained a unique proportion of the variability in lag-1 sparing, showing that the majority of variability is shared across predictors, suggesting a common underlying construct.

One theory of lag-1 sparing states that during an AB task, the attentional “gate”, which was open to accept targets, closes once post-target items begin to interfere with target identification (e.g. Raymond et al., 1992). Given that the gate does not begin to close until the lag-1 item has begun to interfere, it can often sneak into the same

attentional window as T1 and receive sufficient attention for accurate report. According to such theories greater lag-1 sparing would suggest a relatively late closing of the gate. Individuals who are slower to shut out competing information in RSVP may also be the same individuals who are more likely to experience interference from distractor items in the flanker task, and subsequently have slower RT on these tasks. Indeed, the negative correlation between lag-1 sparing and T2 sensitivity approached significance ($p=.11$), indicating that individuals with more lag-1 sparing tend to have lower T2 accuracy overall (see Table 11). In summary, while these findings do not really provide any concrete evidence for or against theories of lag-1 sparing, they are consistent with the sluggish attentional gate theory, or at least with the idea that +1 items receive greater processing due to a less selective filtering mechanism. However, due to the unreliable nature of both the flanker task and the lag-1 sparing measure, any conclusions drawn from these data should be considered with caution and will require further investigation.

Affect and Personality

A variety of predictions were made regarding how affect and personality would relate to the AB. Studies from a variety of paradigms have provided evidence that PA promotes a diffuse attentional state (e.g., Fredrickson, 2001; Rowe et al., 2007), whereas NA promotes a more focused attentional state (Compton, 2000; Rowe et al., 2007). Studies of the AB and affect have also shown that PA is related to smaller AB magnitude, and NA was related to larger AB magnitude (MacLean et al., accepted; Olivers & Nieuwenhuis, 2006; Rokke et al., 2002). In addition, other studies have shown a relationship between affect measures and personality (e.g., Yik & Russell, 2001; Shiota et al., 2006; Uziel, 2006), which allowed for the hypothesis that personality would also

predict AB performance. However, neither affect nor personality significantly related to any of the AB measures in this experiment.

The fact that these relationships were not observed in this study is disappointing. The affect measures did perform as expected in other areas, such as the fact that they showed the expected relationships with personality and cognitive performance on some non-AB tasks. This indicates that the affect measures were valid and contained enough variability to effectively relate to some variables. If self-reported trait affect predicted AB magnitude in the MacLean et al. study, why might it not have done so here? At this point it is unclear, as the Maclean et al. study (accepted) used the same trait affect measure, a similar AB task, and a similar number of participants. Indeed, the means, ranges and standard deviations for the PA and NA measures are remarkably similar in the present study and that of Maclean et al. The reliability of both the affect and personality measures were also found to be extremely high, thus the null findings cannot be explained in terms of measurement error. Further research is required in order to better understand this discrepancy.

While affect and personality were not related to AB performance in this study, they were significantly related to each other, and to some cognitive performance measures that may reflect diffusion of attention. For example, measures of trait and state PA were significantly positively related to extraversion, and trait PA was significantly negatively related to neuroticism. In addition, both trait and state NA were significantly positively related to neuroticism. These results support the existing literature showing that both state and trait extraversion are related to PA (e.g., Nemanick & Munz, 1997) and that both trait and state NA are related to neuroticism (Nemanick & Munz, 1997). These results also highlight the fact that both the affect and personality measures

appeared to be valid measures, despite the non-significant correlations with AB performance.

Multiple significant relationships among affect and other cognitive performance measures were detailed in the results section. For example, PA was found to be significantly negatively related to many of the measures of RT used in this study, such as the flanker task, Posner neutral, and global and local overall RT. This suggests that PA facilitates faster target detection, and thus faster processing. Local overall RT and Posner neutral RT however were also significantly negatively related to NA, which raised the possibility that it is not positive or negative affect per se which is related to performance on these cognitive tasks, but rather overall emotional activation. Indeed, when a measure of activation was created for both trait and state affect, significant relationships among these same measures were found. This indicates that greater overall emotional activation is related to faster target or RT performance, regardless of emotional valence.

Measures of personality were also found to be related to many cognitive measures, most in the expected direction. For example, openness to experience was significantly negatively correlated with local interference on the global/local task, such that individuals who were more open showed less local interference. This is consistent with the hypothesis that diffusion measures would be positively related to openness to experience. It was expected that agreeableness and extraversion would show a similar pattern, but both of these measures did not relate to local interference. However, they did show a positive relationship with Posner costs and benefits, which is contrary to the diffusion hypothesis. It is possible that individuals who are agreeable or extraverted may be more likely to strive to follow researcher instructions, and thus were more likely to use

the cues in the Posner task. Lastly, neuroticism was positively related to a variety of flanker task measures, as well as to Posner benefits and Stroop facilitation.

Some interesting and puzzling relationships among Stroop measures and both openness to experience and neuroticism were found. Openness was negatively correlated with interference, suggesting that individuals who are more open to experience are less susceptible to the Stroop effect. However, openness was also significantly positively correlated with Stroop facilitation, suggesting that individuals who were more open to experience experienced more facilitation on congruent trials. This was puzzling because it suggested that individuals who scored in openness to experience were both less and more influenced by the words in the Stroop task. Going back to the previous discussion of Stroop and the AB, this may be because Stroop facilitation and Stroop interference are not related processes; that is individuals who show more interference are not more likely to show facilitation (MacLeod & MacDonald, 2000). Alternatively, the opposite pattern of relationships can be parsimoniously explained by suggesting that individuals who are open or diffused may have a different neutral RT in the Stroop task, and because facilitation and interference are derived by calculating the RT difference from congruent and neutral, and incongruent and neutral trials respectively, this could change the size of their interference and facilitation. Indeed, there was a significant negative correlation between openness and RT for congruent trials ($r = -.31$) and RT for incongruent trials ($r = -.35$), but a smaller correlation between openness and RT for neutral trials ($r = -.20$). This suggests that for individuals who score higher on the openness to experience variable, RT for all trials is faster, but slower for neutral than for incongruent or congruent trials. Taking into account how interference and facilitation are measured, this

suggests that individuals who are open to experience would show less interference, and more facilitation, as the data suggest.

Future Research/Considerations

While the results of this study have provided some support for both the Olivers and Nieuwenhuis overinvestment hypothesis and some of the diffusion-based hypotheses discussed earlier, many of the cognitive performance measures that were purportedly related to diffusion did not significantly relate to AB magnitude. Most notable was the absence of relationships between AB magnitude and the measures used in the Green and Bavelier (2003, 2006) video game studies. It was expected that the performance of the VGPs in the Green and Bavelier studies was related to their ability to diffuse or better distribute their attentional resources without overfocusing on specific items, but individual differences in the same cognitive tasks in which the VGPs excelled were not related to individual differences in AB magnitude. This naturally leads to the question of whether the VGPs in Green and Bavelier's studies were better able to diffuse their attention, thus allocating their attentional resources more effectively, or if the superior performance of VGPs in the Green and Bavelier studies did not result from diffusion of attention. For example, perhaps VGPs have more cognitive resources at their disposal, are more efficient at dividing their attention, have faster processing speed, or they may be able to quickly disengage attention from irrelevant stimuli. There is some evidence suggesting that VGPs may be using a cognitive strategy other than diffusion. For example, the original Green and Bavelier (2003) study and a subsequent study (Green & Bavelier, 2006) showed that VGPs appeared to have "extra" attentional resources left to process irrelevant distractors in the flanker task on difficult trials, whereas NVGPs showed little interference on difficult flanker trials.

I hypothesized that the difference between VGPs and NVGPs was that the VGPs were diffusing their attention rather than overinvesting and thus had more resources at their disposal. However, in the current study there was no relationship between global/local bias and the difference in flanker interference for easy and difficult conditions, suggesting that diffusion is not the reason why VGPs showed interference even on difficult flanker trials. In addition, previous studies noted that VGPs had a wider spatial distribution of attention than did NVGPs, which suggested that VGPs were using a diffused rather than focused attentional strategy (Green & Bavelier, 2006). However, this same study also noted that VGPs showed superior attentional abilities regardless of the spatial location of a target, suggesting that perhaps they had the ability to actively attend to more than one location at a time, rather than simply having a widened attentional span. Indeed, a recent follow-up study replicated the finding that VGPs have a superior ability to track multiple targets across a wide spatial range, as compared to NVGPs (Boot, Kramer, Simons, Fabiani, Gratton, 2008). Although it had seemed possible that diffusion of attention was responsible for the improvement in VGPs attentional abilities, it appears that diffusion of attention is different than simply dividing attentional resources across space or time.

As noted earlier, diffusion appears to be a more passive process by which participants allow targets or stimuli to “hit them” rather than actively engaging in a task, whereas the superior ability to divide attention, or simply being more efficient with their attention, is a more active process akin to hypervigilance. Therefore it is possible that the diffusers in this current study and the VGPs in the Green and Bavelier studies were attending to objects in space and time in a completely different way. It would be interesting to examine VGPs, and NVGPs to determine whether there is a group

difference in performance on diffusion of attention tasks like the global/local task and whether the group difference can explain the difference in AB magnitude for VGPs and NVGPs. If VGPs did have faster information processing abilities, then I would expect them to show increased overall target accuracy during the AB task (i.e. at all lags), whereas diffusers should show a smaller dip at short lags, but not improved T2 accuracy at long lags. Indeed, there is a suggestion of this in the 2003 Green and Bavelier paper, although it is difficult to convincingly demonstrate this given that performance nears ceiling levels at the longest lags. In the Green and Bavelier (2003) study VGPs showed longer subitizing periods and better overall accuracy in the enumeration task and greater overall accuracy in the UFOV task. In the present study, performance on the enumeration and UFOV tasks were positively correlated with each other, and both enumeration accuracy and UFOV accuracy were positively related to overall target accuracy in the AB task (but not with AB magnitude). Measures that tap processing speed have been found to predict overall target accuracy in AB tasks, but not AB magnitude (e.g., Arnell et al., 2006). The finding that accuracy on the enumeration and UFOV tasks is related to target accuracy but not AB magnitude suggests that VGPs superior performance on these tasks may be the result of superior processing speed, as opposed to concepts like diffusion. Currently it is unclear exactly why VGPs have superior performance on many of the cognitive tasks including the AB. Understanding the nature of the cognitive processing differences between VGPs and NVGPs is a worthy topic of future research, and may help us understand more about the AB and why individual differences on cognitive tasks do predict AB magnitude in some cases, but do not in other cases.

Secondly, the relationships between AB magnitude and both visual search slope on absent trials and Stroop facilitation were somewhat unexpected, and contrary to the

proposed hypotheses. There is evidence to support the idea that these measures are still in some way related to diffusion or focus of attention, but the fact that these same measures explained a unique proportion of the variability in AB magnitude over and above each other and global precedence suggests that different cognitive constructs may underlie their relationship to AB performance. Replication of these results is suggested. If replicable then a decomposition of these measures could be performed to further explore which aspects of these tasks may underlie their relationship to AB magnitude.

Lastly, the null relationship between AB magnitude and both personality and affect proved to be disappointing yet potentially intriguing findings. While past studies have shown a significant relationship between self-reported affect and the AB (MacLean et al., accepted; Rokke et al. 2002), this study showed no such relationship despite using similar affect and AB measures. This discrepancy is difficult to explain at this point, and thus bears further exploration in order to understand the true relationship between AB magnitude and affect. In addition, no significant relationships among personality factors and the AB were found in this study. While AB performance and personality had not yet been examined at the time of this study, making this study the first to attempt to show such a relationship, the strong links between personality and affect (e.g. Yik & Russell, 2001; Shiota et al., 2006; Uziel, 2006), and previous links in the literature between affect and the AB (e.g., MacLean et al., accepted; Jefferies et al., 2008; Olivers & Nieuwenhuis, 2006; Rokke et al., 2002) suggest that further research is required in order to understand why these variables were unrelated to AB performance.

The AB (McLaughlin et al., 2001), trait affect measures (Crawford & Henry, 2004), and personality measures (Costa & McCrae, 1992) have previously shown stable individual differences across time. For example, the AB does appear to be a stable

individual differences variable in that McLaughlin et al. (2001) reported a test-retest correlation of .66 for individual's AB magnitude on two different AB tasks tested six weeks apart in time. The Stroop (Schubo and Hentschel, 1977; 1978), visual search (Van Wert, Nova, Horowitz, & Wolfe, 2008), and UFOV (Edwards et al., 2005) tasks have all been shown in the past to be highly stable across time. However, it does not appear at this time that such investigations have been conducted with the other tasks. (i.e. enumeration, flanker, Posner, and global/local task), making it unclear whether these measures can function effectively as individual differences variables. If one assumes that these tasks need to tap stable individual predispositions or abilities to be of use in individual difference studies, then it may be problematic to use these latter tasks as correlates in an individual differences study. However, the main point of this study was to examine whether individual differences in tasks ostensibly related to diffusion can predict individual differences in AB magnitude within the same session. It is possible that a given individual's scores will vary over days, as a function of their current affective state (e.g. Fredrickson & Branigan, 2005 with the global/local task), but that this affective state may bias processing on all of the tasks within a given test session, allowing meaningful individual differences to be observed even if test-retest reliability across sessions would have been low for some tasks. Regardless, the split-half reliability of many of the tasks was acceptably high, lending some confidence to the interpretation of these results.

It is important to address the issue of using so many predictors in this study, and four different primary dependent variables. The use of an excessive number of variables can lead to an inflated probability of Type 1 errors (e.g. Cohen, Cohen, West, & Aiken, 2003). This study was exploratory in nature, hence the large number of predictors. This has enabled me to highlight areas for possible future investigation. Future studies will

contain more targeted investigations using fewer tasks (e.g., a thorough investigation of the global/local task and AB magnitude) in order to replicate and extend the present findings while reducing the possibility of Type 1 errors.

While it is interesting to investigate how individual differences can influence performance on the AB task specifically, it is also interesting to extrapolate these findings to the larger attention literature and the behaviour outside of the laboratory. This finding could have implications for understanding why some individuals have difficulty with certain attention tasks, and how strategies to induce a diffused attentional state could be used to attempt to aid individuals who have poor selective attention abilities. Indeed, Green and Bavelier (2006) were able to alter participants' performance on cognitive and selective attention tasks with as little as 10 hours of training on action video games. While the performance of the participants in Green and Bavelier's studies did not appear to be related to the ability to diffuse attention specifically, their findings do raise the possibility that diffusion could also be trained in participants.

These findings could potentially help us understand the problems with individuals who have ADHD, or could help us understand why older individuals or individuals with disorders such as schizophrenia perform have such difficulty inhibiting irrelevant information on selective attention tasks. Even further than potential medical applications, the findings of the research could potentially help us improve performance on real world attention tasks such as operating a motor vehicle, or flying an airplane. Perhaps we could train individuals to perform better on these tasks by applying the findings of studies such as this thesis.

Lastly, our knowledge of diffusion in attention could potentially be linked to diffusion in cognitive areas other than attention. For example, diffusion could be linked to

the spreading of semantic activation, such that more diffusion allows for better ability to make associations between distantly semantically related constructs (Fenske, personal communication). Also diffusion might be linked to greater creativity, such that more diffused individuals are better able to make more creative or abstract solutions to problems. Lastly, diffusion might even be related to how individuals interact with each other, such that diffused individuals are more approachable and open to experience. Therefore, understanding how individuals differ in diffusion could potentially be a relevant topic of study for both real world applications, and other areas of cognitive or affective research.

In conclusion, while much research remains to be completed, the main contribution of this thesis was to show that individual differences in a well-established measure of attentional diffusion predicted AB magnitude, where greater global precedence was related to smaller AB magnitude. In addition, this thesis was able to show that performance on two other established cognitive measures (Stroop facilitation and the visual search slope on target absent trials) could also predict AB performance. This is the first study to show that a cognitive performance measure of dispositional diffusion can predict the AB, and paves the way for future research on individual differences in attentional allocation and its relationship with AB performance. This study also showed that speed of processing measures were able to predict overall target accuracy in the AB task, but not AB magnitude. This provides extensive support for the findings of Arnell et al. (2006) which showed that there is a dissociation between cognitive processes which relate to target accuracy in the AB paradigm, and those that relate to overall AB magnitude. As such, this study provides important evidence for

understanding the contribution of both processing speed and the allocation of attention to performance on the AB task.

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Appendix A

REVISED NEO-PI

On the following pages, there are phrases describing people's behaviors. Please use the rating scale below to describe how accurately each statement describes *you*. Describe yourself as you generally are now, not as you wish to be in the future. So that you can describe yourself in an honest manner, your responses will be kept in absolute confidence. Please read each statement carefully, and then circle the response number which best corresponds with your behaviour.

Response Options

- 1: Very Inaccurate
 2: Moderately Inaccurate
 3: Neither Inaccurate nor Accurate
 4: Moderately Accurate
 5: Very Accurate

- #1. Often feel blue 1 2 3 4 5
- #2. Waste my time 1 2 3 4 5
- #3. Am easy to satisfy 1 2 3 4 5
- #4. Believe in the importance of art 1 2 3 4 5
- #5. Make friends easily 1 2 3 4 5
- #6. Rarely look for a deeper meaning in things 1 2 3 4 5
- #7. Make plans and stick to them 1 2 3 4 5
- #8. Have a sharp tongue 1 2 3 4 5
- #9. Am very pleased with myself 1 2 3 4 5
- #10. Am not easily bothered by things 1 2 3 4 5
- #11. Do just enough work to get by 1 2 3 4 5
- #12. Enjoy wild flights of fantasy 1 2 3 4 5
- #13. Know how to captivate people 1 2 3 4 5

- #14. Am hard to get to know 1 2 3 4 5
- #15. Have frequent mood swings 1 2 3 4 5
- #16. Get chores done right away 1 2 3 4 5
- #17. Believe that others have good intentions 1 2 3 4 5
- #18. Enjoy hearing new ideas 1 2 3 4 5
- #19. Avoid philosophical discussions 1 2 3 4 5
- #20. Have little to say 1 2 3 4 5
- #21. Suspect hidden motives in others 1 2 3 4 5
- #22. Rarely get irritated 1 2 3 4 5
- #23. Am not interested in abstract ideas 1 2 3 4 5
- #24. Don't like to draw attention to myself 1 2 3 4 5
- #25. Have a vivid imagination 1 2 3 4 5
- #26. Accept others as they are 1 2 3 4 5
- #27. Am often down in the dumps 1 2 3 4 5
- #28. Am always prepared 1 2 3 4 5
- #29. Pay attention to details 1 2 3 4 5
- #30. Find it difficult to get down to work 1 2 3 4 5
- #31. Insult people 1 2 3 4 5
- #32. Do not enjoy going to museums 1 2 3 4 5
- #33. Am skilled in handling social situations 1 2 3 4 5
- #34. Seldom feel blue 1 2 3 4 5
- #35. Don't see things through 1 2 3 4 5
- #36. Make people feel at ease 1 2 3 4 5

- #37. Do not like art 1 2 3 4 5
- #38. Feel comfortable around people 1 2 3 4 5
- #39. Dislike myself 1 2 3 4 5
- #40. Get back at others 1 2 3 4 5
- #41. Have a rich vocabulary 1 2 3 4 5
- #42. Don't talk a lot 1 2 3 4 5
- #43. Feel comfortable with myself 1 2 3 4 5
- #44. Carry out my plans 1 2 3 4 5
- #45. Cut others to pieces 1 2 3 4 5
- #46. Keep in the background 1 2 3 4 5
- #47. Panic easily 1 2 3 4 5
- #48. Respect others 1 2 3 4 5
- #49. Am the life of the party 1 2 3 4 5
- #50. Shirk my duties 1 2 3 4 5

STATE MEASURE

Indicate to the degree to which you felt each of the different emotions shown below while doing the computer task you just completed. Use the following scale to record your answers.

0	1	2	3	4	5	6	7	8
None								A great deal

	Amusement
	Anger
	Anxiety
	Attentive
	Boredom
	Contentment
	Disgust
	Fear
	Focused
	Happiness
	Interest
	Joy
	Relaxed
	Sadness
	Serenity
	Sleepiness

TRAIT MEASURE

This scale consists of a number of words that describe different feelings and emotions. Read each item and then mark the appropriate answer in the space next to that word. Indicate to what extent you generally feel this way, that is, how you feel ON AVERAGE. Use the following scale to record your answers.

1	2	3	4	5
very slightly or not at all	a little	moderately	quite a bit	extremely

	interested
	distressed
	excited
	upset
	strong
	guilty
	scared
	hostile
	enthusiastic
	proud
	bored
	relaxed

	irritable
	alert
	ashamed
	inspired
	nervous
	determined
	attentive
	jittery
	active
	afraid
	focused
	sleepy

VIDEO GAME QUESTIONNAIRE

How often have you played video games in the past 12 months? (circle the applicable response)

- a) I play video games nearly every day
- b) I play once or twice a week
- c) I play once or twice a month
- d) I play a few times a year
- e) I have not played video games in the past 12 months

How many hours have you played video games in the past two weeks? _____hrs

If you play video games, how many years have you been playing for? _____yrs

What types of games do you most frequently play? (Role Playing Games, Shooter, Adventure etc) (please indicate on line below):

Rank the top three video games you play in descending order BY NAME, from most often to least often (ex. Halo2, Zelda, Gears of War etc). If you do not play, leave this area blank.

#1 _____

#2 _____

#3 _____

Health and Medical History Questionnaire

(Please check all that apply)

Subject ID code: _____ Age: _____ Gender: _____ Date: _____

<i>Item</i>	<i>Past</i>	<i>Continuing problem/relevant details</i>
Special Problems with Reading		
Special Problems with Arithmetic or Number Skills		
Problems with attention or concentration (e.g., ADD)		
Problems with activity level (hyperactivity)		
Problems with mood (Depression/Anxiety)		
Other Psychiatric problems		
Problems with sleep (e.g., falling asleep, frequent or early waking)		

Medications

Are you taking any prescribed or over-the-counter mood-altering medications designed to treat psychological disorders?

Yes ☐

No ☐

Use of Stimulants/Suppressants

(0 = none; 1 = v. light; 2 = light to moderate; 3 = moderate; 4 = moderate to high; 5 = high)

	IN GENERAL	TODAY
caffeine (coffee, tea, chocolate, soft drinks)		
alcohol (beer, wine, liquor)		
Nicotine		
Other		

Appendix B

Consent to Participate in Research
Psychology Department, Brock University, 2008
“Visual Attention and Cognitive Abilities”

Invitation to Participate

You are invited to participate in this research study of attention and cognition being conducted by Dr. Karen Arnell and Gillian Dale. Dr. Karen Arnell is an Associate Professor in the Department of Psychology at Brock University. She can be reached by phone at (905) 688-5550 ext. 3225. The Psychology Department can be reached by phone at (905) 688-5550 ext.3542, or by email at lindap@spartan.ac.brocku.ca. This study has received ethics clearance (08-045) from the Brock University Research Ethics Board, and is funded by the Natural Sciences and Engineering Research Council (NSERC).

Basis for Participant Selection

This experiment requires you to visually attend to letters, shapes, and colors presented rapidly on the computer screen, and to make accurate and rapid button press responses to these items. Individuals with poor visual acuity, colour blindness, and persons who have learned English after the age of 8 will be unable to participate in this experiment. Please tell the experimenter now if any of these conditions apply to you. Note that we will be administering a brief eye test in order to ensure that the vision requirements are met for this experiment. We plan to include about 100 people in this experiment.

Overall Purpose of the Study

Your participation will help us learn more about how our minds process (cope with or respond to) rapidly presented information, and under what conditions attention is effectively engaged. In this study the computer will present visual letters, digits, pictures, and colors and you will use the computer keyboard to make responses in a variety of tasks. We will examine the speed and accuracy of the responses you make to these items. Ultimately, we hope to learn more about how different cognitive abilities relate to selective attention.

Explanation of Procedures

This study will be conducted in this room and will take approximately 2 hours to complete.

- 1. (15 minutes)** We will administer a simple eye test, and you will complete a short medical history questionnaire.
- 2. (15 minutes)** You will complete 3 short questionnaires.
- 3. (80 minutes)** You will perform each of the seven cognitive tasks. The seven computerized tasks include: 1) Estimating the number of squares that are presented briefly on the computer screen, 2) Reporting the ink colour of words presented on the computer screen, 3) Searching for a target shape amongst other shapes on the computer screen, 4) Reporting the location in which a target was briefly presented, 5) Viewing a series of letters presented rapidly one after another in the same location on the computer

screen and detecting target items in the series, 6) Reporting the location of a target that follows a useful cue and, 7) Reporting the identity of a target that is presented amongst similar distractors.

The experimenter will begin each task for you, supervise you while you perform a few practice trials, and then leave the room while you complete the task. Feel free to ask any questions about the task during these practice trials. Each task will take between 5 and 20 minutes to perform.

4. (5 minutes) You will be required to complete another short questionnaire.

5. (5 minutes) The experimenter will further explain the purpose of the study and provide compensation.

Potential Risks and Discomforts

You may experience mild fatigue while performing the trials. Feel free to take a short break whenever you require one. You will also be asked in this experiment to **anonymously** disclose some personal medical information. This information will in no way be linked to your name or identity, and may be used to help us understand your pattern of results, not for exclusionary purposes. If you are uncomfortable with performing one or more of the tasks or answering one or more of the questions, then please make this clear to the experimenter, and you will be permitted to omit that portion of the experiment.

Potential Benefits

This research will help us develop a better understanding of how our minds focus attention, while attempting to make sense of information which is rapidly presented. If you are not familiar with cognitive psychology, then the experiment will expose you to a new area of psychology.

Compensation for Participation

You will receive 2 hours of research participation toward any participating Brock University course, or \$20 (your choice).

Assurance of Confidentiality

The information we collect from you in this study (your responses) will be coded by a number, not your name. Your identity will not be revealed or connected with the experimental results. We are interested in combining data from all of the participants, not in separately examining the pattern for each person. Your data will be combined with the data from other participants, and reported in summary form. Data and records created by this project are the property of the University and the investigator. You may have access to the overall results of the experiment by making a written request to Dr. Karen Arnell (Department of Psychology, Brock University, St. Catharines, ON, L2S 3A1). A copy of the summary results will then be sent to you when the experiment has been completed. This right of access extends only to the data combined from all participants, and not to your individual data nor the individual data of other participants.

Withdrawal from the Study

Your participation is voluntary, and you may withdraw from the study at any time without penalty. Your decision of whether or not to participate will not affect your course grades or your eligibility for other studies. If you decide to participate now, you are free to withdraw your consent and to discontinue participation at any time.

Offer to Answer Questions

You should feel free to ask the experimenter questions now or at any time during the study. If you have further questions or concerns, at any time you can contact Dr. Karen Arnell, at (905) 688-5550 ext. 3225. If you have questions about the rights of research participants, contact the Brock Research Ethics Officer in the Office of Research Services (905) 688-5550 ext. 3035.

Consent Statement

The procedures and potential harms/benefits have now been explained to you. You are voluntarily making a decision about whether or not to participate in the study. Your signature below indicates that you have freely decided to participate in this research study, having read and understood all of the information above, and understanding that you may ask questions now and in the future.

Print full name of participant	Signature of participant	Date
Age	Sex (M/F)	Signature of Researcher

I am participating in this experiment for 2 (two) hours of research participation in a Brock University course and will not receive monetary payment for this experiment.

Signature of participant	Course	Signature of Researcher

I am participating in this experiment for \$20. This experiment will not count towards research participation in a Brock University course.

Signature of participant	Signature of Researcher

Thank you for your participation in this study. Please keep a copy of the consent form for your records.

Research Feedback Form

Thank you for participating in our research study! We hope it has been an interesting and positive experience for you.

If you wish you may have access to the overall results of this experiment by making a written request to Dr. Karen Arnell (Department of Psychology, Brock University, St. Catharines, ON, L2S 3A1). A copy of the summary of results will then be sent to you when the experiment has been completed (approx. 5 months). This right of access extends only to the data combined from all participants, and not to your individual data nor to the individual data of other participants.

In this experiment, you completed multiple computerized cognitive tasks. In one task, you were rapidly presented with letters on the screen and asked to identify a target from within the stimulus stream (the last computerized task you completed). At varying intervals after the presentation of the first target, a second target was presented which was a colour word that had to be identified. The interval between target one and target two ranged between 200-800ms, or 3-8 items. In normal trials, when the second target is presented within two to three items after the first, the second target is often overlooked, because the brain is still busy processing the first target. This is known as the “Attentional Blink”.

We were interested in seeing how performance on the other cognitive tasks you completed predicted the size of the attentional blink. Past studies show that individuals who are more diffused or “broadened” in their attentional state have a smaller attentional blink. The cognitive tasks you performed today will enable us to determine the degree to which you diffuse your attention. In addition, previous studies show that current mood states can predict the size of the attentional blink, so we asked you to complete two short mood questionnaires. We also had you complete a small personality questionnaire in order to better understand which personality types are related to attentional blink performance. We expect that individuals high in conscientiousness and neuroticism may have larger attentional blinks as they are focusing their attention on the targets, rather than diffusing their attention across the entire stimulus stream.

Finally, you completed a short questionnaire which assessed the extent to which you play video games. Past studies show that action video game players perform differently on all of the cognitive tasks you just completed. We wanted to know if you fell in that category so that we could better understand your results.

Your participation in this research study should help us gain a better understanding of the attentional limitations of our brains. Thank you once again.

Appendix C

Verbal Script—Visual Attention and Cognitive Abilities

*Greet each participant at the door, and give them two copies of the consent form. Ask them to read and sign one copy, and to retain the other copy for their records. If a participant is completing the study for course hours, make sure that you also sign their consent form because many classes require an official researcher signature. Ask them to indicate when they have completed this task, and ensure that they have consented to participating in the study. Remind them that the study duration is 2 hours, but that **they** are free to take breaks whenever desired.*

Step #1. Administer the eye-test. If participant does not meet the cut-off requirements, pay them for an hour of their time and send them on their way.

Step #2. *Give participant a copy of the medical questionnaire, and a sealable envelope. We are giving you this questionnaire in order to gather information that may help us better understand our pattern of results. As this information is personal, we wish to keep the responses anonymous and ask that you insert the completed questionnaire in the given envelope and seal it before returning it to me. Be advised that you have the right to refuse to answer any questions in this survey.*

Step #3. Trait Questionnaire. *Give the participant the trait questionnaire. Please rate the extent to which you experience the following moods IN GENERAL using the scale provided (give example).*

Step #4. Personality Questionnaire

Give the participant a copy of the personality questionnaire. This is a small questionnaire which will help us to understand you a little better. Please fill this out according to the directions printed at the top and follow the rating scale that is given. If you have any questions, please let me know before beginning, and let me know when you finish.

Step #5. State Questionnaire. *Give the participant the state questionnaire. Please rate the extent to which you are experiencing the following moods AT THIS MOMENT using the scale provided (give example).*

Step #6. Attentional Blink

On each trial you will see a series of letters presented one at a time in the center of the screen. All of the letters will be black except for one letter near the middle of the series which will be white. On half of the trials a black 'X' will be presented sometime after the white letter. On the other half of the trials no black 'X' will be presented anywhere in the series of letters.

On each trial you will have to identify the white letter by hitting the corresponding key on the keyboard, and decide whether the 'X' was present or absent
If the "X" was present hit the number 1, and if it was not, hit the number 0. Try to be as accurate as possible. I will observe a few trials to make sure that you understand, and then you will complete the remaining trials on your own. Begin when you are ready.

Step #7. Stroop Task*Active Keys: ASKL**A=Red**S=Yellow**K=Blue**L=Green*

At the beginning of each trial a fixation cross will appear in the middle of the screen. Focus your attention on it. A coloured word will then briefly be presented on the screen. Indicate the FONT COLOUR of each presented word by pressing the corresponding colour key as QUICKLY as possible. I will observe a few trials to make sure that you understand, and then you will complete the remaining trials on your own. Begin when you are ready.

Step #8. Enumeration

Focus your attention on the fixation cross at the beginning of each trial. A number of boxes will be briefly flashed on the screen. Your task will be to try to see how many boxes were flashed on the screen. Between 1 and 10 boxes will be flashed on each trial. Indicate how many boxes you saw using the numbers 1 through 9 on the keyboard. If you think there were ten boxes, hit the 0 key. Try to be as accurate as possible. I will observe a few trials to make sure that you understand, and then you will complete the remaining trials on your own. Begin when you are ready.

Step #9. Visual Search*Active Keys are T and Y**T=Target Present**Y=Target Absent*

Focus your attention on the fixation cross in the center of the screen at the beginning of each trial. Shortly after, a display will appear which will appear to be made up of a bunch of small "L" shapes. These are distractors. On some of the trials a "T" shape will appear amongst the "L" shapes. This is the target. Your task will be to indicate whether the target was present or absent. If you see the target press the "t" key on the keyboard, and if you do not see the target press the "y" key. Try to press as soon as you decide whether or not the target has appeared. We want you to be as quick and as accurate as possible. I will observe a few trials to make sure that you understand, and then you will complete the remaining trials on your own. Begin when you are ready.

Step #10. Useful Field of View

A wheel with 8 spokes will appear on the screen. The spokes all contain boxes. A cue will very briefly flash in one of the spoke boxes, after which a mask will cover the display. You will then be shown a display of numbered spokes. Press the number on the keyboard which corresponds to the spoke location of the previously flashed cue. Try to be as accurate as possible. As this is a very difficult task, try not to become discouraged as you proceed. I will observe a few trials to make sure that you understand, and then you will complete the remaining trials on your own. Begin when you are ready.

Step #11. Posner Cueing*Active Keys: DJ**D=left side of screen**J=right side of screen*

Focus your attention on the center of the screen at the start of each trial. A cue will appear in the center of the screen, after which a target will appear on either the left or the right side of the screen. The cue will either indicate the direction of the target, or will be a neutral cue. Your task will be to indicate which side of the screen the target appeared on. If it appeared on the right side of the screen hit the “j” key, and if it appeared on the left side of the screen hit the “d” key. The cues will be correct most of the time, but sometimes will be incorrect. Try to use the cues to help you. Reaction time will be examined in this experiment, so try to respond to the target location as quickly and accurately as possible. I will observe a few trials to make sure that you understand, and then you will complete the remaining trials on your own. Begin when you are ready.

Step #12. Flanker Compatibility*Active keys: G and H**G=diamond**H=square*

A wheel of circles will appear on the screen. Some of the circles may contain shapes, and some may not. A square or a diamond shape will be presented outside of the wheel of circles. Your task will be to indicate whether this shape outside is a square or a diamond. If it is a square, hit the “h” key. If it is a diamond, hit the “g” key. Try to be as quick and accurate as possible. I will observe a few trials to make sure that you understand, and then you will complete the remaining trials on your own. Begin when you are ready.

Step #13. Global/Local task*Active keys: T and H*

In this task, on each trial a large single letter that is made up of smaller letters will appear on the screen. On some of the trials you will be asked to indicate via button press what the LARGE letter is, and on some of the trials you will be asked to indicate what the SMALL letter is. You will receive instructions on the screen that tell you which size letters you are to respond to (*show them that the first block requires them to quickly indicate the large global letter*). Try to indicate the appropriate letter as quickly and accurately as possible. For this task, only two possible letters can appear: H or T, so you may want to place your fingers on those keys to ensure that you are going as fast as you can. I will observe a few trials to make sure that you understand, and then you will complete the remaining trials on your own. Begin when you are ready.

Step #14. Video Game Survey

Give the participant a copy of the video game survey. This is a small survey used to assess how often you play video games, and what types of games you play. Please let me know if you have any questions.

Step #15. Feedback and Compensation

Thank the participant and give them the feedback form. Explain briefly the purpose of the study. Compensate the participant for their time, and thank them once again.