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Modulating the attentional blink: investigations in attentional investment, conscious perception, attentional capture and visual masking

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General Abstract

This thesis discusses factors that modulate the magnitude of dual-task interference during an attentional blink task. For our purposes, dual-task interference occurs when capacity to process information is exceeded by the demands of multiple target stimuli. The factors discussed are *levels of task-irrelevant 'noise' originating in peripheral regions of the visual field* (Chapter 2), *signal-strength of target stimuli* (Chapter 3), *the role of T1-masking in Lag-1 Sparing* (Chapter 4), *task-relevance of attention capturing stimuli* (Chapter 5), and finally *task-relevant feature congruence between target stimuli and backward interruption masks* (Chapter 6). Chapter 7 will illustrate how Chapters 2-6, along with selected examples of previous literature, indicate that dual-task interference can be manipulated at multiple points during the time-course of AB-related processes.

Chapter Abstracts

Chapter Two: Task Irrelevant Activity Promotes Attentional Investment: An Evaluation of the Overinvestment Hypothesis

The Overinvestment Hypothesis proposed by Olivers and Nieuwenhuis (2006) suggests task irrelevant activity benefits information processing by reducing attentional investment. Here we attempt to verify this claim by examining an electrophysiological component known to index attentional preparedness, the *contingent negative variation* (*CNV*). In contradiction to the Overinvestment Hypothesis, in a condition that meets the overinvestment prerequisite for yielding less of an AB, we found task-irrelevant activity significantly increases attentional investment for trials on which an AB did not occur compared to those on which an AB did occur. In a control condition where task-irrelevant activity was not present and a normal AB was elicited, the CNV did not differentiate between correct and incorrect trials. Our findings are interpreted as indicating a need to re-evaluate reduced attentional investment as a mechanism underlying cognitive benefits from task-irrelevant stimuli. Results are also framed within the context of previous works linking increased attentional investment to enhanced cognitive processing.

Chapter Three: Target Strength Determines Whether Consciousness is Graded or Dichotomous During Divided Attention

Using a measure referred to as the subjective-visibility-scale, Sergent and Dehaene (2004) and Sergent, Baillet, and Dehaene (2005) claim to support the assertion that conscious awareness for T2 is not obtained during AB trials. I evaluated their results under varying levels of signal-strength for T2. T2 signal-strength was altered by manipulating contrast-ratio for the T2 stimulus and its background. Results suggest that the findings of Sergent and colleagues are valid only for the specific set of stimulus parameters used in their experiments. Conscious awareness can be obtained for the T2 stimulus and yet participants may still fail to report T2 identity correctly. It is suggested that the results are indicative of greater biased-competition on behalf of T2 stimuli that are highly distinguishable from surrounding non-target distracters in an RSVP stream.

Chapter Four: Does Failure to Mask T1 Cause Lag-1 Sparing in the Attentional Blink

The attentional blink (AB) effect demonstrates that when participants are instructed to report two targets presented in a rapid visual stimuli stream, the second target (T2) is often unable to be reported correctly if presented 200 – 500 msec after the onset of the first target (T1). However, if T2 is presented immediately after T1, in the conventional lag-1 position (100-msec stimulus onset asynchrony; SOA), little or no performance deficit occurs. The present experiments add to the growing literature relating the "lag-1 sparing" effect to T1 masking. Using a canonical AB paradigm, our results demonstrate that T2 performance at lag-1 is significantly reduced in the presence of T1 masking. The implications of this outcome are discussed in relation to theories of the AB.

Chapter Five: Attentional Capture and the Attentional Blink: A Dissociation of Spatial and Temporal Discontinuity

The search for a target item in a regular temporal sequence of items is disrupted by a perceived discontinuity in the sequence. This discontinuity can *benefit* target search if it leads to general alerting. But it can also *impair* search if it disrupts the match between the internal search template and the target features in the stream. Three experiments explored the consequences of sequence discontinuity in the attentional blink (participants attempted to identify two target letters in a serial stream of non-target letters). Because letter identification is inherently a spatial task, we hypothesized that a spatially defined discontinuity prior to the target would impair search (Experiment 1), whereas a temporally defined discontinuity would benefit search (Experiment 2). These hypotheses were supported. Experiment 3 bolstered these hypotheses by testing spatially- and temporally-defined discontinuities with reference to the same standard task and in the same group of participants.

Chapter Six: Establishing and Confirming Object-Hypotheses in the Presence of Multiple Task-Relevant Features

Recently publications have emerged that question the traditional idea that visual masking interferes with target processing exclusively during the initial feed-forward progression through information processing (Di Lollo, Enns, & Rensink, 2000; Enns & Di Lollo, 1997; Enns & Di Lollo, 2000; Enns & Oriet, 2007). These publications have proposed reentrant (i.e., feed-back) processes also play an important role in masking, and have lead to the formulation of *the reentrant theories of perception and successful backward masking.* Chapter 5 outlines these theories and examines the role of *object-hypotheses* when participants are instructed to report upon two task-relevant features of a single target object. The results are interpreted as suggesting that multiple object-hypotheses can be established and tested for a single target object (Experiment 1). Experiment 2 examines the potential for multiple object-hypotheses to be established under the demands of dual-task interference in an attentional blink task. It is suggested that establishing multiple object-hypotheses for a single stimulus might serve as a useful mechanism in a visual system that is prone to selective impairments in object processing.

Chapter Seven: Final Discussion – Temporal Attention Maintains Flexibility Across the RSVP stream

Chapter 7 begins with a brief review of results from Chapters 2-6. The main discussion in this chapter illustrates how results from Chapters 2-6, in conjunction with selected examples of previous publications, indicate that dual-task interference during the AB can be modulated at multiple points during the time-course of AB-related processes. The "time-course" I refer to is the sequential series of attentional processes required in order to successfully report upon two targets in an RSVP stream. For the purposes of discussion this time-course is divided between three stages of RSVP presentation. Stage One: *Before RSVP Onset.* Stage Two: *Before, During, and After Presentation of T1 and its Mask.* Stage Three: *During and After Presentation of T2 and its Mask.* When relevant it will be discussed how the potential to modulate dual-task interference at various points during the time-course of AB-related processes corresponds to popular accounts of the attentional blink.

Chapter One: Our Focus Within the Field of Attention

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The current chapter briefly introduces topics that are relevant to theories and concepts contained in Chapters 2 - 7. These topics are *biased-competition in attentional processing*, *selective attention*, *neuropsychology of attention*, and *dual-task deficits in divided attention.* Chapter 1 also presents a detailed introduction to the *Attentional Blink* (*AB*) paradigm. The AB is a popular paradigm for examining dual-task interference on a temporal scale. Importantly, literature vital to Chapters 2–6 - i.e., the literature from which hypotheses were derived – is reviewed within each chapter. As a final note before proceeding, all experiments in Chapters 2 – 6 deal exclusively with the sensory modality of vision.

Part 1:

The Broader Topics of Attention

Biased-Competition: A Basis for Attention-Related Processing

Experiments and related discussions presented in Chapters 2 – 7 adhere to the idea that mental processes operate within the confines of a limited-capacity system (Broadbent, 1958), and that biased-competition for this capacity serves as the basis for attention-related processing (Desimone & Duncan, 1995; Duncan, 1996; Van Essen & DeYoe, 1995). Biased-competition refers to a weighted advantage in favour of information relevant to ongoing behaviour. Once established, competitional bias in favour of task-relevant information resonates throughout various brain systems and levels of processing. Biased-competition thus serving to ensure the information

we require not only wins-out in the initial engagement of attention, but carries on to contribute heavily toward coherent perceptions and appropriate actions (Duncan, 2006).

Establishing competition bias requires a high level of dissimilarity between task-relevant and task-irrelevant stimuli. For example, Duncan (1987) found task-relevant and irrelevant stimuli distinguishable only by minor differences in shape competed equally – thus biasing competition in favour of task relevance was not possible. Even when competitional bias is established it does not guarantee task-relevant information is successfully processed. Using a partial report task[1], Duncan (1980) demonstrated that as the number of task-relevant stimuli increases, competition within the limited-capacity system intensifies. The result is a lessening of processing capacity devoted toward each task-relevant stimulus - the potential for accurate report of each task-relevant stimulus decreasing in direct relation to the total number of these stimuli.

Neurological evidence supporting biased-competition has been reported from multiple brain structures. Chelazzi, Duncan, Miller and Desimone (1998) reported results consistent with biased-competition for the *inferior temporal lobe* (*IT*) – an anatomical region strongly associated with the later stages of object identification (e.g., Tanifuji, Tsunoda, & Yamane, 2004). Chelazzi and colleagues trained behaving monkeys to yield either very strong or very weak levels of IT activity for two stimuli. When both stimuli appeared together as non-targets, IT activity was midway between when the strong-yielding and weak-yielding stimuli were presented alone. This outcome reflects equal competition for processing capacity when neither stimulus was capable of biasing competition on the basis of task relevance. On the

[1] Partial-report tasks involve presenting a display of mixed target (to-be-reported) and non-target (to-be-ignored) stimuli. The number of targets accurately reported is interpreted as a measure of the interference between target and non-target stimuli.

other hand, when both stimuli were presented together with one being classified as a target and the other a non-target, biased-competition ensued, causing IT activation to return to levels found when the target stimulus was presented alone. The intensity of neurological activity has also been reported to fluctuate as a function of task-relevance in other cortical areas. These include, but are not necessarily limited to, the occipital, parietal, and superior colliculus of the monkey cortex (Bushnell, Goldberg, & Robinson, 1981; Luck, Chelazzi, Hillyard, & Desimone, 1997). Such findings indicate that neural processing is influenced by task-relevance across multiple early stages of visual processing – superior colliculus[2] and occipital areas - as well as later stages involved in spatial operations (i.e., parietal areas).

Even before a task-relevant stimulus has been presented, cell populations involved in processing that stimulus gain access to processing capacity. Coming back to Chelazzi et al. (1998), during a 1,500 - 3,000 ms interval of no visual input, which occurred between offset of a cue indicating the target stimulus and onset of the search display, IT cells were found to maintain an active state when the target was to be the strong-yielding stimulus. In other words, once cued to search for a specific target, cells involved in processing that target continued to fire in anticipation of stimulus onset. Such pre-active states likely contribute significantly toward a biased advantage in competition for processing capacity. Similar pre-active states have also been reported in the monkey cortex for areas V1 and V2 when cues indicate targets will appear in specific spatial locations (Luck et al., 1997).

The biased-competition account thus provides a mechanism for explaining *how* task-relevant information shapes perception within a limited capacity system.

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[2] The experiments cited here focused on superficial layers of neurons within the superior colliculus that are often associated with sensory function – particularly for relaying visual information. Deep layers of neurons within the superior colliculus involved in motor related functions – e.g., eye movements – were not believed to play a role in these results.

Throughout Chapters 2 – 7 biased-competition serves as one of several useful mechanisms for placing empirical findings within a larger framework of attentional processing. Moving on, next to be introduced is the first of three remaining attention related topics covered in Chapter 1 – selective attention.

Selective Attention

The following discussion of selective attention will include brief introductions to three topics. First is the debate between *early and late-selection accounts*. Both early and late-selection accounts ask: To what extent is all sensory information processed before we limit the information to undergo higher-order processing? Second is the debate between *spatial and object based accounts of visual attention*. In other words, do we attend to items depending on *where* or *what* they are. To phrase these issues another way, early and late-selection accounts ask *when* do we select the items we attend to, while spatial and object based accounts ask *how*. The third topic is *visual selection according the biased-competition account*.

Early and Late-Selection Accounts: Broadbent (1958) was the first to advocate early selection with what he referred to as filter theory. Broadbent postulated that cognitive processes responsible for recognising/identifying stimuli (e.g., a specific digit or word) are limited in so far as the amount of information that can be handled at one time. Broadbent suggested as a means of compensating for this limitation, that the majority of sensory information is processed only to the point where physical attributes (e.g., location, pitch, loudness, etc.) are explicitly represented. Once representation of physical features is established Broadbent believed we select what information undergoes further processing (e.g., to the point

of recognition/identification).

Shortly after Broadbent proposed his filter theory evidence emerged suggesting sensory information is processed to a greater degree before selection. Moray (1959) reported that when instructed to attend to one channel of auditory information while ignoring another, participants noticed the occurrence of their own name in the to-be-ignored channel. On a similar note, Treisman (1960) had participants shadow one channel while ignoring another channel. She reported participants often switched which channel they were shadowing when messages in the to-be-ignored and to-be-attended channels were contextually relevant. At the time Treisman suggested that ignored information is not rejected completely, but rather only attenuated, and that recognition takes place as information "accumulates" – accumulating bits of information were referred to as "detector-units". In other words, ignored information is processed but to a much lesser extent than attended stimuli. Only when contextually relevant to attended stimuli do ignored stimuli generate enough detector units to induce recognition.

Moray (1969) suggested his own 1959 result and Treisman's (1960) result could in fact be accounted for by Broadbent's filter theory. Moray claimed information from the to-be-ignored channel might not have been processed beyond the point of simple feature analysis; rather, participants may have periodically shifted their attention between channels during the experiment. If such switching occurred, early selection theory can account for these findings with relative ease.

Publications such as those by Treisman (1960) and Moray (1959) nevertheless spawned a wealth of research postulating accounts commonly categorised under the heading of late-selection (e.g., Deutsch & Deutsh, 1963; Mackay, 1973; and Norman, 1968). These accounts propose selection takes place

sometime after feature analysis - exactly how much processing occurs before selection varies across experiments. For example, Duncan (1980) demonstrated visual selection could occur at the level of categorisation (e.g., letters among digits). In the same publication Duncan demonstrated that manipulating stimulus complexity could cause visual selection to occur after targets and non-targets have breached conscious awareness. We will briefly return to the topic of late-selection momentarily when presenting Duncan's integrated competition hypothesis.

Spatial and Object-Based Accounts: Eriksen and Eriksen (1974) were among the first to investigate this issue, postulating that visual attention acts as a spotlight. This is to say all information within the spatial location of visual focus will engage attention. Erickson and Erickson's original experiment involved a flanker task. Participants were required to respond with either the left or right hand depending upon the identity of a target letter (e.g., S & C = right hand; H & K = left hand). If the target was for instance "C", then distracter items could appear to the left or right (i.e., the flankers) that were also of the left hand group (e.g., S), or were of the opposite group (e.g., H or K). When distracter items were from the opposite group responses to targets were significantly slower, thus indicating that the distracters had engaged attention. The spatial area for maximum interference was found to be 1 degree of visual angle, as distracters presented beyond this point produced less interference. Other studies supporting spatial based attention include Eriksen and Yeh (1985), demonstrating participants' difficulty attending to more than one spatial location at a time. Eriksen and James (1986) showed the attentional spotlight to be adjustable – i.e., the size of the beam can be increased or decreased via endogenous control mechanisms.

One of the early findings to contradict spatial based visual attention was

reported by Duncan (1984). Duncan asked participants to make judgements on two attributes that could either be from the same object or different objects. Accuracy was worse for the second attribute judgement when the two attributes belonged to different objects. Unlike Eriksen and colleagues, Duncan's findings suggest attention is isolated to specific objects rather than locations of visual focus.

Further support for the object-based account has been demonstrated with a paradigm known as *negative priming*. The conventional negative priming outcome (Tipper, 1985) demonstrates that when two objects are presented in the same location (i.e., overlapping) with one object serving as a target and the other a distracter, response times are worse when the target was the distracter in the previous trial. In other words, when item (A) is to-be-ignored (i.e., distracter) in trial 1, responses are slower when (A) is the target in trial 2. Tipper, Brehaut, and Driver (1990) modified the original negative priming experiment so that the target and distracter were presented in different spatial locations across trials. This manipulation is significant because if attention is object-based the earlier 1985 outcome should still occur. Indeed, the significant negative priming effect obtained suggested this was the case. However, in 1994 Tipper, Weaver, Jerreat, and Burak found evidence suggesting attention can be both object and spatial-based using a paradigm known as *Inhibition of Return (IOR)*.

IOR demonstrates the effects of inhibition for visual search. If a target occurs within approximately 250 ms of a cue indicating its location, then response times for target detection are facilitated. On the other hand, if the target occurs more than 250 ms after the cue response times are increased. In regards to visual search, IOR illustrates our tendency to not focus our attention on an area we have already searched. Tipper and colleagues found that both object based and spatial based

attention can exist for IOR. These authors reported longer response times when the target and cue shared either the same object or spatial location.

Selection and the Biased-Competition Account: According to the biased-competition account many stimuli within a visual scene compete for attentional selection. Biases in this competition favouring information relevant to ongoing behaviour are established via both bottom-up and top-down influences. Novelty and salience provide examples of bottom-up influences that contribute to biased-competition. Stimuli that are novel or appear more suddenly, larger, brighter, or move faster that other stimuli, often have important consequences for ongoing behaviour (Jonides & Yantis, 1988; Treisman & Gormican, 1988). Processing mechanisms attuned to exogenous indicators of novelty and salience provide a way to insure stimuli not previously deemed task-relevant, but that are nevertheless important for ongoing behaviour, become strong competitors for processing capacity.

In the case of salient stimuli it has been suggested mechanisms exist that automatically direct attention toward inhomogeneitites in the visual field (Donderi & Zelnicker, 1969; Sagi & Julesz, 1984; Treisman & Gelade, 1980). Fahy, Riches, and Brown (1993) suggested a mechanism promoting selection of novel stimuli involving the IT region of the monkey cortex. Activation of IT neurons became suppressed as stimuli became more familiar. It was suggested that the stronger neural responses elicited by novel stimuli allow for a processing advantage over familiar stimuli. Interpreted within the biased-competition account, strong activation signals bolster selection of novel stimuli by allowing their encoded representations to be strong competitors for limited processing capacity.

Establishing goal-directed competition bias requires considerable top-down

influence. For our purposes "goal-directed" refers to top-down modulation of selection mechanisms in preparation for stimuli deemed task-relevant prior to presentation – e.g., from selection cues or prior knowledge of task demands. One example of goal-directed competition bias has already been mentioned. Recall Chelazzi et al. (1998) reported IT cells in the monkey cortex maintained a pre-active state of firing between when a selection cue was presented and when the search array appeared.

Another example of goal-directed activation likely promoting biased-competition is Maunsell and Ferrera (1995). These authors reported goal-directed activation in area V4 of the monkey cortex for simple features. Monkeys in their experiments were trained to respond to orientation gratings matching a pre-trial cue. Two types of V4 neurons were relevant to their findings. Type (A) neurons always responded preferentially to specific orientations regardless of whether or not they matched the cue. For example some type (A) neurons yielded activation to right oblique patterns, while others responded more to left oblique patterns. Type (B) neurons were also orientation specific, but only activated when their preferred orientation matched the cue. For instance, if a type (B) cell were responsive to left oblique gratings, that cell would only activate if the cue contained a left oblique pattern. Maunsell and Ferrera (1995) also demonstrated that V5/MT neurons operate in a similar fashion. It was concluded simultaneous activation of both type (A) and type (B) neurons represented successful goal-directed selection. Within the context of the biased-competition account, it may be argued that a stimulus was a stronger competitor for limited processing capacity when both neuron types (A) and (B) were activated simultaneously, as opposed to when just type (A) neurons were activated.

Goal-directed competition bias leading to attentional selection can also occur

on the basis of location. Moran and Desimone (1985) reported that when two items were presented – a distracter and a target - with target stimuli being determined strictly by their location, V4 and IT neurons in the monkey cortex reduced the size of their receptive fields to cover only the target area. Compared to when targets and distracters were presented in same receptive field, the result was normal levels of activation for the target, but attenuated levels for the distracter. Here as well biased-competition is as work. Reducing the neural activation elicited by distracters likely allowed targets to become even stronger competitors for limited processing capacity.

The Integrated Competition Hypothesis (ICH): The ICH (Duncan, Humphrey's, & Ward, 1997) promotes integrated processing across multiple brain systems, each engaged in biased-competition. Once biased-competition is established in one system, the resulting advantage in processing carries on to other systems. Biased-competition then ultimately causes multiple systems to "converge", so that each system analyses the properties and implications for future action of "dominate" stimuli. According to the ICH, achievement of such convergence between systems constitutes visual selection for focused attention. The ICH promotes both object-based and late-selection accounts of selective attention. Regarding the former, objects are the fundamental units of visual information upon which multiple systems are claimed to converge. As for the latter, establishing integration across multiple systems takes time, which means objects are likely processed past the point of simple feature analysis before selection can occur.

Neuropsychology of Attention

'Attention' per se involves a complex assortment of cognitive operations. Not surprisingly, the anatomical hardware supporting these operations is diverse. For this

reason, researchers attempting to map attention onto physiology commonly make reference to neural networks (i.e., spatially separate anatomical areas working in conjunction to produce behaviour). Neural networks operate according to the principles of *concurrent processing*. Van Essen and DeYoe (1995) described concurrent processing as progressing along distinct pathways, which interact at numerous points. Large numbers of interactions allows various systems to be linked by convergent and divergent connections. In other words, the output for any one system becomes the input for multiple others. For example, processing the velocity of an oncoming object would contribute to form and depth perception, as well as initiation of motor actions (Stoner & Albright, 1993; Van Essen & DeYoe, 1995).

Concurrent processing is made possible by the progressively complex neuronal architecture of the visual system. If the output for a single system serves as input for multiple others, then during the initial feed-forward sweep of visual processing the number of neurons should increase as processing becomes more complex. In the monkey cortex approximately one million neurons are believed to make up the pathways leading from LGN to V1 (Van Essen & DeYoe, 1995). In V1 there are approximately 250 million neurons. Each extrastriate visual area (i.e., V2, V3, V4, and V5) contains approximately 400 million neurons (Buzsaki, 2007). In order for the number of neurons to increase exponentially, at each anatomical level individual cells must output to multiple cells at higher levels.

Networks involved in attentional processing span across neocortical and subcortical structures. In the neocortex, many structures involved in attentional processing can be classified as belonging to either the dorsal or ventral processing streams (Goodale & Milner, 1992). The dorsal and ventral streams are commonly cited to originate in the primary visual cortex (V1), although neurons feeding into

them are highly segregated as far back as magnocellular and parvocellular pathways of the lateral geniculate (LGN). Leaving the occipital lobes, the dorsal stream extends into the parietal region, contributing to operations of spatial perception and visuomotor-performance (Husain & Nachev, 2007; Jokisch & Jensen, 2007; Kiesel, 2007; Klaver et al., 2007; Kunda, Landgraf, Paelecke, & Vakalopoulos, 2007; Lee & Donkelaar, 2002; and Pammer, Hansen, Holliday, & Cornelissen, 2006, etc.). The ventral stream on the other hand projects into the inferior temporal lobes and carries out operations involved in numerous aspects of object recognition (Borowsky, Esopenko, Cummine, & Sarty, 2007; DiCarto & Cox, 2007; Keizer, Colzato, & Hommel, 2008; and Mruczek & Sheinberg, 2007, etc.). Moving further forward in the cortex, the ventral and dorsal streams carry on into the frontal lobes, where the two streams have been shown to maintain their distinctiveness – spatial operations being tied to the dorsolateral frontal cortex (Goldman-Rakic, 1988) and aspects object processing to ventrolmedial frontal areas (Kowalska, Bachevalier, & Mishkin, 1991). Ventral and dorsal stream distinctions within frontal regions have also been found for spatial and colour memory (Mohr & Linden, 2005; Mohr, Rainer, & Linden, 2006).

Incorporating neocortical and subcortical structures, Posner (see 2004 work for full review) put forth a taxonomy organising attention-related networks into three parts - the *orienting network*, the *executive network*, and the *alerting network*. The orienting network, which is purported to work at an unconscious level, operates primarily to shift attention among various locations and/or stimuli. This network can be tracked anatomically by considering the steps involved in an attentional shift. Assuming attention is already fixed on stimulus (A), disengaging from (A) requires operations of posterior parietal regions. Next, sub-cortical regions in the midbrain

(i.e., superior colliculus) execute the actual shift of attention away from (A) toward stimulus (B). Finally, the pulvinar of the thalamic sub-cortical region underlies the engagement of attention by stimulus (B). Moreover, orienting attention seems to be associated more with the right than left parietal region, as studies with patients have revealed significantly less impairment on orienting tasks when neurological insult is isolated to the left posterior parietal regions (Fuster, 2003).

The executive network underlies the guidance of future behaviour via. attention-engaging stimuli. Examples include exogenous cues directing attention toward letters, digits, or specific locations (Colegate, Hoffman, & Eriksen, 1973). When such cues are perceived a state of 'process readiness' can be established that facilitates and/or suppresses respective processing pathways. That is to say the executive network 'controls' or 'regulates' attention by taking in bottom-up information, analysing it, and then issuing control directives (top-down) that allow for the most efficient use of information processing capacity. Less obvious, but nonetheless important examples of executive operations are planning strategies, monitoring progress, and processing feedback – operations which themselves require an ongoing devotion of attention.

The frontal lobes are traditionally viewed as the functional epicentre for the executive network (Baddeley, 1986; Norman & Shallice, 1986; Shallice, 1982). The capacity to carry out executive operations is often attributed to the highly flexible response properties of frontal cortex neurons. Unlike more posterior cortex, neurons in the frontal lobes respond to the input, output, working memory contents, rewards, etc. for virtually any task (Duncan, 2001; Duncan and Owen, 2000; Rainer et al., 1998a&b; Sakagami and Niki, 1994).

Linking Posner's executive network with the biased-competition account, the

flexible and integrative operations of the frontal lobes – specifically prefrontal regions (Desimone and Duncan, 1995; Miller and Cohen, 2001) – initiate top-down commands that prime posterior neurons for the occurrence of task-relevant stimuli. Being 'primed' prior to stimulus onset likely provides neurons encoding task-relevant information with a significant advantage in the competition for limited processing capacity. Examples of such operations considered thus far in our discussion are results from Moran and Desimone (1985) and Chelazzi et al. (1998).

Questions have however been raised as to whether frontal regions are solely responsible for top-down control, or whether secondary structures – specifically regions of the parietal lobes – play a parallel role. Empirical results promoting these questions include coactivation of prefrontal regions and inferior parietal lobules (IPLs) during action planning (Baker et al., 1996; Fincham et al., 2002) and cognitive set-shifting (Asari et al., 2005; Collette et al., 2005; Shafritz, Kartheiser, & Bolger, 2005). Chafee and Goldman-Rakic (1998) reported 222 posterior parietal neurons in the monkey cortex showed highly flexible response properties very similar to the frontal lobes. In a review of 275 PET and fMRI studies, Cabeza and Nyberg (2000) reported that multiple parietal and frontal regions have often been shown to produce similar response patterns across a wide range of task demands. Peers et al. (2005) assessed performance on a variety of task demands for two patient groups – one group suffering from neurological insult to parietal areas and another group for frontal areas. For both groups significant correlations were reported between lesion volume and performance on tasks requiring top-down control.

The precise role played by parietal regions in top-down control is still unknown, although suggestions are beginning to emerge. Jubault, Ody, and Keochlin (2007) examined the issue with an fMRI protocol requiring participants to carry out

over learned sequences of motor acts and cognitive tasks. Their findings indicated a functional dissociation in the top-down related roles played by the left vs. right *intraparietal sulci* (*IPS*). The left IPS was suggested to process the serial structure of ongoing behavioural sequences, while the right IPS engaged in the preparation to execute those sequences.

Returning to Posner's three networks of attention, the alerting network plays a modulatory role influencing the orienting and executive networks. When 'alerted', Posner suggest the information processing system can adjust itself to a more efficient state of processing. Once an alerting event has been perceived the process begins by signalling the reticular thalamic nuclei. These signals are then passed on to the posterior hypothalamus as well as regions of the brainstem – specifically the tegmentum region that includes the substantia nigra of the midbrain and rostral portion of the pons. Such regions serve as the origins of cholinergic (i.e., acetylcholine), monoaminergic (i.e. dopamine; seratonin), and histaminergic (i.e., histamine) neurotransmitter pathways. Before ascending to the neo-cortex respective pathways must pass again through the thalamus where they are broadcast via relay neurons. The thalamus thus serves as a sort of 'gatekeeper' for cortical arousal.

Dual-Task Deficits in Divided Attention

Divided attention involves analysing multiple sources of attentionally demanding information either simultaneously or within a short temporal sequence. Failures in information processing that occur when multiple sources of information exceed available processing capacity are commonly referred to as *dual-task deficits.* How successful we are at dual tasking is thus dependent upon whether sufficient processing capacity is available for each task. At their most extreme, capacity

limitations result in *serial processing*. On the other hand, a total absence of processing limitations would allow stimuli to be processed in parallel throughout all stages of processing.

The mere existence of capacity limitations does not however rule out the potential for parallel processing. In fact, cognitive models accounting for dual-task interference typically presume either that certain stages of information processing operate in a serial fashion, while others operate in parallel, or that the proficiency of parallel processing itself is impacted. Townsend (1974) for instance, suggested capacity limitations may impact the speed with which parallel processing can be executed – the more severe the limitations the longer it takes to process multiple stimuli simultaneously. Another idea is that capacity limitations may cause processing of two stimuli to begin at different times, yet allow their overall processing to overlap in time (Townsend and Ashby, 1983).

Sources of capacity limitations are often explained with the concepts of cognitive resources and functional bottlenecks. Both concepts are meant to represent failure of processing mechanisms to accommodate the information presented to them. Resource accounts, originating with Kahneman (1973), view these limitations as resulting from a depletion of centralised processing capacity, of which only a finite amount is thought to exist – "centralised" referring to the idea that all tasks are carried out at the expense of the same 'pool' or resources.

Alternatively, it has been argued multiple 'pools' of resources exist. Evidence supporting this claim comes primarily from research showing dual-task interference is exacerbated when both tasks fall under the same sensory modality, require similar processing (e.g., two memory tasks), or involve similar responses (e.g., motor vs. verbal; Wickens, 1984). However, an alternative suggestion is that

task-similarity increases dual-task interference not because the same 'pool' of resources is being depleted, but rather because similar tasks require the same neural wiring. Because neural pathways are believed limited in the amount of information that can be transmitted simultaneously, task-similarity is likely to exacerbate dual-task interference even in a centralised capacity-limited system (Fuster, 2003).

Also in favour of centralised capacity limitations, Bourke, Duncan, and Nimmo-Smith (1996) demonstrated that when tasks are not at all similar (e.g., speech shadowing vs. random number generation), increasing the level of task-difficulty magnifies dual-task interference. If multiple 'pools' of processing resources were available it seems unlikely dissimilar tasks would interfere with one another as a function of difficulty. Placing centralised vs. divided allotments of resources aside, coordinating the allocation of resources between multiple tasks has been linked to executive operations of the frontal lobes (Allain, Etcharry-Bouyx, & Le Gall, 2001; and Baddeley, Della-Sala, Papagno, & Spinnler, 1997). Baddeley and colleagues (1997) even went so far as to suggest that dual tasking is more sensitive to frontal dysfunction than the more traditional executive operations of planning and monitoring.

Bottleneck accounts view capacity limitations as resulting from differences in the amount of information that can be handled at various processing stages. The approach has also been referred to as single-channel theory (Craik, 1947; Welford, 1952; 1967). For example, if processing a given stimulus involves two stages, and stage (A) can process more information at once than stage (B), then it is said that a bottleneck occurs between (A) and (B). While bottlenecks in information processing have been suggested to occur during stages of perception (Broadbent, 1958 – early-selection theories), performance decrements arising from dual-task interferences are

often suggested to occur from bottlenecks during memory-consolidation, decision-making, and response-related processing stages.

Examples of proposed bottlenecks involving response-related stages can be found in research investigating the *Psychological Refractory Period* (*PRP*). The PRP outcome illustrates that observers' *reaction time* (RT) in responding to the second of two stimuli increases as the temporal proximity of stimulus onsets decreases (Telford, 1931). In the typical paradigm, two target stimuli – S1 and S1 – are presented with S1 preceding S2 by a variable SOA. The SOA typically varies between 0 and 1000 ms. Response measurements include the time intervals between S1 and RT1 (i.e., the response prompted by S1) and S2 and RT2 (i.e., the response prompted by S2). Both simple RT measurements and choice RT are commonly used. While the stimuli used in PRP experiments have been predominately visual or auditory, tactile stimuli have also been used (Brebner, 1977). Diverse methods of responding to S1 and S2 are also present in the PRP literature (eye-movements – Pashler, Carrier, & Hoffman, 1993; vocal responses – Pashler, 1990; foot responses – Osman & Moore, 1993; vocal and foot responses – Pashler & Christian, 1996).

Welford (1952) was the first to promote the idea that the PRP effect is due to a bottleneck in information processing. On the basis of experiments reporting the effect when diverse responses (e.g., responses from different modalities) were used, Welford reasoned dual-task interference must occur during a modality-independent bottleneck involved in response selection, when S1 and S2 were held in a "central processor". Multiple other PRP investigators have also purported that a bottleneck during response selection underlies the PRP effect. For example, Karlin and Kestnebaum (1968) and Smith (1969) reasoned that a bottleneck during response selection would allow RT2 latency to be manipulated as a function of the number of

decisions required for each response. Indeed, these authors reported the PRP effect was exacerbated when the number of response alternatives was increased.

An alternative suggestion is that the PRP bottleneck involves response execution – motoric rather than cognitive limitations (Keele, 1973; Norman & Shallice, 1986). While a considerable number of experiments have claimed to refute this idea with results confirming a role for response selection (e.g., Fagot & Pashler, 1992; Hawkins, Church, & de Lemos; 1978; Pashler & Johnston, 1989; Pashler, 1989; McCann & Johnston, 1992), the potential for a response execution bottleneck has not been completely ruled out under a limited set of circumstances. Pashler and Christian (1994) reported that when the response to S1 (i.e., R1) involved a sequence of key presses with one hand, and the response to S2 (i.e., R2) required only a single key press with the opposite hand, R2 was delayed until the final key press from R1 was emitted. The sequence of key presses for R1 was viewed as preventing R2 from accessing a capacity limited stage in the production of motor movements with hands and feet. Pashler and Christian interpreted their finding within the framework of previous research suggesting bottlenecks involved in motor function occur separately from bottlenecks in information processing (Heuer, 1985; McLeod & Mierop, 1979; McLoed, 1977, 1980). In the following section we continue to consider dual-task deficits within the context of the Attentional Blink Paradigm.

Part Two: The Attentional Blink Paradigm

At this point we narrow our focus to dual-task deficits reflected by the Attentional Blink. Raymond, Shapiro, and Arnell (1992) were the first to use the phrase "Attentional Blink" though the phenomenon was first discovered by Broadbent and Broadbent (1987). Like the PRP paradigm, the AB examines dual-task deficits on a temporal scale – illustrating fluctuations in the severity of dual-task demands as a function of the time interval between onsets of two target stimuli. Unlike PRP, the AB typically asks observers to detect or identity two targets embedded within an RSVP stream of non-target distracters. Also unlike PRP, responses in the AB are typically delayed rather than speeded. The *second target* (*T2*) is often undetected if presented 200-500 ms post onset of the *first target* (*T1*; Raymond et al. 1992). Embedding targets with an RSVP stream means target processing is impacted by backward masking. Backward masking attenuates target processing. The AB thus reflects the 'temporal availability' or 'time-course' for attentional systems engaged in selecting and processing targets presented among competing task-irrelevant stimuli.

The following discussion of the AB is organised into four parts – each introducing a topic within the literature that has contributed significantly toward current understanding of the AB bottleneck. Listed in the order they are discussed, these four topics are *psychological accounts of the AB*, *the role of target-masking*, *the Lag-1 Sparing phenomenon*, and finally *the neuroanatomical locus of the AB*. Chapter 1 is concluded with a brief summary of topics to be considered in subsequent chapters.

Psychological Accounts of the AB

For the current discussion, psychological accounts of the AB are divided into two camps – those promoting *limited capacity explanations*, and those in favour of *top-down influences over target processing*. In the case of the former, T1 processing demands prevent T2 from accessing sufficient processing resources. The latter category proposes the AB is caused either by the level of attentional investment toward the RSVP stream (Olivers & Nieuwenhuis, 2006), or a recalibration of attention in response to the T1+1 stimulus (Di Lollo et al., 2005; Olivers, 2007).

Limited Capacity Accounts: Shapiro, Raymond, and Arnell (1994) proposed the *competition hypothesis.* This account proposes T1, T1+1, T2, and T2+1 items compete with each other during retrieval from a *short-term memory* (*STM*) buffer. Items entering STM are prioritized regarding the order they are to be processed – priority being determined by the order of presentation and how well items match a pre-set target filter. As T1 is the first item to enter STM, the system recognizes it as the highest priority for allocation of processing capacity. Processing of T1 and its subsequent mask is carried out at the expense of T2, which receives a lower priority rating due to its position in the RSVP stream. T2 is believed to receive too few cognitive resources to effectively compete with other items, and is therefore lost in STM.

The first alternative to the competition hypothesis was Chun and Potter's (1995) *delay of processing or bottleneck hypothesis.* At several points throughout the current document I refer to this model as the *two-stage model of processing*. This account proposes differences in capacity limitations for two stages of processing. In a first stage, all stimuli presented are rapidly processed at the level of feature and meaning. A second, capacity limited serial processing stage referred to as a "central

processor", completes processing by consolidating stimuli at a level sufficient for report. As the serial nature of the second stage implies, T2 is denied access to the central processor until processing of T1 is complete. It has been suggested that the encoded representation of T2 is overwritten by subsequent masking while waiting to enter the central processor (Giesbrecht & Di Lollo, 1998; but also see Giesbrecht, Bischof, & Kingston, 2003, 2004 and also Mari, Paradis, Thibeault, & Richer, 2006).

Jolicoeur and Dell'Acqua (1998) proposed that under conditions when AB responses are speeded – i.e., when RT is measured - dual-task interference between T1 and T2 occurs due to a central bottleneck involving short-term memory consolidation. These authors suggest this may be the same processing bottleneck that underlies the PRP effect. Much like Chun and Potter's account, Jolicoeur and Dell'Acqua propose the bottleneck occurs at the point of transferring a temporarily active target into a more durable representation.

Top-Down Influence Accounts: In 2005 Di Lollo, Kawahara, Ghorashi, and Enns proposed *the Temporary Loss of Control* account. In these authors' view the T1+1 item, due to incompatibility with a target search template, induces a loss of control over monitoring processes. In other words, prior to RSVP onset endogenous top-down mechanisms are set to monitor the stream for certain target defining features. Once T1 occurs and attention is engaged, a following stimulus lacking target-defining features will disrupt monitoring processes. This disruption takes approximately 500 ms to recover from, during which time observers are unable to effectively monitor for additional targets (e.g., T2).

Di Lollo et al. (2005; Experiment 2) presented three target stimuli with no intervening non-target masks. All three targets shared the same target-defining feature –i.e., category. The three targets (i.e., T1, T2, & T3) were reported equally well – thus

no AB effect was found. Alternatively, when T2 differed from T1 and T3 in category, T1 performance was significantly better than for T2 and T3. This outcome stands in stark contrast to limited capacity accounts. If the demands of processing T1 and the T1+1 item prevent subsequent stimuli from gaining access to sufficient processing capacity, then T3 performance should have been poorer than T1 regardless of the category assigned to T2. To restate the implications for this result; the way in which the information processing system responds to items not matching a T1 target template may be equally if not more important that the demands of processing T1 itself.

Reaching a similar conclusion, Olivers (2007) reviewed results from multiple studies illustrating dissociations between how top-down mechanisms respond to task-relevant and task-irrelevant stimuli. Olivers postulated that when the T1+1 non-target item appears, attention 'adapts' to the occurrence of task-irrelevant stimuli by suppressing analysis of future RSVP items. This suppression is believed to 'protect' processing of T1 at the expense of T2.

Another account of the AB promoting top-down influence is the *Overinvestment Hypothesis* (Olivers & Nieuwenhuis, 2006). This account postulates that T2 performance decrements are not due to the demands of processing T1 per se, but rather the extent to which observers invest attention toward the RSVP stream. This account has been supported by studies reporting that the AB is attenuated either by presenting continuous task-irrelevant activity throughout the duration of the RSVP stream, or instructing observers to simultaneously engage the AB as well as a concomitant cognitive task. Examples include background music, visual motion or images presented peripheral to the RSVP stream, free-association tasking, and memory tasking (Arend, Johnston, & Shapiro, 2006; Olivers & Nieuwenhuis, 2005, 2006).

The overinvestment hypothesis presumes task-irrelevant activity and

concomitant tasking induce a "diffused" state of attentional processing. During the diffused state less attention is invested toward the AB task. In turn, the total number of RSVP items receiving sufficient investment to warrant competing for later processing stages is diminished – the reduction in competing items allowing more resources to be available for T2. Chapter 2 of the current document presents a neurological investigation of the overinvestment hypothesis – an investigation that refutes the idea of a diffused attentional state.

Although all the *limited capacity* and *top-down* accounts mentioned above are still commonly cited as viable explanations of the AB, the differences among them represent an evolution of ideas regarding the complexity of underlying mechanisms. Processing capacity accounts view the AB as resulting from a limited ability to processes targets along a single feed-forward sweep in information processing. Top-down accounts view the AB as related to the highly flexible nature of attention – asserting T2 performance decrements are due either to over investing attention (Olivers & Nieuwenhuis, 2005, 2006), a temporary loss of control over monitoring processes (Di Lollo et al., 2005), or inhibition of future stimulus processing (Olivers, 2007).

The Role of Target Masking

A significant role for target masking was realized in the earliest AB experiments. Raymond et al. (1992) concluded in order for an AB to occur T1 must be effectively masked. This conclusion was drawn when replacing the item immediately following T1 (i.e., the lag-1 position) with a blank interval failed to produce an AB. Several studies have suggested the primary role of a T1 mask is to increase the amount of attentional resources required for T1 processing, thus either increasing the delay before later stages of T2 processing can begin, or further reducing the amount of

resources that T2 can access (see Shapiro, 2001 for review).

Seiffert and Di Lollo (1997) demonstrated T1 can be effectively masked by either visual *integration masking* (i.e., T1 and the item normally in the lag-1 position are presented superimposed as one item) or visual *interruption masking* (i.e., the T1 mask item is presented at its normal temporal position post T1 offset). It should be noted these masking types differ not only in appearance, but also in the point at which they induce interference during processing. As an integration mask is perceived to be part of the target, interference is taking place at an early low-level stage of visual processing. On the other hand, an interruption mask interferes with processing by overwriting a partially encoded representation of the target. This is believed to represent interference occurring at later higher levels of visual processing - during which the target and mask engage in competition for attentional resources devoted to object recognition (Brehaut, Enns, & Di Lollo, 1999).

Moore et al. (1996) further demonstrated the importance of visual masking by showing that in the absence of a mask for both T1 and T2, accuracy is close to ceiling for both targets. Moore's findings support the notion that, much like for T1, it is the occurrence of visual masking that brings T2 accuracy into a performance range sensitive to the AB (Enns et al., 2001). Giesbrecht and Di Lollo (1998) demonstrated not only will failure to mask T2 result in no AB, but unlike T1, T2 performance is sensitive to the type of mask presented. Following in the footsteps of previous AB studies examining T1 masks, the effects of both integration and interruption masking on T2 were considered. Only when interruption masking was applied were the signature temporal constraints on T2 processing observed (i.e., processing deficits for 200-500 ms post T1 onset).

Giesbrecht and Di Lollo explained their findings in terms of the competition

(Shapiro, Raymond, & Arnell, 1994) and two-stage delay of processing (Chun & Potter, 1995) hypotheses. It was proposed that in the two-stage model T2 representation is lost due to being overwritten while waiting on resources to be freed from processing T1 and its mask. Had integration T2 masking resulted in an AB, it would have been concluded that passive decay, as opposed to object substitution, was responsible for performance deficits.

The competition model was suggested to not so easily account for these findings. Although the effectiveness of an interruption T2 mask is in accord with the model, as the trailing mask would compete with T1 and T2 in VSTM, the model provides no explanation of why integration T2 masking failed to produce a conventional AB. According to the competition hypothesis, the closer the temporal proximity of target and mask presentation, the greater the probability the mask will enter VSTM. This implies an integration mask should enter VSTM with greater ease than an interruption mask. This was not reflected in Giesbrecht and Di Lollo's findings.

Recent publications have suggested the importance of T1 masking is tied directly to the stimulus properties of T1. Kunar and Shapiro (2004) concluded if the resource requirement for processing T1 is great enough then no T1 mask is required. Their design presented T1 not as a conventional letter or digit, but rather a to-be-completed mathematical calculation varying on the dimension of difficulty. It was found that with a difficult calculation (e.g., 5 x 8) no T1 mask was required to induce an AB. However, with an easy calculation (e.g., 5 + 8) no AB occurred unless a T1 mask was present. In accord with the previously mentioned suggestions regarding the role of T1 masking, Kunar and Shapiro proposed the resource requirement for completing the difficult calculation was sufficient to cause an AB without the added

demands T1 masking.

Reporting a similar outcome, Visser and Ohan (2007; Experiment 1A) demonstrated that when T1 processing time is extended a trailing mask is not required to produce the AB. Visser presented T1 as a pair of rectangles varying in size. The T1 task was to judge whether the two rectangles were identical or different in size. The "easy" condition presented rectangles very different in size and the "hard" condition presented rectangles similar in size. It was expected more time would be required to make a judgement in the "hard" condition. With no T1 mask an AB was found in the "hard" but not the "easy" condition. Visser interpreted his findings as validating the claim that in conventional AB tasks T1 masking serves the purpose of increasing first-target processing demands.

Lag-1 Sparing Phenomenon

The term "lag", as it relates to the RSVP paradigm, refers to an item's sequential position amongst a series of other items (e.g., position of target items among distracters in the AB). The Lag-1 Sparing phenomenon refers to an absence of dual-task deficits when T2 appears immediately after T1 – in the lag-1 position approximately 100 ms post T1 onset. Many accounts of the AB explain lag-1 sparing with the *attentional gate hypothesis* (Chun & Potter, 1995; Raymond et al., 1992; Shapiro & Raymond, 1994; and Visser, Bischof, & Di Lollo, 1999). Among theorists advocating this hypothesis a fair amount of consensus exists regarding the idea that the gate initially opens upon presentation of T1 and remains open for 150-200 ms. During this brief temporal window it is argued T1 and T2 are encoded as one perceptual episode.

Although early AB studies found the gating hypothesis attractive as it easily

accounted for lag-1 sparing, by the late 1990s a trend emerged showing this effect only occurred in about 50% of AB studies (Shapiro, 2001). Visser et al. (1999) suggested this trend reflected an additional requirement for the attentional gate other than simple temporal proximity. In a meta-analysis including findings from over 100 studies, Visser and colleagues examined the role of task-switching for lag-1 sparing. It was determined that four classes of task-switching had been used in AB studies. These included categorical shifts in target identities (e.g., digits vs. letters), shifts in the task itself (e.g., detection vs. identification), shifts in sensory modality (e.g., auditory vs. visual), and shifts in spatial locations (e.g., central vs. peripheral). Results indicated lag-1 sparing occurs as an inverse function of task-switch. When no reconfiguration is required between T1 and T2 lag-1 sparing usually occurs.

In regards to shifts in modality, Visser and colleagues concluded that an AB typically does not occur in the presence of modality shifts. As the occurrence of an AB was a criterion for inclusion in the meta-analysis, no cases of cross-modal lag-1 sparing were analyzed. However, although not discussed here, it should be noted that since the Visser et al. (1999) publication it has been demonstrated that an AB can occur when targets are presented in different sensory modalities (Arnell & Jolicoeur, 1999).

Visser et al. (1999) concluded that in order for an item to pass through the attentional gate, not only must it occur within 150-200 ms of T1, but it must also match certain criterion set by another mechanism operating as a gate filter configured to T1 task requirements. Therefore, if T2 is presented in the lag-1 position and matches the task requirements of T1, then lag-1 sparing will occur. On the other hand, if T2 is presented in the lag-1 position but does not match the filter criterion, then a new filter must be configured to match the task requirements of T2. As reconfiguration takes

time the gate will have closed before the new filter is complete. As a result, T2 fails to be encoded in the same perceptual episode as T1, and suffers from the same processing deficits as items occurring at later lags.

Hommel and Akyürek (2005) attempted to gain evidence in favour of either the attentional gate hypothesis as presented here, which advocates integration of T1 and T2, or an alternative hypothesis suggesting when in the lag-1 position T2 competes with T1 for attentional resources. As the idea of resource competition implies, the latter of these two hypotheses speculates that increased processing of T2 results in deficits for T1 (Potter et al., 2002). Overall, Hommel and Akyürek's results suggest whether T1 and T2 are integrated into the same episode or compete with one another for resources is dependent on their "discriminability". In their experiment target 'discriminability' referred to difficulty in perceiving targets as different from the visual background on which they were presented. Three levels of target discriminability were used, all of which consisted of a letter presented on a grey background (e.g. easy condition = white letter; medium condition = black letter; difficult condition = gray letter).

In trials where T1 and T2 were equally discriminable, evidence was found for target integration. In addition to the identity of both targets being reported with a high degree of accuracy, information was lost regarding the order of target presentation – i.e., participants could not report whether a particular stimulus appeared as T1 or T2. Confusion of temporal order has been previously reported to accompany lag-1 sparing, and has been attributed to the integration of targets into one perceptual episode (Chun & Potter, 1995; Shapiro et al., 1994).

On the other hand, when T1 and T2 differed in discriminability, evidence was found suggesting targets competed for resources. The more discriminable target was

identified with a higher degree of accuracy. Thus, when T2 was more discriminable than T1, more resources were allocated to T2 and vice versa. When targets differed in discriminability participants were also able to report whether a given stimulus appeared as T1 or T2 – i.e., information regarding temporal order was not lost.

Hommel and Akyürek concluded the integration and competition accounts should not be viewed as opposing interpretations of the same cognitive phenomenon. Rather, they suggested T1 and T2 likely always compete for resources, but it is the strength of competition on behalf each target that determines whether integration occurs, or one target is processed exceptionally well at the expense of the other. Being equally discriminable, both targets compete equally well for resources – only under such circumstances can T1 and T2 be integrated during the 150 – 200 ms window of lag-1 sparing. According to these authors then, equal competition between targets is therefore a requirement for the type of integration underlying lag-1 sparing. It was suggested that when T1 is the more competitive target T2 is unable to access sufficient resources to make integration possible. On the other hand, when T2 is the more competitive target, preventing integration serves as an adaptive mechanism for protecting T1 processing. Importantly, Hommel and Akyürek suggested that although preventing integration may initially serve the purpose of protecting T1, it does not prevent T2 from benefiting at the expense of T1 during memory consolidation stages critical to the AB.

Using *magnetoencephalograhy* (MEG), Kessler et al. (2005) also examined whether T1 and T2 are integrated or compete for resources. It was believed with T2 in the lag-1 position M300 evoked potentials for T1 and T2 (i.e., an index of target processing) would occur later and display weaker amplitudes if targets were engaged in competition as opposed to integrated. If targets were being integrated the M300

elicited by T2 was expected to occur early enough to overlap temporally with the M300 for T1. T2 followed T1 either in the traditional lag-1 (i.e. 100 ms SOA) or lag-2 (i.e. 200 ms SOA) position.

The results of this experiment provided a negligible amount of evidence for competition between targets. Compared to lag-2 trials, during lag-1 trials a delayed T1 M300 component was found in the left temporo-parieto-fronto (TPF) region, but the T2- evoked component from this region was found to occur earlier than in lag-2 trials. If competition was taking place, both M300 components should have been delayed relative to lag-2 trials. Moreover, no amplitude differences were found for T1/T2 M300 components between lag-1 and lag-2 trials. The integration account was however supported in the above study. Although it was determined T1 and T2 are not treated as one perceptual episode at all stages of processing as no temporal overlap for T1/T2 components was observed in pre-frontal-cortex (PFC) and right TPF region, a clear display of M300 overlap took place in the left TPF region.

Interpreted within the context of Hommel and Akyürek (2005), it could be argued that Kessler and colleagues failed to support the competition account because T1 and T2 were equally discriminable in their experiment. Taken together these two studies suggest both integration and competition may play an important role in lag-1 sparing. More support however currently exists in favour of integration, as evidence supporting competition between targets has not been reported at the neurological level. However, such evidence may be uncovered if the M300 or P300 components were examined with targets differing in discriminability.

Neuroanatomical Locus of The Attentional Blink

Functional Magnetic Resonance Imaging: The limited temporal resolution of *functional magnetic resonance imaging* (*fMRI*) – due to slow haemodynamic baseline recovery – has necessitated innovative approaches for studying the AB. Marois, Chun, and Gore (2000) mapped the haemodynamic activity for presentation of a single target – equivalent of T1. Participants were required only to detect the presence of the target, which could appear as one of three letters (B, C, or D). These authors justified their approach by arguing that it is T1 that triggers the AB, while T2 only serves to illustrate ensuing processing deficits (Chun and Potter, 1995; Duncan et al., 1994; Jolicoeur, 1998, 1999; Raymond et al., 1992; Ward et al., 1996).

This single-target paradigm produced a right hemispheric-parietal-frontal network of activation. These authors concluded this network represents the brain regions recruited when distracter stimuli interfere with target processing. Pointing out that such a network is consistent with brain regions recruited by attentional orienting, control, and enhancement processes (Corbetta et al., 1993, 1995, 1998; Coull et al., 1996; Kastner et al., 1998, 1999; Kim et al., 1999; Nobre et al., 1998, 1999; Wojciulik & Kanwisher, 1999), Marois and colleagues suggested that neural networks involved in the control of visuo-spatial attention may also form a capacity-limited bottleneck for visual information[3].

With a more traditional two-target paradigm, Kranczioch et al. (2005) and Marcantoni et al. (2003) mapped the haemodynamic activity triggered by T1 and T2 combined (i.e., fMRI data being analysed with the approach that the appearance of T1 and T2 represents a single event). Marcantoni and colleagues analysed fMRI data for

[3] The results of Marois, Chun, and Gore (2000) presented here were not dependent upon whether the single target was detected or undetected. Analyses in this publication were based upon average differences between conditions with high vs. low levels of interference from competing non-target distracters. The present summary of results represents the overall pattern of neural areas activated by the single target paradigm across both high and low interference conditions.

trials when T1 and T2 were presented at a short (300ms) vs. a long (700ms) SOA[4]. Relative to long SOA trials, presenting T2 at short SOA yielded bilateral increases in BOLD response for inferior temporal and inferior frontal regions. Additionally, increases in activation were found in the left posterior parietal cortex and posterior cerebellum. These findings were interpreted as indicating that increased BOLD activation represents enhanced levels of 'effort' required on behalf of attentional systems when two targets are presented within short temporal proximity. Specifically, the attentional systems influenced by dual-task demands of the AB were said to be those involved in orienting attention, short-term memory consolidation, working memory, and conscious identification[5]

Kranczioch and colleagues examined differences between haemodynamic activity for short lag trials when T2 was detected (No-AB trials) vs. when undetected (AB trials). It was found that activation in the occipital-temporal region was greater during AB trials relative to No-AB trials. Alternatively, for parietal and frontal areas activation was greater during No-AB trials. These results were believed to reflect different roles played by occipital-temporal and frontal-parietal regions. It was suggested that during AB trials participants spend more time searching for T2 than during No-AB trials – hence the greater activity for occipital-temporal areas during AB trials. Frontal-parietal regions were suggested to include attentional networks underlying control and visual awareness, which are interrupted during AB. This interruption of processing was suggested to underlie the AB, and be the cause of reduced haemodynamic activity for these brain areas during No-AB trials.

Unlike the three experiments mentioned above, which used visually simplistic

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[4] Marcantoni et al. (2003) did not look at differences in neural activation between AB trials and No-AB trials. Rather these authors only looked at differences between short and long-lag trials.

[5] Marcantoni et al. (2003) did not draw any specific conclusions as to precisely how T1 and T2 interact during the AB. Rather, they only concluded that certain systems were heavily burdened by the demands of divided attention incurred by the two targets.

stimuli (e.g., letters and digits), Marois, Yi DJ, and Chun (2004) used stimuli they anticipated would activate different cortical areas for T1 and T2 (i.e., face T1; visual scene T2). Being able to anatomically differentiate between T1 and T2 related activation allowed processing of each target to be evaluated separately. The most interesting outcome did not involve the *fusiform face area* (*FFA*) for T1, but rather the *parahippocampal place area* (*PPA*) of the medial temporal cortex for T2. Known to activate in response to visual scenes (Epstein, Harris, Stanley, & Kanwisher, 1999; Epstein & Kanwisher, 1998, etc.), PPA activation was at a maximum when T2 was consciously perceived, regardless of whether or not the second target was reported correctly. A similar level of frontal activity was found only when T2 was correctly reported. The resulting interpretation was that medial temporal regions are capable of rapidly categorizing visual input, while frontal areas underlie the capacity-limited bottleneck preventing accurate T2 report.

Shapiro et al. (2007) postulated that Marois's (2004) results represent BOLD activity when T2 performance is limited by perceptual factors rather than attention based processing limitations. The rational for this distinction was based on the temporal and masking parameters used in Marois's experiment. Marois allowed SOA between T1 and T2 to vary between participants. This was done to insure participants produced an equal number of AB and No-AB trials. The average T1-T2 interval across participants was 450 ms – very near the end of the 500 ms it is thought to take to recovery from T1 processing. Even with the 450 ms average SOA T2 accuracy in Marois's experiment was approximately 50%. Shapiro and colleagues suggested such low T2 performance with long inter-target SOAs was the result of atypical levels masking interference.

Shapiro et al. (2007) replicated Marois's experiment but with two changes.

First, altering the effectiveness of target masking reduced T1/T2 task difficulty. In Marois's experiment target masks were composed of several small pieces of scrambled scenes. In Shapiro's experiment the size of pieces making up these masks were increased, thus potentially reducing masking interference by making the mask a 'less complex' stimulus (Enns, 2004). Second, Shapiro et al. (2007) used a consistent SOA of 200 ms across all participants. The outcome was that the maximum PPA BOLD activation was found for No-AB trials – when T2 was correctly reported. PPA activation was significantly less for AB trials. Recall that in Marois's experiment maximum PPA activation was found when T2 was only consciously perceived. From their findings Shapiro and colleagues developed the following hypothesis. When conventional temporal and masking parameters are used, PPA activation represents the 'effort' required to process T2 when attention is unavailable. On the other hand, when task difficulty is increased – e.g., via masking interference - PPA activity at long inter-target intervals reflects perception.

In sum, investigations of the BOLD response indicate that mechanisms responsible for processing two targets in close temporal sequence span across large portions of the cortex – e.g., occipital, temporal, parietal, frontal areas. Moreover, involvement of these regions has lead researchers to suggest interference in processes of attentional control, awareness, perceptual decisions under masking interference, and categorisation of visual input, may contribute to the AB. Finally, future research must take into account differences that attention vs. perceptual influences have for the BOLD index.

Electrophysiological Modulation: More indicative of how the brain processes rapidly occurring events is the high temporal resolution of the electrophysiological approach – either electrical (EEG) or magnetic-based (MEG). In the first

electrophysiological AB study, Vogel, Luck, and Shapiro (1998) showed that despite not being able to successfully report T2, the second target nevertheless elicits a N400 component. The implication being that the AB does not prevent T2 from being processed to the level of meaning. Recently this finding has been shown to depend on the perceptual demands of T1. Giesbrecht, Sy, and Elliot (2007) carried out a replication of Vogel, Luck, and Shapiro with the addition of manipulating how perceptually demanding T1 was. When the complexity of visual features making up the T1 stimulus was increased a N400 for T2 was no longer found. These authors interpreted their finding as affirming the view that the fate of T2 processing is contingent on T1 processing demands (e.g., Kunar & Shapiro, 2007; Visser & Ohan, 2007).

Attempting to replicate another aspect of the Vogel, Luck, and Shapiro experiment, Kranczioch, Debener, and Engel (2003) investigated the P300 ERP component elicited by the T2 stimulus. In accordance with Vogel, Luck, and Shapiro, these authors reported that missed T2 targets – i.e., AB trials - did not elicit clear P300 components. As also demonstrated by Vogel, Luck, and Shapiro, Kranczioch and colleagues reported that clear P300 components were observed for correctly reported T2 stimuli – i.e., No-AB trials. Both sets of authors interpreted these outcomes as indicating that the AB prevents a maintainable representation of T2 from entering working memory.

Beyond measuring the amplitude of single ERP components, some researchers have begun to investigate how distant brain regions interact during target processing. Often such interactions are interpreted within the context of *neural synchronicity*. When two neural regions share the same frequency of activation it has been suggested they are 'synchronised'. Synchronicity is believed to reflect

communication between distant neural regions. Fell, Elger, and Fernandez (2002) investigated why dual-task deficits are most severe 300 ms post T1 onset – as opposed to 100 ms at lag-1. As an alternative to the ad-hoc explanation of gating mechanisms closing post T1, these authors propose a chronometric relationship between T1 processing and suppression of the gamma band (i.e., approx. 40 Hz) response to T2. Comparing a combination of single and dual-target trials, these authors revealed that a robust P300 occurring for T1 interrupts early gamma band responses to T2 – the respective timings of these events underlying the maximum impact of the AB 300 ms post T1 onset. The gamma band has been suggested to represent integration or 'bringing together' of information required to form a coherent conscious percept (Engle, Fries, & Singer 2001; Wagner, 2001; Varela, Lachaux, Rodriguez & Martineze, 2001).

Further examining synchronisation in the gamma band, Nakatani et al. (2005) measured the degree of synchronization between pairs of electrodes during the AB. The first important finding is that phase synchrony on average was higher when participants were instructed to detect two targets as opposed to just one. This was interpreted as reflecting an anticipatory modulation of top-down mechanisms in the presence of greater task demands. In other words, this is a physiological testament to our capacity for cognitive adaptation in the face of challenging tasks. Moreover, these authors report that on No-AB trials (i.e., when T1 and T2 were correctly identified), brief periods of even stronger synchronicity occurred approximately 100 ms before T2.

Gross et al. (2004) reported differences in patterns of synchronised activity for AB and No-AB trials. During No-AB trials synchronisation in the beta band (i.e., approx. 15 Hz) was significantly stronger over the entire RSVP stream compared to

AB trials. Also compared to AB trials, in No-AB trials beta-synchronisation was significantly stronger to targets and significantly weaker to masks. Gross and colleagues claim their findings affirm previous research suggesting that as a general rule, synchronicity represents neurological sensitivity to task-relevant events.

Numerous experiments prior to Gross et al. (2004) have suggested the beta band plays a role in attentional processing. Examples include synchronization between extrastriate areas during short-term memory maintenance (Tallon-Baudry, Bertrand, & Fischer, 2001), synchronisation between temporal and parietal areas during object processing (Von Stein, Rappelsberger, Sarnthein, & Petsche, 1999), and perception related modulation during binocular-rivalry (Gail, Brinksmeyer, & Eckhorn, 2004). Comparing the beta and gamma bands, neuronal simulation models have suggested stability of long-range synchronicity is facilitated by the beta range activity, while gamma activity is more optimal for maintaining local interactions (Bibbig, Traub, & Whittington, 2002; Kopell, Ermentrout, Whittington, & Taub, 2000).

Gross et al. (2006) followed-up their 2004 results by further examining the relationship between synchronicity and target processing. Because communication between cortical areas is expected to be under top-down control, these authors hypothesised that synchronicity would fluctuate as a function of target expectation. Their paradigm consisted of a single target occurring in one of three locations within a RSVP stream – the target occurred either as the 4th, 5th, or 6th item. The rational was that with each passing RSVP item the probability, and thus expectancy, of target presentation increased. As predicted, target-locked synchronicity in the beta band increased progressively as a function of target expectancy. In addition to further affirming the idea that synchronicity reflects sensitivity to task-relevant events, Gross and colleagues interpreted their findings as indicating that through

synchronicity, top-down control operations link rapidly occurring perceptual events with expectations about future stimuli.

Taken together, the studies cited above suggest a direct relationship between heightened levels of synchronicity and successful target processing. It is believed synchronicity aids target processing not only by linking information across neurons, but also by stabilising the target processing network as to make it less susceptible to interruption from adjacent cells (Buzaski, 2007). In all studies linking the AB with synchronicity it has been proposed that increased levels of synchronicity help to protect the T2 object network from being degraded by the AB bottleneck.

Neuropharmacology and the Attentional Blink: Nieuwenhuis, Gilzenrat, Holmes, and Cohen (2005) proposed a pharmacological-based mechanism of the AB involving neurotransmitter systems originating in the locus coeruleus. In light of previous work linking attentional processing with the norandrenergic catecholamine neurotransmitter norepinephrine (*selective attention*: Bunsey & Strupp, 1995; Steketee, Silverman, & Swann, 1989; *time perception*: Penney, Holder, & Meck, 1996; *attention deficit disorders*: Kim et al., 2006), these authors sought to map the time course of locus coreuleus projections to higher-level cortices. It was determined that each time the locus coeruleus projects norepinephrine through the brain a refractory period exist matching the AB time course. In other words, once this system 'fires' in response to a single target – such as T1 – it is unable to do so again for approx. 500 ms. Importantly, Nieuwenhuis and colleagues only acknowledged the similar time- courses for the AB and the locus coreuleus. These authors did not provide empirical evidence indicative of a causal relationship.

In a follow-up study, Nieuwenhuis, Nieuwpoort, Veltman, and Drent (2007) attempted to reaffirm the role of norepinephrine in the AB by manipulating respective

chemical levels for participants. After administering clonidine - a norandrenergic agonist - it was found AB performance was not exacerbated as a result of respective attenuations in norepinephrine levels. In short, this finding is inconsistent with the 2005 suggestion that the 500 ms refractory period of the locus coeruleus is directly tied to temporal limits of attention. As these authors discuss in great detail however, their findings do not definitively show that the time course of the locus coeruleus is inconsequential to the AB. Their most convincing argument regards the sensitivity of their design for detecting desired effects. Specifically, individual systolic and diastolic blood-pressure readings revealed that for several participants clonidine took its maximum effect after the time of testing.

De Martino, Strange, and Dolan (2008) made the argument that clonidine may not be the optimal method of assessing the role of norepinephrine during attentional processing. Clonidine works by inhibiting norepinephrine release via presynaptic $\alpha 2$ – adrenergic receptors. Clark et al. (1986) reported this mechanism of influencing norepinephrine levels leads to subjective withdrawal of task interest and difficulties concentrating – outcomes with obvious consequences for attentionally demanding tasks. Alternatively, blocking norepinephrine uptake via postsynaptic β-adrenergic receptors with the drug propranolol has not been reported to produce a sedative effect (Hammer et al., 2001).

De Martino et al. (2008 – Experiment 2) examined how the AB would respond when norepinephrine levels were reduced via the drug propranolol vs. when increased by the drug reboxetine – i.e., a selective norepinephrine reuptake inhibitor. De Martino and colleagues presented T2 as either an emotional or neutral word – e.g., "rape" or "omit". T1 was always presented as a neutral word. Unlike Nieuwenhuis et al. (2007), blood pressure readings in De Martino's experiment indicated drug administration and

AB tasking coincided with the effects of both drugs.

The results of De Martino's experiment showed that compared to a placebo group, propranolol impaired T2 performance during the AB interval regardless of whether emotional or neutral words were used. Reboxetine on the other hand selectively enhanced performance for emotional T2 stimuli only – increasing performance relative to a placebo group. De Martino and colleagues concluded norepinephrine does play an active role in dual-task interference as demonstrated by the AB – an idea Nieuwenhuis et al. (2007) failed to support. The emotionally selective effect of reboxetine was explained by differential effects of the drug at that neocortical vs. subcortical levels. In the neocortex selective norepinephrine reuptake inhibitors potentiate attentional gains. At the subcortical level they increase the refractory period of the locus coeruleus. In the case of neutral T2 stimuli, these effects may have been in relative equilibrium. Thus the subcortical effects cancelling out attention benefits in the neocortex. Emotional T2 stimuli however likely induced an increase in arousal – another factor known to increase norepinephrine levels (Jouvet, 1969; Robinson & Berridge, 1993). The factor of arousal may then have imbalanced the neocortical and subcortical effects of reboxetine in favour of emotional targets.

Chapter One References

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Chapter Two: Task Irrelevant Activity Promotes Attentional Investment: An Evaluation of the Overinvestment Hypothesis

Chapter Two

Task Irrelevant Activity Promotes Attentional Investment: An Evaluation of the Overinvestment Hypothesis

Introduction

Processing information across time is a limited faculty for the human information processing system. The *Attentional Blink* (*AB*; Raymond, Shapiro, & Arnell, 1992) illustrates this via an inability to detect the second of two targets presented within close temporal proximity. The AB presents targets within a *rapid-serial-visual-presentation* (*RSVP*) paradigm - the temporal duration between targets varying across trials. On trials when the first target (*T1*) is correctly identified, the second target (*T2*) goes unreported when presented approximately 200 – 500 ms post T1 onset.

Theoretical models explaining the AB postulate feed-forward or feed-back mechanisms limiting resource availability. Feed-forward accounts include competition between targets and distracters whilst held in visual-short-term-memory (Shapiro, Raymond, & Arnell, 1994), as well as multi-stage processing bottlenecks preventing T2 from entering advanced information processing stages occupied by T1 (Chun & Potter, 1995 – two stage model; Jolicoeur and Dell' Acqua, 1998 – PRP model). Although the two stage model and PRP accounts differ as to the exact locus of the bottleneck, both suggest T2 fails to be encoded into a more durable representation suitable for further processing.

Turning to feed-back accounts, one prominent account is based on a loss of control over the monitoring process. Because the T1+1 item does not match a pre-set target search template, attentional control is temporarily lost, which suggests the ensuing blink reflects the time taken to regain control (Di Lollo, Kawahara,

Ghorashi, & Enns, 2005). Another feed-back account attributes the AB to top-down modulation of adaptive processing mechanisms. The mechanisms in question regulate how we process various forms of attentionally demanding stimuli (Olivers, 2007). Taking into account a variety of behavioural findings examining attention-based responses to task-relevant and irrelevant stimuli, Olivers concludes attention is enhanced by task-relevant stimuli, but shut-down by task-irrelevant stimuli. The implications of this theory for the AB involve the role of task-irrelevant distracter items in the RSVP stream – particularly the T1+1 and T2+1 item, which serve as target-masks.

What may seem counterintuitive is the idea that task-irrelevant activity – either in the form of continuous stimulus presentation or cognitive engagement – can actually decrease dual-task deficits as indexed by the AB. To attempt to find support for this idea Olivers and Nieuwenhuis (2005) presented either task-irrelevant music or had participants engage in free association during an AB task with the result that either activity dramatically attenuated the AB. The authors hypothesised that task-irrelevant activity induces a "diffused" state of attentional processing - the result being a distraction of attentional focus away from the RSVP stream that benefits second target processing.

In an attempt to specify the mechanism underlying the relationship between diffused attentional processing and its effect of attenuating the AB, Olivers and Nieuwenhuis (2006) proposed the *overinvestment hypothesis*. This account postulates that, once a diffused processing state is established, each item in the RSVP stream receives less attentional investment. In turn, the number of stimuli receiving sufficient investment to warrant competing for later processing stages is

diminished – the reduction in competing items allowing more resource availability for T2.

The idea that reducing attentional investment toward task critical items can benefit performance has been suggested previously. Snodgrass, Shevrin, and Kopka (1993) found performance on subliminal perception tasks worsened with increased motivation; motivation suggested to reflect a heightened state of attentional investment. Hence a less motivated more relaxed state resulted in much better performance. Likewise, Smilek, Enns, Eastwood, and Merikle (2007) found instructing participants to relax their attentional focus increased performance in a visual search task.

Attempting to further examine the overinvestment hypothesis, Arend, Johnston, and Shapiro (2006) found task-irrelevant activity in the visual domain produced a similarly reduced AB magnitude as that shown by Olivers and Nieuwenhuis (2005, 2006). In Arend et al.'s experimental approach an AB task was implemented at fixation with a moving star-field surrounding the RSVP stream. Diverging from Olivers and Nieuwenhuis's account, these authors suggest the key factor might not be a reduction in attention toward the entire RSVP stream, but rather toward T1 specifically; a reasonable assumption given the significant role T1 and its mask have been shown to play in triggering the AB.

In addition to behavioural models predicated on T1 and its mask preventing T2 from occupying key processing stages (Chun & Potter, 1995; Jolicoeur and Dell' Acqua, 1998), or that the T1+1 item initiates loss of control over monitoring processes (Di Lollo et al., 2005), recent neurophysiological data has emerged confirming a critical role for T1 and its mask. Kessler et al. (2005) revealed that the T1 mask was responsible for inducing a "robust state" of processing for T1 – a state

of processing induced to protect T1 from the deleterious effects of the mask and therefore not easily perturbed. Such a robust state manifested itself in the form of a shorter peak latency M300 (*Magnetoencephalography* (*MEG*) equivalent of P300) component for masked, compared to unmasked T1 stimuli. It was suggested that for the duration of this state – likely until T1 processing is complete – T2 deficits would occur. Also citing differences in M300 magnitude, Shapiro et al. (2006) reported a direct correlation between the M300 for T1 and AB magnitude – the larger the M300 for T1 the greater the AB.

Our Focus

Our focus is not to determine whether a diffused state of processing reduces attention toward the entire RSVP stream or just T1. Rather, we ask a different question: Can a neural signature of preparatory attention confirm the overinvestment hypothesis? In other words, when task-irrelevant activity distracts attention away from the RSVP stream, is there a measurable difference in the amount of preparation prior to engaging the AB task? To address this question we chose to measure the contingent negative variation (CNV) as an index of preparation for the AB task.

Contingent Negative Variation

Categorized by Vaughan (1969) as a 'steady' negative potential shift, the *contingent negative variation* (*CNV*) is also commonly referred to as a 'slow' potential shift. Either terminology refers to the CNV taking longer to develop than its sensory-evoked or motor related counterparts (Andreassi, 2006). Early investigations described the CNV as occurring between the offset of a warning stimulus (S1) and the onset of a second stimulus (S2) cueing a motor response

(Walter, Cooper, Aldridge, McCallum, & Winter, 1964). It has since been established that a measurable CNV can occur even when (S2) does not require a motor response - Cohen and Walter (1966) demonstrated anticipation of pictorial stimuli produced a measurable CNV. While Cohen and Walter conceptualized the CNV as a neural reflection of expectancy, other authors have suggested the CNV reflects attention (McCallum, 1969; Tecce & Scheff, 1969), motivation (Irwin, Knott, McAdam, & Rebert, 1969), effort (Low, Coats, Rettig, & McSherry, 1967), intention to carry out action (Low, Borda, Frost, & Kellaway, 1966), task interest (Fenelon, 1984), anticipation of energy expenditure (Low & McSherry, 1968), enhanced preparation triggered by positive reinforcement (Boyd, Boyd, & Brown, 1980), and investment of attentional resources – the more attention devoted to a given task the greater CNV amplitude should be (Tecce, 1972, Tecce & Cattanach, 1993; Tecce, Savingnano-Bowman, & Dessonville, 1984.)

These accounts do not postulate opposing views; rather they reflect the specific task demands of each experiment. Taken together, it is clear the CNV reflects cognitive preparation in anticipation of engaging tasks that demand attention. In this way, attention, motivation, effort, interest, expectancy, intention to act, and attentional investment are cognitively intertwined. Neuroanatomical origins of the CNV are believed to involve large portions of the cerebral cortex engaged in periods of increased excitation. Such excitability is believed to be modulated via thalamic nuclei, though subcortical structures contribute little toward measured potentials due to their distance from the scalp (Elbert et al., 1991).

Tecce and Cattanach (1987) argued task-irrelevant distraction is the most common disruptor of CNV development. Further support for this notion comes from McCallum and Walter (1968), who demonstrated a direct relationship between the

degree participants reported being able to concentrate and CNV amplitude; CNV amplitude was significantly less when distracting stimuli were introduced, which participants reported as interfering with concentration. Likewise, in a strikingly similar scenario to Olivers and Nieuwenhuis (2006), Tecce and Scheff (1969) required participants to respond to an attentionally demanding stimulus (i.e., an auditory tone) while retaining a series of either letters or digits in short-term memory. The result was a reduction in preparation compared to when no auditory tone was presented – reflected by reduced CNV amplitude prior to the auditory interval. In a similar fashion, Olivers and Nieuwenhuis (2006) presented the AB task during the retention interval of a short-term memory task.

If the overinvestment hypothesis is correct, and task-irrelevant stimuli distract attention away the AB task, then the prediction from the overinvestment hypothesis is that an ensuing *reduction* in CNV amplitude will be present when measured prior to onset of the RSVP stream. More specifically, task-irrelevant activity should produce less attentional investment for No-AB (i.e., T2 correct) trials than for AB (i.e., T2 incorrect) trials in the condition where participants are distracted. Differences in CNV amplitude are not expected between No-AB and AB trials when task-irrelevant activity is not present.

Methods

Participants

Twenty-four[1] undergraduate psychology students (mean age 21.4 years; 15 females, 9 males) from Bangor University volunteered to participate. All participants reported normal to corrected-to-normal visual acuity. In a between-subjects design participants were randomly assigned to one of two conditions (i.e., static or motion – see design section below). The static condition was comprised of 8 females and 4 males (mean age 20.7 years; 11 right handed; 1 left handed). The motion group was comprised of 7 females and 5 males (mean-age 22.3 years; 9 right-handed, 3 left handed).

Visual Apparatus

Stimuli were viewed on twenty-two inch LCD flat monitor – EIZO model S2100 Flex Scam Slim Edge Design. Participants were seated approximately 62 centimetres from the screen. Stimuli were created with E-prime Version 1.1 experimental software (Psychology Software Tools, Inc., Pittsburgh, PA.).

AB Task Parameters

Dual-Target Motion Vs. Static: We employed the procedure used by Arend, Johnston, and Shapiro (2006), which showed task-irrelevant visual motion to attenuate the AB. In all trials an RSVP stream of 24 digits (New Times Roman 18-point bold font) was presented in the center of a black screen. All but two items in the stream (T1 and T2) were white. T1 and T2 were represented as red digits (i.e.,

[1] Twenty-four was the total number of participants that were included in data analysis. Data was actually collected on a grand total of 64 participants in accord with the full behavioral and electrophsiological measures indicated in the methods section. A total of 40 participants were excluded do to either poor eeg data quality or failure to complete the experiment.

both targets either 2, 3, 8, or 9; randomly chosen without replacement) and were presented with T2 always preceded by T1. T1 always occurred as the 5th item in the stream (i.e., 373 ms after RSVP onset). T2 occurred either 160 ms (i.e., short-lag) or 640 ms (i.e., long-lag) after T1. Short lags produce an AB on a significant number of trials, whereas long lags do not. Non-target visual distracter items were drawn from randomly alternating letters of the English alphabet.

Each trial began with the appearance of a white fixation-cross presented in the center of the screen. The fixation-cross remained on for two seconds. During the final 500 ms the fixation-cross changed to red to warn participants that the RSVP stream was about to begin. At the end of each RSVP stream a green response-cross appeared prompting responses to T1 and T2. The response-cross stayed on the screen until participants entered a response for both targets. Responses were entered by pressing the numeric keys 2, 3, 8, or 9. The inter-trial interval varied between 2-4 sec around an average of 3 sec (jittering in 500 ms increments) to minimize preparatory attention during the baseline.

RSVP presentation differed between motion and static conditions only in the presence or absence, respectively, of peripheral movement of a star field in the visual periphery. On static trials the star field was present, but did not move. On motion trials the star field continuously moved outward toward the participant. In both the motion and static condition the star field appeared at the same time as the white fixation cross that preceded RSVP onset. The star field was thus present for 2 seconds before onset of the RSVP stream. In both the motion and static conditions

four trial blocks were completed, each containing 100 trials (70 short lag and 30 long lag[2]; See Figure 1 Panel A & B).

The starfields were constructed of 32 particles; each particle was a round dot varying in diameter, randomly, between 1 and 10 pixels. The moving star field showed particles travelling from the center of the screen to the periphery, creating an apparent outward motion (See Figure 1, panel A). Dots disappearing from the edge were replaced by new dots appearing from their "origin" near the RSVP stream. The static star field was created by randomly choosing one frame from the motion set. This frame remained constant throughout the static trials (See Figure 1, panel B).

Single-Target Condition: In addition to the motion or static trials, all participants completed a single-target control condition with no star field present in the visual periphery. The single target in these trials occurred either 533 or 1013 ms after RSVP onset; placing the target at temporal positions identical to T2 in motion and static trials. The target stimulus used in these trials was identical to targets used in experimental trials. This condition was always completed first to prevent any carry-over effects from experimental trials. Including this condition was critical for ensuring that there were no significant differences between the experimental and control groups in revealing an equivalent CNV. Two hundred trials were completed in the single-target control condition (See Figure 1. Panel C).

[2] More short-lag trials were used to ensure a sufficient number of AB and No-AB trials would be available for averaging ERPs.

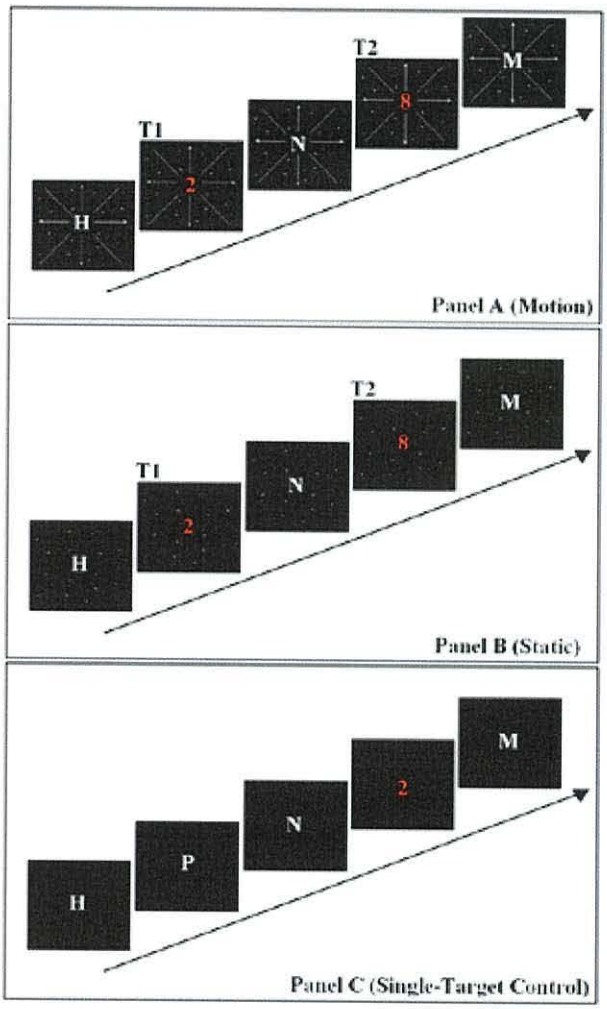

Figure 1: Illustrates dual-target motion and static star field manipulations as well as single-target control. As indicated at the bottom of page 73, in both the motion and static condition the star field was present for 2 seconds before onset of the RSVP stream. This is not depicted in Figure 1.

Electrophysiological Recordings

Electrophysiological recordings were obtained within the confines of a Faraday cage to prevent electrical noise from contaminating the data. The recording system included Brain Vision Recorder software Version 1.04 and BrainAmps DC amplifiers – both manufactured by Brain Products Corporation. Electrodes were attached to the scalp with an Easy Cap (Falk Minow Systems Corporation) using an elastic chest strap to secure the cap in place. Digitization of scalp activity occurred with a sampling rate of 500 Hz using a Pentium 3 recording computer. The recording montage consisted of 64 Ag/AgCl electrodes distributed in accordance with the

international 10-10 system (American Electroencephalographic Society, 1991). The ground electrode was placed at the AF4 site and the reference at Cz. Horizontal and vertical *electrooculograms* (*EOG*) were recorded from 1 cm above the nasion and 1 cm centimetre below the eyelids (left and right) over the orbicularis oculi muscle. During recording electrode impedances were maintained below 5kΩ. Online filtering was set to a high-pass DC correction and low-pass of 250 Hz.

Offline, data analysis and graphical visualizations were produced with BESA Version 5.1.6 and Bplot Version 1.4.0.7 (Megis Software). EOG correction was applied using the Multiple Source Eye Correction algorithm implemented in BESA. Trials with residual artefacts were excluded by visual single-trial inspection. After exclusion for artefact contamination, 401 correct[3] single-target control trials (191 motion group; 210 static group), and 792 dual-target experimental trials (365 motion-star-field No-AB[4]; 99 motion-star-field AB; 182 static-star-field no-AB; 146 static-star-field AB) remained. These values reflect only those trials with T2 presented at 160 ms post T1 onset (i.e., short lag). Trials with T2 presented at 640 ms post T1 onset (i.e., long lag) were used only to verify behavioural recovery of the AB – long-lag trials were omitted from electrophysiological analysis. For each participant the EEG was re-referenced to an average reading of all channels then band pass filtered (.05 – 30 Hz). ERP waveforms were averaged for a 5,000 ms interval corresponding to each trial. This interval began 1,000 ms prior to fixation onset and 3,000 ms before RSVP onset. The interval ended 2,000 ms after RSVP onset. The CNV was measured for a 1,000 ms period occurring immediately before RSVP onset (See Figure 2).

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[2] Correct trials were those for which participants correctly identified the single-target stimulus.
[3] No-AB refers to trials for which both targets were identified correctly. AB trials were those when T1 was identified correctly but T2 was not.

Procedures

The entire experimental session lasted approximately 2.5 hours. Upon arrival participants were instructed to wash their hair to reduce impedance. The experiment began by presenting 60 practice trials (20 single-target and 40 dual-target trials). Between trial blocks participants were given approximately 3 minutes to rest their eyes and relax. At the end of the session participants were allowed to wash their hair before being debriefed.

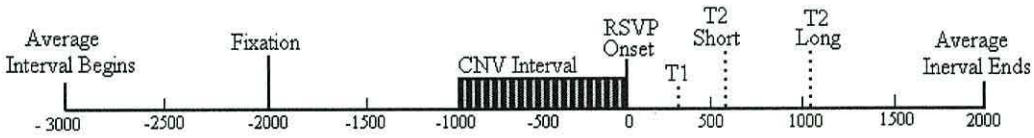

Figure 2: Critical temporal markers for averaged ERP waveforms. As shown the CNV was measured between fixation and RSVP onset.

Results

Behavioural Results

With the between-subjects factor of condition (i.e., motion vs. static) and the within-subjects factor of lag (i.e., short vs. long), individual 2x2 *analyses of variance* (*ANOVA*) were carried out separately for dual-task T1, dual-task T2, and single-target control performance. Effect sizes are reported with Eta-Square (η^2). All post-hoc tests were carried out with the Bonferroni correction for multiple comparisons. All statistical tests were deemed 'significant' at the .05 level.

Dual-Task T1 Performance: There was no overall effect of condition $F(1, 22) = .381$, $MSE = .015$, $p = .543$, $\eta^2 = .017$, but an effect of lag was present $F(1, 22) = 74.161$, $MSE = .310$, $p < .001$, $\eta^2 = .771$. An interaction between condition and lag was not found $F(1, 22) = .241$, $MSE = .001$, $p = .628$, $\eta^2 = .011$. Post-hoc comparisons revealed significant differences between short and long lags for both Motion and Static trials (see Table 1 and Figure 3), revealing that T1 performance

was reduced at short lags for both conditions. Such an effect often occurs and has been suggested to reflect a trade-off between T1 and T2 performance at short lags (Potter, Staub, & O'Conner, 2002).

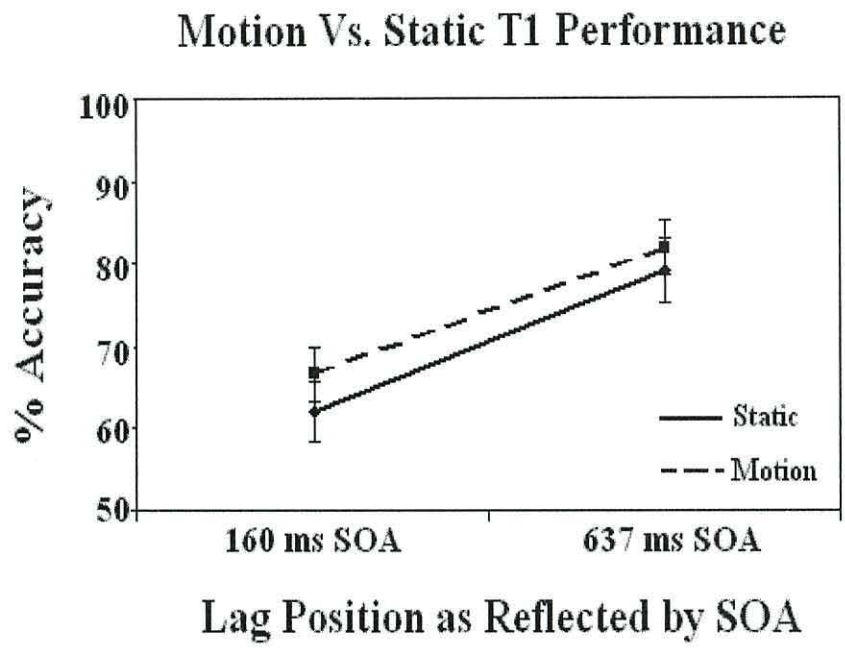

Figure 3: Behavioural T1 performance for Motion vs. Static dual-task trials. Error bars represented standard error of the mean.

Table 1

T1 Performance for Dual-Task Motion Vs. Static Tasks

	160 ms SOA	640 ms SOA
Motion	66.58 (16.48)a*	81.75 (14.29)a*
Static	62.08 (15.80)a*	79.08 (12.88)a*

Note: Means values are provided with respective standard deviations in parenthesis. Means in the same column with the same designation "a" did *not* differ at the .05 level with the Bonferroni correction for multiple comparisons calculated at .01. Means in the same row with the designation "*" *did* differ significantly at this criteria.

Dual-Task T2 Performance: An overall significant effect of condition was found $F(1, 22) = 6.327$, $MSE = .184$, $p < .05$, $\eta^2 = .223$, as well as both an effect of lag $F(1, 22) = 60.783$, $MSE = .319$, $p < .001$, $\eta^2 = .734$, and interaction between

condition and lag $F(1, 22) = 7.246$, $MSE = 3.79$, $p < .05$, $\eta^2 = .248$. Post-hoc comparisons revealed a significant difference between motion and static conditions at short, but not long lag (see Table 2 and Figure 4) replicating Arend et al (2006) and indicating the reduction in T2 in the motion condition suggested by Olivers and necessary to test our hypothesis.

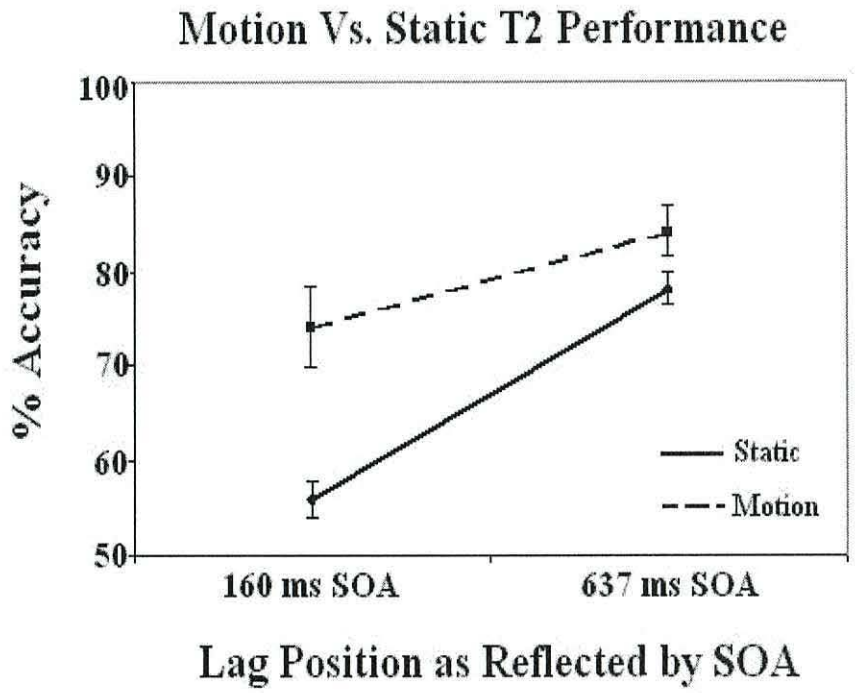

Figure 4: Behavioural T2 performance for Motion vs. Static dual-task trials. Error bars represent standard error of the mean.

Table 2

T2 Performance for Dual-Task Motion Vs. Static Tasks

	160 ms SOA	640 ms SOA
Motion	73.58 (17.51)a*	84.25 (13.21)a*
Static	55.58 (10.09)b*	77.50 (10.12)a*

Note: Mean values are provided with respective standard deviations in parenthesis. Means in the same column with the same designation "a" or "b" did *not* differ at the .05 level with the Bonferroni correction for multiple comparisons calculated at .01. Means in the same row with the designation "*" *did* differ significantly at this criteria.

Single-Target Control Performance: No overall effects of lag $F(1, 22) = 1.668$, $MSE = 2.133$, $p = .210$, $\eta^2 = .070$, or condition[5] $F(1, 22) = 3.481$, $MSE = 1.92$, $p = .065$, $\eta^2 = .099$, were found. No interaction was present between group and lag $F(1, 22) = .104$, $MSE = 1.33$, $p = .750$, $\eta^2 = .005$ (See Table 3 and Figure 5).

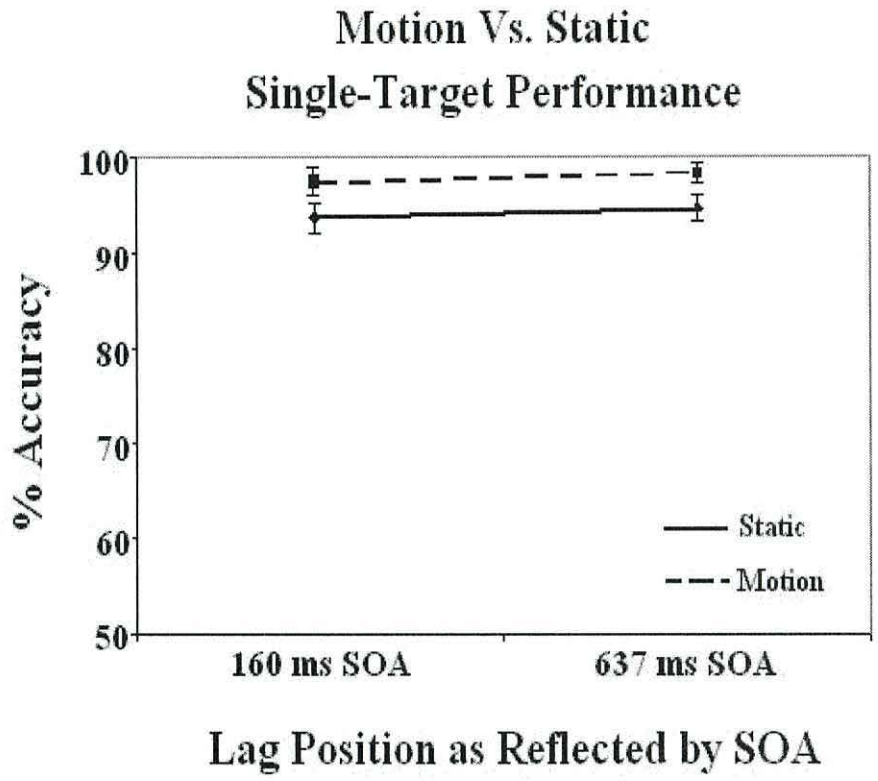

Figure 5: Behavioural performance for Motion Group and Static Group participants on single-target control trials. Error bars represent standard error of the mean.

Table 3

Single-Target Control Performance

	160 ms SOA	640 ms SOA
Motion	97.33 (4.61)	98.33 (2.06)
Static	93.67 (6.48)	94.67 (6.45)

Note: Means values are provided with respective standard deviations in parenthesis. Post-hoc comparisons were not carried out due to the lack of differences found between variables.

[4] "condition" refers to Ss from the motion and static groups though they were not treated differently in these trials.

Behavioural Summary: In a replication of Arend et al. (2006), we demonstrate an attenuation of the AB with a moving star field presented in the periphery of the RSVP stream. Although there were no differences in T1 performance between static and motion conditions, this cannot be taken to indicate that an equivalent amount of attention was allocated in both conditions. By analogy, one can jump a hurdle and just barely clear it or one can clear it with a large margin: Although the hurdle has been equally cleared in both metaphorical conditions, the amount of effort that went into clearing it would not be presumed to be the same. This underscores the necessity to evaluate the 'overinvestment' hypothesis using a non-behavioural approach.

Electrophysiological Analysis

As previously stated, measurable differences in CNV were predicted to occur during the 1,000 ms interval leading up to RSVP onset. Visual inspection of the data revealed the greatest differences in mean CNV amplitude to have occurred in the middle of this interval – between 750 and 250 ms prior to RSVP onset. This 500 ms interval was therefore used to calculate measurements of mean amplitude used in the following analysis. Recording channels Cpz, Pz, P3, and P1, were included in the analysis. These channels were selected due to the expected topography of the CNV waveform in combination with visual inspection of the data.

To insure any differences in CNV amplitude were attributable to experimental manipulations and not between-subjects variability, initial one-way between-subjects ANOVAs for each recording channel were carried out for single-target control trials. The factor for these analyses was condition (i.e., motion vs.

static groups; See Footnote 4). Only correct response trials were included in this analysis.

Dual-task trials were first analyzed with a 4x2x2 mixed-factor ANOVA for the between-subjects factor of condition (i.e., motion Vs. static), and the within subject factors of recording channel and AB/No-AB (i.e., AB – T2 incorrect vs. No-AB – T2 correct trials). Only trials with T1 correct responses were included in the dual-task electrophysiological analysis. As indicated earlier, no factor of lag was required as only short-lag trials were included. Recalling that our hypothesis anticipated finding an effect of AB vs. No-AB trials in the motion, but not static condition, we conducted apriori planned comparisons for each channel using univariate mixed-factor 2x2 ANOVAs – factors of condition and AB vs. No-AB – despite not finding an omnibus three-way interaction of AB vs. No-AB, Condition, and Channel (See Below).

For Dual-Task trials, within subjects main effects and interactions are reported with the Greenhouse-Geisser adjustment. Effect sizes are reported with Eta-Square (η^2). All post-hoc tests were carried out using the Bonferroni correction for multiple comparisons. All statistical tests were deemed 'significant' at the .05 level.

CNV Interval for Single-Target Control Trials

No group differences were found for any of the reported channels. A statistical summary of this outcome and respective waveforms can be viewed in Table 4 and Figure 6.

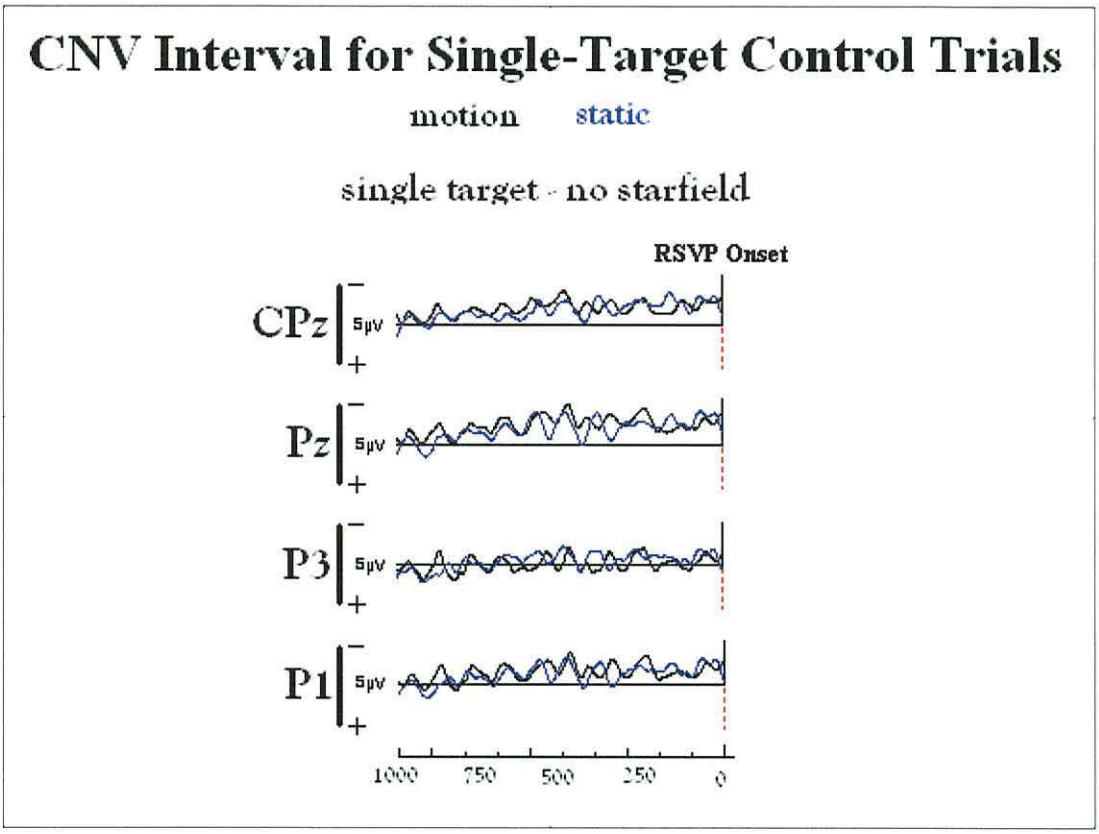

Figure 6: Respective ERP waveforms for single-target control trials – with the single target identified correctly. Only the two temporal interval between -750 ms and -250 ms was included in the analysis.

Table 4

Statistical Summary of CNV Analysis for Single-Target Control Trials

	Null Effects of Condition
Cpz	$F(1, 22) = .005$, $MSE = .014$, $p = .947$, $\eta^2 = .000$
P3	$F(1, 22) = .877$, $MSE = 1.32$, $p = .359$, $\eta^2 = .038$
P1	$F(1, 22) = .039 = MSE = .070$. $p = .845$, $\eta^2 = .002$
Pz	$F(1, 22) = .326$, $MSE = .549$, $p = .574$, $\eta^2 = .015$

Note: Statistical summary of non-significant effects of group for CNV amplitude compared between Motion and Static groups.

CNV Interval for Dual-Target Trials

Omnibus Effects: No omnibus effects of Channel $F(2.04, 44.90) = .104$, $MSE = .246$, $p = .905$, $\eta^2 = .005$, or Condition $F(1, 22) = 2.96$, $MSE = 30.41$, $p = .099$, $\eta^2 = .119$, were found. A significant main of AB vs. No-AB was found $F(1, 22) = 7.34$, $MSE = 145.42$, $p = .013$, $\eta^2 = .250$. A significant interaction of Channel (x) AB vs. No-AB $F(1.65, 36.46) = 3.68$, $MSE = 10.65$, $p = .016$, $\eta^2 = .144$, was found. Interactions of Channel (x) Condition $F(2.04, 44.90) = .148$, $MSE = .351$, $p = .867$, $\eta^2 = .007$, AB vs. No-AB (x) Condition $F(1, 22) = 1.98$, $MSE = 39.29$, $p = .173$, $\eta^2 = .083$, and Channel (x) AB vs. No-AB (x) Condition $F(1.65, 36.46) = .445$, $MSE = 1.28$, $p = .608$, $\eta^2 = .020$, were not found. Compared waveforms for dual-task trials are shown in Figure 7. Topographical distributions of measured amplitude are shown for dual-task trials in Figure 8.

Recording Channel Cpz: There was no effect of condition $F(1, 22) = 1.496$, $MSE = 6.39$, $p = .234$, $\eta^2 = .064$, nor was there an interaction between condition and AB/No-AB $F(1, 22) = 2.340$, $MSE = 11.72$, $p = .140$. Importantly however, an effect of AB/No-AB by itself was found $F(1, 22) = 9.448$, $MSE = 47.32$, $p = .006$, $\eta^2 = .300$. Post-hoc comparisons revealed this effect was due to differences in CNV amplitude between AB and No-AB trials for the motion condition (See Table 5 and Figures 7 & 8).

Recording Channel Pz: No effect of condition $F(1, 22) = 1.42$, $MSE = .627$, $p = .246$, $\eta^2 = .061$, or interaction between condition and AB/No-AB $F(1, 22) = .553$, $MSE = 4.97$, $p = .465$, $\eta^2 = .025$, was present. An effect of AB/No-AB was found $F(1, 22) = 7.299$, $MSE = 5.65$, $p = .013$, $\eta^2 = .249$. It was indicated by Post-hoc comparisons that this effect reflected differences in CNV amplitude between AB and No-AB trials for the motion condition (See Table 5 and Figures 7 & 8).

Recording Channel P3: Effects of condition $F(1, 22) = 2.64$, $MSE = 6.21$, $p = .118$, $\eta^2 = .107$, and AB/No-AB $F(1, 22) = 1.749$, $MSE = 6.32$, $p = .200$, $\eta^2 = .074$, were not found. There was however a significant interaction between condition and AB/No-AB $F(1, 22) = 4.787$, $MSE = 17.298$, $p = .030$, $\eta^2 = .179$. Post-hoc comparisons indicated this interaction was due to differences in CNV amplitude for the motion condition between AB and No-AB trials (See Table 5 and Figures 7 & 8).

Recording Channel P1: No effects of condition $F(1, 22) = 3.018$, $MSE = 12.17$, $p = .096$, $\eta^2 = .121$, or interaction between condition and AB/No-AB $F(1, 22) = 1.051$, $MSE = 7.31$, p = .316, $\eta^2 = .046$, were found. A significant effect of AB/No-AB was present $F(1, 22) = 6.26$, $MSE = 5.56$, $p = .020$, $\eta^2 = .222$. Post-hoc comparisons revealed this effect was due to differences in CNV amplitude between AB and No-AB trials for the motion condition (See Table 5 and Figure 7 & 8).

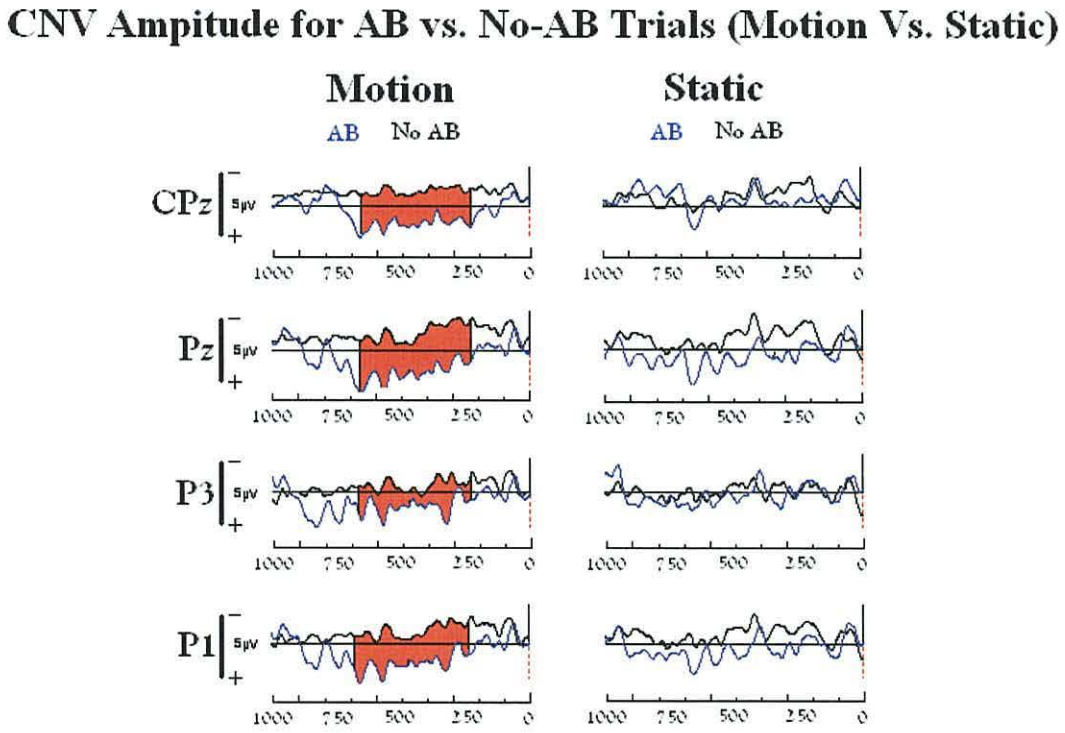

Figure 7: Respective ERP waveforms for dual-target trials. Shown are AB vs. No-AB trials for the motion and static conditions. Vertical bars mark the temporal interval analyzed to reflect CNV amplitude. Red coloring indicates a statistically significant difference between AB and No-AB trials as revealed by post-hoc comparisons.

Table 5

Mean CNV Amplitude for Motion and Static Conditions (AB Vs. No-AB trials)

	Cpz	Pz	P1	P3
Motion AB	1.88μv	2.00μv	1.95μv	1.48μv
Motion No-AB	-1.09μv	-.979μv	-.726μv	-.444μv
Static AB	1.64μv	.636μv	.171μv	.036 μv
Static No-AB	-.833μv	-1.05μv	-.953μv	-.438μv

Note: Mean amplitudes for the analyzed CNV interval (i.e., 750 – 250 ms before RSVP onset) as reflected in Figure 7.

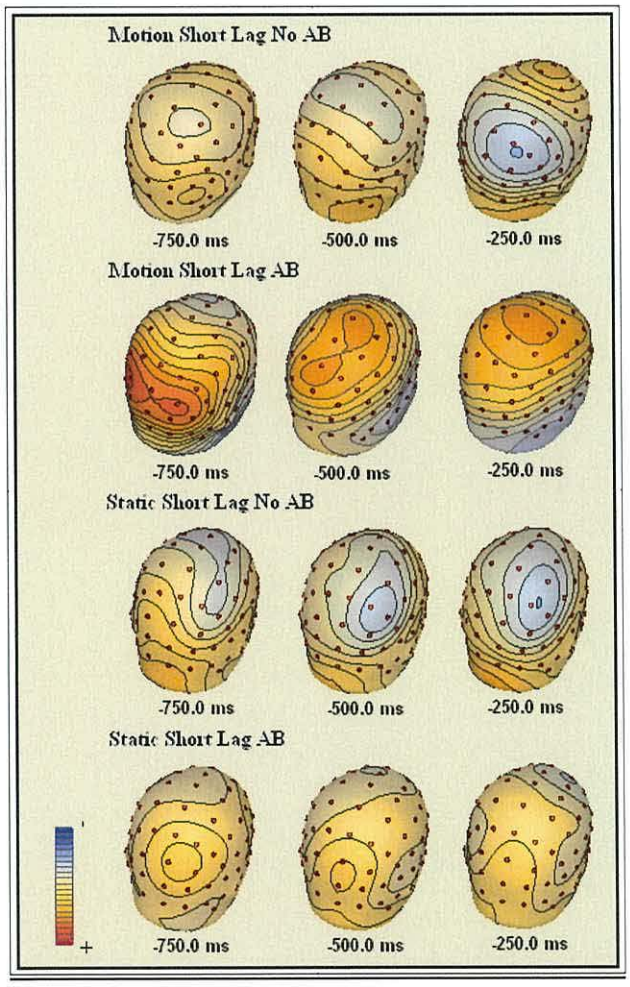

Figure 8: Respective topography maps for AB vs. No-AB trials for the motion and static condition. Topography maps are shown for the analyzed portion of the recorded epoch (i.e., -750, -500, and -250 ms) – time point 0 ms being RSVP stream onset.

Discussion

Our behavioural data replicates Arend, Johnston, and Shapiro's (2006) demonstration that task-irrelevant visual activity attenuates the AB, which allows us to assess our main hypothesis: If the overinvestment hypothesis is correct and task-irrelevant activity draws attention away from either T1 (Arend et. al., 2006) or the entire RSVP stream (Olivers & Nieuwenhuis, 2005, 2006), then existing electrophysiological literature predicts *reduced* CNV amplitude for No-AB compared to AB motion trials. We found just the opposite. Our data reveal No-AB trials show greater CNV amplitude. This outcome suggests task-irrelevant activity attenuated the AB not by reducing attentional investment, but rather by increasing it.

Placing the overinvestment hypothesis aside for the moment, it is important to note that many past experiments contradict the idea that task-irrelevant activity can benefit task performance (Dalton & Lavie, 2006; Jonides & Yantis, 1988; Kim & Cave, 1999; Lamy, 2005; Lamy & Egeth, 2003; Theeuwes, 1992; Wee & Chua, 2004,). The key difference between these experiments and investigations of the overinvestment hypothesis is *when* task-irrelevant activity occurred. Previous experiments reporting deleterious effects present suddenly occurring task-irrelevant events in the middle of the task. Such events range from distracters in a visual search task (Lamy & Egeth, 2003) to square frames surrounding distracters in a visual monitoring task (Wee & Chua, 2004). The resulting outcome is commonly interpreted to reflect failure to disengage attention from task-irrelevant events before target onset.

In contrast, investigations of the overinvestment hypothesis initiate presentation of continuous task-irrelevant activity before the task begins. This important difference of when distracting activity is presented provides an insight into

why the moving star field increased – as opposed to decreased – preparatory attention. When an event occurs before task onset – as the moving star field did in the present experiment – we suggest the observer has the opportunity to adjust the level of attentional investment depending upon whether they predict the event will increase or decrease task difficulty. On the other hand, we contend attentionally related processing adjustments are more difficult to make mid-task. In fact, the literature suggests suddenly occurring mid-task events benefit processing only if the event is required to complete the task. Such cases are thought to reflect a capturing effect by which the suddenly occurring event becomes the immediate focus of attention (Wee and Chua, 2004).

It is conceivable participants increased attention in the motion condition in anticipation that the moving star field would make target detection more difficult. Motion being the strong attracter of attention that it is (Abrams & Christ, 2005; Bex, Dakin, & Simmers, 2003; Bradshaw, & Warren, 2007; James, 1890; Pashler, 2004; Rajimehr, Vaziri-Pashkan, Afraz, & Esteky, 2004; Rushton, Morvan & Wexler, 2005), continuous movement of the star field before RSVP onset may have prompted participants to anticipate difficulty in maintaining attentional focus on the RSVP stream. The attenuated AB effect suggests such difficulty was overestimated, and sufficient 'attention' was available to benefit target processing. In comparison, due to the lack of motion in the static condition, participants likely anticipated target detection to be less difficult for static trials; resulting in a lesser investment of attention.

In conclusion, our data suggest the overinvestment hypothesis should be reconsidered. If Olivers and Nieuwenhuis are correct in their assertion that task-irrelevant activity reduces attentional investment, respective attenuations of CNV

amplitude should have been found in the motion condition. In fact the opposite was found. The idea that more attention leads to better task performance stands in accord with a great deal of previous work (Boyd, Boyd, & Brown, 1980; Fenelon, 1984; Irwin, Knott, McAdam, & Rebert, 1969; Low, Coats, Rettig, & McSherry, 1967; McCallum, 1969; Pashler, 2004.). That less attention can somehow benefit performance – as the overinvestment hypothesis suggests – will need to be reconciled with the results of the present report.

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Chapter Three: Target Strength Determines Whether Consciousness is Graded or Dichotomous During Divided Attention

Chapter Three

Target Strength Determines Whether Consciousness is Graded or Dichotomous During Divided Attention

Introduction

Is the *Attentional Blink* (*AB*) outcome such that during AB trials observers are never aware (i.e., conscious) that T2 occurs in the RSVP stream? Perhaps observers are aware a target occurs, but the encoded representation is insufficient for reporting target attributes? Sergent and Dehaene (2004) and Sergent, Baillet, and Dehaene (2005) considered these possibilities by asking the question: Does consciousness emerge in a graded or all-or-none fashion under demands of divided attention? In other words, with ongoing dual-task interference, can the perceptual experience of detecting T2 be dissected into multiple (i.e., graded) levels of 'quality', or is T2 detection a binary outcome (i.e., complete or non-existent)? The current chapter reviews Sergent and colleague's findings and tests the validity of their claims using an alternative set of stimulus parameters. Results of the current investigation are interpreted within the context of past experiments examining the fate of T2 for AB trials.

The idea of graded consciousness implies that the 'quality' or 'completeness' of perceptual experiences can vary. In other words, the conscious representation of a given stimulus may contain anything from knowledge of its simple presence (as opposed to absence), to categorical knowledge, to a 'complete' percept allowing for recognition and understanding of meaning. Alternatively, all-or-none consciousness implies the brain is incapable of producing 'incomplete' perceptual experiences. In other words, we do not experience perception until the brain has processed sufficient

information to produce a 'complete' percept – i.e., percept of sufficient 'quality' to allow for stimulus recognition and understanding of meaning.

Proponents of graded consciousness often cite the *activation strength hypothesis (ASH* - Kanswisher, 2001) – also known as the *'quality' of representation* (Farah, 1994), or *activation* (Palmer, 1999) hypotheses. The ASH is founded in signal detection theory (Green & Sweets, 1966), which postulates a continuum in the amount of information that can be extracted from a stimulus. ASH proposes that the 'quality' of a perceptual experience is directly tied to the strength of underlying cortical activity. "Strength of cortical activity" refers to the intensity of whichever neurological index is used in a given experiment (e.g., BOLD response – fMRI; mean amplitude – EEG), and what these measures are thought to reflect about firing neurons. The stronger cortical activity is the better the 'quality' of a conscious percept is believed to be. Publications supporting the ASH report positive correlations between the strength of cortical activity and how well observers can describe a stimulus (Bar et al., 2001; Grill-Spector, Kushnir, Hendler, & Malach, 2000; Moutoussis & Zekki, 2002). The ASH also proposes that the strength of cortical activity, and thus awareness, is tied to the *signal-strength* of stimuli – "signal-strength" referring to the degree that a task-relevant unit of sensory information is shrouded by task-irrelevant sensory noise. As the signal-strength for a given stimulus increases observers often report becoming more aware of what they have seen (Farah, 2000; Kanwisher, 2001). We return to the topic of signal-strength in a moment.

Supporting all-or-none consciousness are studies reporting large all-or-none differences in cortical activity between when target stimuli go undetected as opposed to when detected (Dehaene et al., 2001; Lamme, Super, Landman, Roelfsema, &

Spekrijse, 2000; Super, Spekreijse, & Lamme, 2001). Theories advocating a qualitative/all-or-none difference between unconscious and conscious processing advocate the requirement of widespread concurrent and recurrent connections between distant brain areas – referred to by Baars (1989) as the "neuronal workspace" (Dehaene, Kerszberg, & Changeux, 1998; Dehaene & Naccache, 2001; Dehaene, Sergent, & Changeux, 2003; Di Lollo, Enns, & Rensink, 2000; Lamme, 2003; Lamme & Roelfsema, 2000).

One such theory is known as the *global neuronal workspace hypothesis* (*GNW* -Dehaene et al., 1998). GNW proposes that consciousness is dependent upon the neural representation of a stimulus exceeding a processing threshold. Once the threshold is exceeded, sudden all-or-none increases in cortical activation ensue, allowing stimulus information to gain access to systems involved in operations such as working memory, verbal report, voluntary manipulation, voluntary action, and long-term memorization. Only when this threshold is exceeded do we experience conscious perception - the extent of interaction across the workspace contributing to the high 'quality' percept we experience. GNW thus promotes two basis tenants. First, consciousness is a mental state that cannot be sub-divided into multiple levels of 'quality'. Second, consciousness manifest in a sudden all-or-none fashion once a critical threshold in neural processing has been crossed.

To reiterate, Sergent and Dehaene (2004) examined whether consciousness emerges in a graded or all-or-none fashion under the demands of divided attention. Participants were asked to rate the "subjective-visibility " of T2 in an AB task. Consciousness was indexed by instructing participants to enter a number between 0 and 100 – in increments of 5 – that indicated "how well" T2 could be 'seen' during the RSVP stream. The key outcome was that for trials when T1 identity was reported

correctly, subjective-visibility ratings for T2 were distributed in an extremely bimodal fashion at all lag positions – i.e., a significant majority of responses either fell into the lowest (i.e., "not seen at all") or highest (i.e., "seen very well") extremes of the visibility scale. Intermediate points in the scale – ratings between 5 and 95 – were never used for more than 10% of trials at any lag position (See Figure 1). It was suggested the bimodal distributions indicated consciousness for T2 emerged in an all-or-none fashion. The scarce use of intermediate visibility ratings was interpreted as indicating that the experience of 'T2 awareness' could not be divided into various levels of 'quality' – i.e., either the observer obtained a 'complete' percept of T2 or didn't see it at all. Interpreting their findings within the context of the GNW hypothesis, Sergent and Dehaene concluded that when T2 succumbs to the AB the encoded representation of T2 fails to exceed the processing threshold that allows integration across the neuronal workspace.

Following up their original experiment, Sergent, Baillet, and Dehaene (2005) used a similar AB paradigm, this time with additional electrophysiological measures. In addition to replicating the bimodal response distributions reported by Sergent and Dehaene (2004), these authors showed ERP components evoked by T2 differed as a function of visibility[1]. Although early components P1 and N1 were not impacted by visibility, N3, P3a, and P3b were present only on trials when visibility was rated above 50 – these components were interpreted as occurring only when the consciousness-yielding processing threshold was exceeded.

[1] The electrophysiological analysis of Sergent, Baillet, and Dehaene (2005) was carried out by splitting trials into 4 groupings dependent upon T2 visibility ratings. First trials were split between those assigned visibility ratings ≤ 50 and ≥ 50. Within each of these groupings trials were again split at the median.

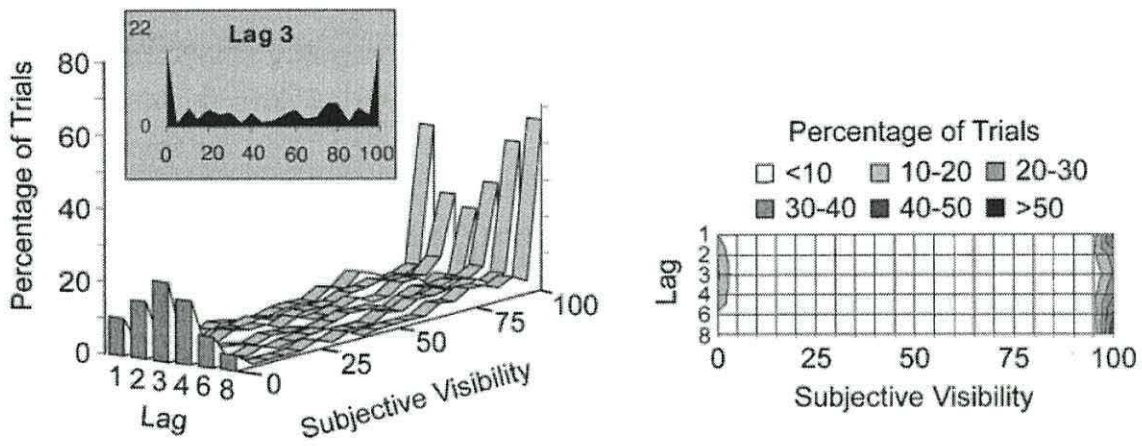

Figure 1: Subjective-visibility response distributions by lag position as illustrated in Sergent and Dehaene (2004). Data shown are cumulative of all participants.

My Focus

Experiment 1 re-examined the question of whether consciousness emerges in a graded or all-or-none fashion under the demands of divided attention. Two potentially problematic aspects of Sergent and colleague's 2004 and 2005 experiments gave rise to this investigation. First, as shown in Figure 2, in both experiments T2 and non-target distracter items did not differ on the dimensions of chromaticity and luminance. Sergent and Dehaene (2004) matched T2 and non-target items for chromatic value and luminance. Sergent, Baillet, and Dehaene (2005) used no chromatic value; matching only for luminance –i.e., all items were presented in white, which possesses an absence of chromaticity. In both cases contrast (i.e., ratio of luminance between a RSVP stimulus and its background) was identical across all stimulus frames[2] – excluding the T1 frame in Sergent and Dehaene (2004; See Figure 2). The only difference between T2 and non-target distracters in these experiments was therefore categorical.

[2] In an RSVP task stimuli appear in temporal isolation of one another – one stimulus appears, then disappears, then another replaces it. "Stimulus frame" refers to each instance of a single stimulus and its background.

Matching T2 and non-target distracters for contrast is not a new concept for the AB paradigm. Beginning with Raymond, Shapiro, and Arnell (1992), experiments instructing participants to perform present/absent judgments on T2 are often set up in such a way. Other experiments instructing participants to report the identity of T2, including those presented in other chapters of the current work, often present T2 as differing from non-target distracters in luminance and/or chromaticity. Viewed as a whole, the literature suggests either method is suitable for revealing an AB when T2 accuracy is measured objectively (e.g., present/absent; identity report). I argue these methods may not however be equally suitable for the subjective-visibility measure used by Sergent and Dehaene (2004) and Sergent, Baillet, and Dehaene (2005).

When matched for contrast with non-target distracters T2 is difficult to discriminate from the surrounding RSVP stream. This is due to a low signal-to-noise ratio between T2 and other RSVP items[3]. In other words, the overall signal-strength of the T2 stimulus is low (Gescheider, 1997; Hommel & Akyürek, 2005; Kanswisher, 2001). Raising T2 signal-strength by increasing contrast of the T2 stimulus frame should make the T2 stimulus easily distinguishable from other RSVP items. In turn, increasing signal-strength should also make T2 a stronger competitor for processing resources relative to surrounding distracter items.

Citing the biased-competition account reviewed in Chapter One, Duncan (1987) argued that the ability of a task-relevant stimulus to compete for resources is directly tied to how distinguishable it is from task-irrelevant stimuli – i.e., the task-relevant stimulus being a stronger competitor when easily distinguishable from task-irrelevant stimuli. Once a task-relevant stimulus is established as a strong

[3] In the AB paradigm T2 serves as a to-be-detected 'signal'. Surrounding RSVP items serve as task-irrelevant noise shrouding the T2 signal.

competitor, the encoded representation of that stimulus continues to be a strong competitor across multiple stages of information processing (See Chapter One). Being a strong competitor allows task-relevant stimuli to 'win-out' and be successfully processed at the expense of task-irrelevant stimuli. For processing stages critical to consciousness, it therefore seems reasonable to expect the likelihood of obtaining a conscious representation to increase, as the encoded representation of T2 becomes a stronger competitor for resources.

This logic is valid regardless of whether consciousness emerges in a graded or all-or-none fashion. Strong competition for resources and dual-task interference likely operate as opposing forces – strong competition promotes target processing while dual-task interference impedes it. If consciousness is only capable of emerging in an all-or-none fashion, altering the strength of one of these two opposing forces will only change the potential for T2 processing to produce either a 'complete' conscious percept or no percept at all. According to the GNW hypothesis, manipulating either of these forces will only change whether T2 processing will or will not exceed the critical threshold of neural processing. If, on the other hand, consciousness can emerge in a graded fashion, altering the strength of one of these forces will vary the 'completeness' of a conscious percept of T2.

I propose that in the experiments carried out by Sergent and colleagues a low signal-to-noise ratio between the T2 stimulus and non-target distracters made the second target a weak competitor for processing resources. For trials when dual-task interference significantly hindered T2 processing, the weak competitive nature of T2 prevented a conscious percept of the second target from emerging – thus the resulting subjective-visibility ratings obtained in these experiments suggest consciousness emerges in an all-or-none fashion under the demands of divided

attention. To be certain of this hypothesis, the emergence of consciousness needs to be examined when a strong competitive advantage is capable of being established in favor of T2 – such an examination was the goal of Experiment 1.

Experiment 1 was thus predicated on the idea that Sergent and colleagues may have underestimated the importance of signal-strength when designing their experiments. In Experiment 1 I examined whether bimodal distributions of visibility ratings remain when the signal-to-noise relationship between T2 and non-target distracters is manipulated – i.e., when contrast for the T2 stimulus frame is greater than for other non-target items. If consciousness always emerges in an all-or-none fashion the bimodal distributions should remain. If increasing T2 signal-strength allows consciousness to emerge in a graded fashion, visibility responses should shift toward a more unimodal distribution, perhaps becoming more skewed toward the high end of the visibility scale.

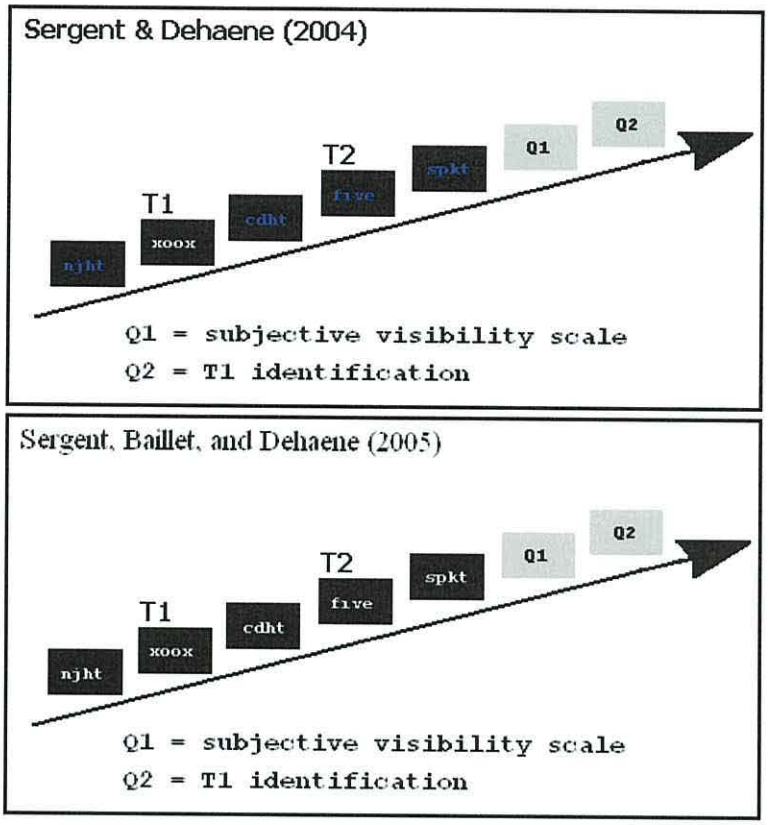

Figure 2: In the Top panel is the visual parameters used by Sergent and Dehaene (2004). The Bottom Panel shows visual parameters for Sergent, Baillet, and Dehaene (2005). In both experiments the T1 task was to detect whether the center two letters were "oo" or "xx". The T2 task was to provide a subjective visibility rating. The subjective visibility rating was always taken before T1 report. This was done to minimize the risk that participants' ability to assess subjective visibility would degrade over time.

The second potential problem for Sergent and colleague's experiments is that a visibility rating of "100" was assumed to be representative of a "No-AB" trial[4]. No-AB trials are commonly said to occur when participants are able to report a second target attribute (e.g., identity) after the RSVP stream has ended. The exception is of course studies asking for T2-present/absent judgments (e.g., Raymond, Shapiro, & Arnell, 1992). These two response measures have interesting implications for the graded vs. all-or-none consciousness debate. Graded consciousness implies T2 may be correctly judged as being present in the RSVP stream even though participants are unable to correctly report its identity. All-or-none consciousness implies if T2 can be detected in the RSVP stream, then identity

[4] The only T2 response in Sergent and colleagues' experiments was subjective-visibility.

can also be reported. Subjective-visibility alone does not provide any indication of 'how well' participants can describe T2 after the RSVP stream has ended. Experiment 1 therefore asked participants to not only rate the subjective-visibility of T2, but also report the identity of T2. This allowed for the question to be answered: Can observers be aware that T2 occurs and yet fail to correctly report its identity?

To summarise, Experiment 1 was predicated on the hypothesis that Sergent and colleagues (2004, 2005) findings are valid only for their specific stimulus parameters – i.e., when the stimulus frames for T2 and non-target distracter stimuli are of equal contrast. More specifically, this hypothesis predicted increasing contrast for the T2 stimulus frame would increase T2 signal-strength, which in turn, would alter visibility ratings in such a way as to suggest consciousness can emerge in a graded fashion under the demands of divided attention. To test this hypothesis Experiment 1 was designed to answer two specific questions. First, do bimodal response distributions for visibility ratings remain when contrast for the T2 stimulus frame is increased? Because bimodal response distributions were the basis for Sergent and colleague's claim of all-or-none consciousness, any contradicting claim predicated on a critique of stimuli – such as is presented here – bears the responsibility of demonstrating an opposing outcome for the same response measure. The second question is: On AB trials, when participants fail to accurately report T2 identity, can visibility ratings be obtained that indicate T2 was nevertheless seen?

Experiment 1

Methods

Participants

Twenty undergraduate students from Bangor University took part in the experiment (9 males, 11 females: $M = 19.85$; $SD = 1.53$). Students were compensated for participating with either course credit or monetary payment. All participants reported normal to corrected-to-normal visual acuity.

Apparatus

Stimuli were presented on a 1024 by 768 pixel, 32-bit colour, 17-inch cathode ray tube (CRT) monitor using E-prime version 1.1 experimental software (Psychology Software Tools, Inc., Pittsburgh, PA). All stimuli were presented in intervals of the 17 ms refresh rate of the monitor.

Design

In a within-subjects blocked design data was collected for three conditions. The order in which conditions were completed was counterbalanced across participants using the Latin Square method[5]. The variable manipulated between conditions was the contrast for the T2 stimulus frame. Contrast for the T2 frame was either equivalent to (*low contrast condition*), moderately increased (*intermediate contrast condition*), or heavily increased (*high contrast condition*) compared to non-target distracter frames. In all cases contrast was manipulated by altering the luminance of the T2 stimulus. See Figure 3 and Table 1 for specific stimulus values.

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[5] The Latin Square method of counterbalancing produced three orders in which participants completed conditions. Listed by contrast-ratio manipulation, these orders were (high, intermediate, low – n = 7; intermediate, low, high – n = 7; and low, high, intermediate – n = 6.

In all conditions a RSVP stream of 24 items was presented in the center of a black screen. All RSVP stream items were presented at a rate of ~ 10 items per second (i.e. 17 ms 'on'; 85 ms 'off'). All stimuli contained letters presented in Times New Roman 20-point font. Prior to RSVP onset a red fixation-cross appeared that lasted for 500 ms. Afterward, a 500 ms blank screen separated offset of the fixation cross and RSVP onset.

T1 onset occurred between the sixth and twelfth items with its specific position determined randomly. T1 was always present as an achromatic white stimulus, and appeared as either "XOOX" or "OXXO". The T1 task was to report whether the two center letters were "XX" or "OO". Non-target distracters as well as T2 were always presented as achromatic gray stimuli – see figure 3 for an illustration of how T2 luminance varied across conditions. Non-target distracters were presented as non-words containing four consonants. T2 was always one of three numeric words – four, five, or nine. Participants were required to provide three responses for each trial. These responses were subjective-visibility of T2, T1 identity, and T2 identity. As stated, Sergent and colleagues had participants report subjective-visibility first, followed by T1 identity. This order was adopted because these authors feared participants' ability to judge visibility would diminish with longer response delays. In hopes for preventing response order from confounding visibility ratings, I adopted this response order as well – adding T2 identity as the last response given. The visual screens used to prompt responses can be viewed in Figure 3.

The temporal position (i.e., lag-position) of T2 onset varied randomly appearing amongst lag-positions 1, 2, 3, 6, and 7 - the numerical representation of lag representing the varying SOA between targets of 102 ms (lag-1) to 714 ms (lag-

7). In each condition 60 T1/T2-present trials were presented for each lag position – a total of 300 trials per condition. There were also 20 additional T2-absent trials added to each condition. T2-absent trials were included to ensure participants used the visibility scale in its entirety. As pointed out by Sergent and Colleagues, the expectation that T2 will occur in every trial may lead participants to overestimate judgments of visibility. In total then, participants completed 320 trials per condition – 960 for the entire experiment. During the instruction phase of the experiment participants were informed that some trials would not contain a T2 stimulus. A response for the T2 identity response prompt (See Figure 3) was required for all trials. T2 identity responses for trials when T2 was absent were discarded from analyses.

Use of the Subjective-visibility Scale

To ensure participants understood what the scale was intended to measure, and therefore used it in an appropriate fashion, detailed instructions were given prior to the experiment. It was explained that a rating of "0" was to only be used when confident T2 did not occur in the RSVP stream. A rating of "100" on the other hand, was only to be used when confident that T2 not only occurred in the RSVP stream, but was seen so well that its identity could be reported correctly. Intermediate ratings between "0" and "100" were to be used depending upon how close the experience of seeing T2 was toward either extreme end of the scale. Participants were also instructed to respond to the visibility scale in increments of 5.

Procedure

Upon arrival a brief introduction to the task was given and informed consent was obtained. Participants were informed of their right to withdraw from the experiment at any time. After completing each of the first two conditions a five-minute break was offered. At the end of the session participants were debriefed as to the nature of the experiment. The total experiment took approximately 120 – 160 minutes. The exact duration fluctuated substantially depending upon how quickly participants responded.

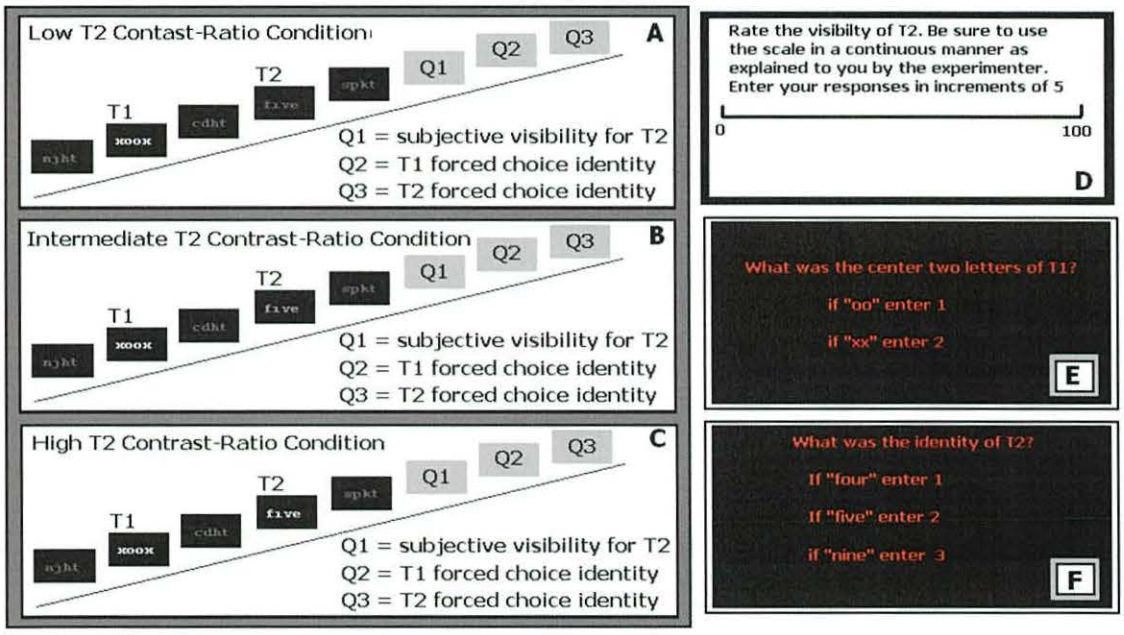


Figure 3: Panel (A) – shows the low contrast condition for which the luminance of T2 is the same as distracter stimuli. *Panel (B)* – shows the intermediate contrast (luminance of T2 is 2x that of distracter stimuli). *Panel (C)* shows the high contrast condition (luminance of T2 is 4x that of distracter stimuli). For actual measurements of luminance and calculated contrast-ratios see *Table 1*. *Panel (D)* shows the response screen for T2 visibility. *Panel (E)* shows the response screen for T1 and *Panel (F)* shows the response screen for T2.

Table 1

Luminance Values, sRGB, and Contrast-Ratio Calculations

Condition	Background		Non-Target Distracters		T1		T2		Contrast Ratios
Low T2 Contrast	Lm = .06cd/m^2		Lm=19.6cd/m^2		Lm=102.3cd/m^2		Lm=19.6cd/m^2		T2: 326:1
	sRGB	R=0	sRGB	R=113	sRGB	R=255	sRGB	R=113	
		G=0		G=113		G=255		G=113	Dist: 326:1
		B=0		B=113		B=255		B=113	
Intermediate T2 Contrast	Lm = .06 cd/m^2		Lm=19.6cd/m^2		Lm=102.3cd/m^2		Lm=41.1cd/m^2		T2: 685:1
	sRGB	R=0	sRGB	R=113	sRGB	R=255	sRGB	R=157	
		G=0		G=113		G=255		G=157	Dist: 326:1
		B=0		B=113		B=255		B=157	
High T2 Contrast	Lm = .06 cd/m^2		Lm=19.6cd/m^2		Lm=102.3cd/m^2		Lm=81.4cd/m^2		T2: 1356:1
	sRGB	R=0	sRGB	R=113	sRGB	R=255	sRGB	R=209	
		G=0		G=113		G=255		G=209	Dist: 326:1
		B=0		B=113		B=255		B=209	

Note: Luminance (Lm) was measured in candelas per square meter (cd/m^2). *Red/Green/Blue* values are provided from the standard RGB (sRGB) color gamut used by Microsoft Windows – the operating system used to present stimuli. Numerical representations for R, G, and B represent the proportion of red, green, and blue light contained within a given display of chromaticity. The sRGB gamut produces achromatic displays (i.e., black, white, and gray) by merging equal amount of red, green, and blue light waves. Contrast-Ratio for the T2 and non-target stimulus frames were calculated as follows: {luminance of stimulus / luminance of background}.

Results

T1 and T2 Accuracy Analyses for Identity Report

For the within-subject factors of Condition and Lag, as well as the between-subjects factor of Order, separate 3x5x3 mixed analyses of variance (*ANOVA*) were carried out for T1 and T2 accuracy. T2 accuracy was only measured for T1-correct trials – for T1 incorrect trials it is impossible to assess the cause of T2 errors (Raymond, Shapiro, & Arnell, 1992). The dependent measure for these analyses was percentage of trials responded to correctly. All post-hoc tests for T1 and T2 accuracy were carried out using the Tukey's HSD test. Only T2-present trials were included in T1/T2 analyses of identity report.

T1 Performance

No overall effects of Condition $F(2, 34) = .29$, $MSE = 61.81$, $p = .74$, Lag $F(4, 68) = .06$, $MSE = 48.78$, $p = .99$, or Order $F(2, 17) = .52$, $MSE = 32.55$, $p = .60$, were found. There were no interactions present between variables (See Figure 4 and Table 2). Thus, T1 performance did *not* differ as a function of Condition, Lag, or Order.

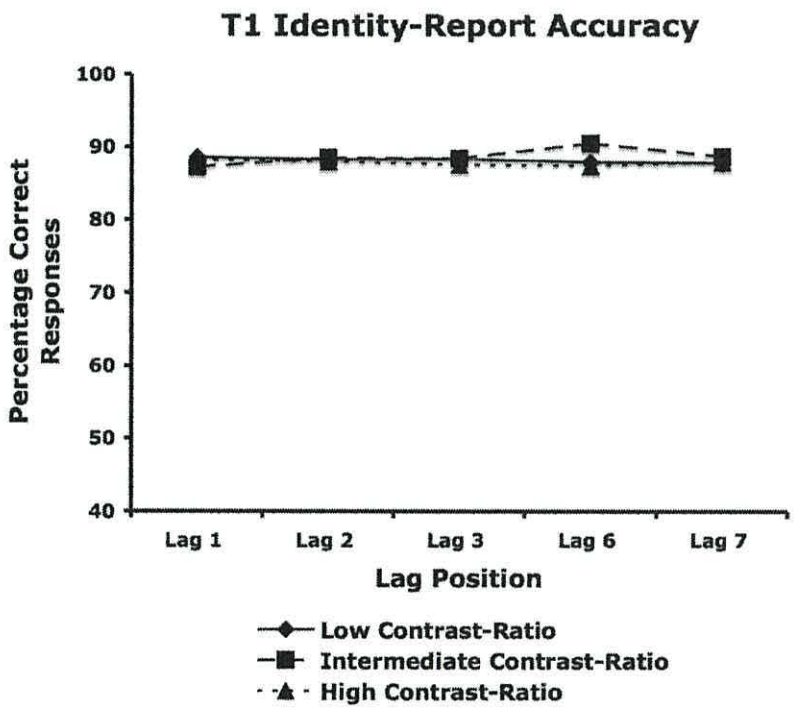


Figure 4: Illustrates averaged percentage of T1 accuracy across factors of Condition and Lag. Standard Error bars are not visible due to the low amount of variability between measurements (See Table 2). Lag positions represent the temporal relationship of SOA between T1 and T2 onset (Lag 1 = 102 ms SOA; Lag 2 = 204 ms SOA; Lag 3 = 306ms SOA; Lag 6 = 612 ms SOA; Lag 7 = 714 ms SOA).

Table 2

Averaged T1 Identity-Report Performance

Condition	Lag 1 102 ms SOA	Lag 2 204 ms SOA	Lag 3 306 ms SOA	Lag 6 612 ms SOA	Lag 7 714 ms SOA
Low T2 Contrast	88.58 (8.17) *SE = 1.82*	88.79 (6.58) *SE = 1.47*	88.33 (7.07) *SE = 1.58*	87.91 (6.96) *SE = 1.55*	87.82 (7.09) *SE = 1.58*
Intermediate T2 Contrast	87.24 (5.60) *SE = 1.25*	88.49 (6.83) *SE = 1.52*	88.41 (6.38) *SE = 1.42*	90.23 (5.82) *SE = 1.30*	88.66 (7.77) *SE = 1.73*
High T2 Contrast	88.24 (6.20) *SE = 1.38*	87.99 (5.80) *SE = 1.29*	87.58 (6.45) *SE = 1.44*	87.41 (6.82) *SE – 1.52*	87.91 (5.56) *SE = 1.24*

Note: Mean percentages of T1 accuracy across factors of Condition and Lag. Standard deviations are included in parenthesis. The standard error is included below the mean and standard deviation in italics.

T2 Performance

Significant effects of Condition $F(2, 34) = 171.89$, $MSE = 52.07$, $p < .001$, and Lag $F(4, 68) = 102.07$, $MSE = 65.79$, $p < .001$, were present. There was no significant effect of Order $F(2, 17) = 1.49$, $MSE = 23.64$, $p = .11$. There were no interactions present between variables.

Contributing to the main effect of Lag, post hoc comparisons revealed that in all three conditions lag 3 performance was significantly lower than lags 1 and 7 – thus indicating all three levels of T2 contrast resulted in an AB. Because performance at lags 1 and 7 did not differ *within* any of the three conditions, it can be said all three levels of contrast allowed for a conventional AB function – gradual reduction in T2 accuracy through lags 1, 2, and 3, after which accuracy gradually improved through lag 7.

Regarding the main effect of Condition, T2 contrast significantly impacted T2 accuracy across conditions. Only at lag 3 however did T2 accuracy differ between all three conditions – accuracy becoming increasingly better as T2 contrast

increased. For all other lag positions the low and intermediate contrast conditions did not significantly differ. High contrast trials showed significantly better T2 accuracy than either low or intermediate contrast trials at lags 1, 2, and 3. At lags 6 and 7 high contrast trials only showed significantly better T2 performance than low contrast trials.

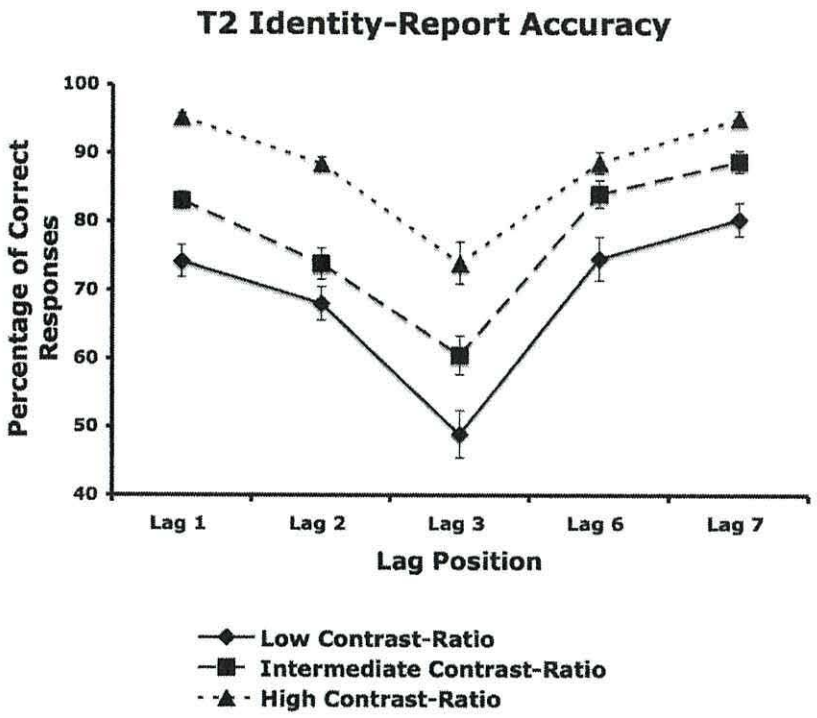


Figure 5: Illustrates averaged T2 accuracy across all conditions. Error bars represent standard error of the mean. Lag positions represent the temporal relationship of SOA between T1 and T2 onset (Lag 1 = 102 ms SOA; Lag 2 = 204 ms SOA; Lag 3 = 306ms SOA; Lag 6 = 612 ms SOA;
Lag 7 = 714 ms SOA).

Table 3

Averaged T2 Identity-Report Performance

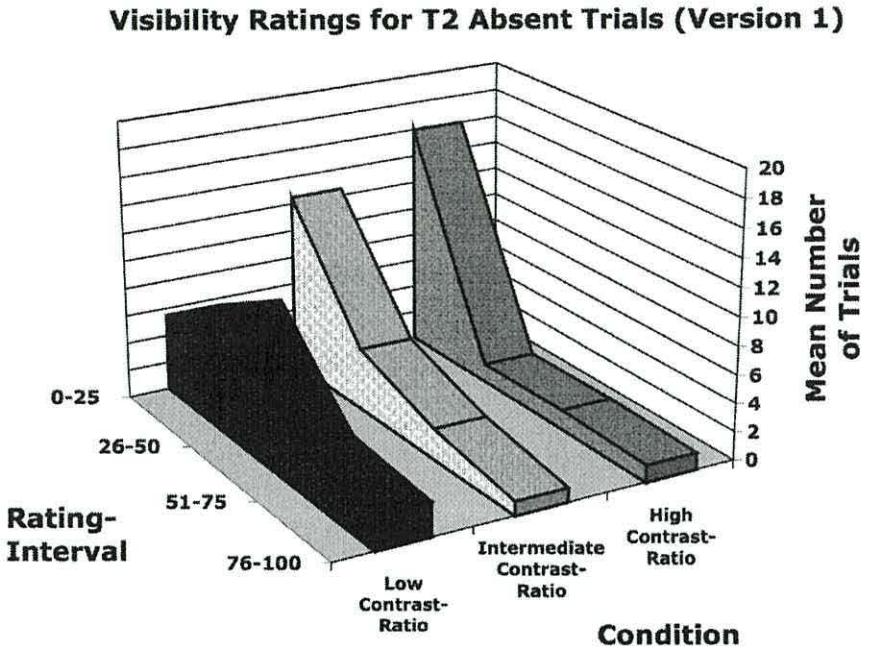
Condition	Lag 1 102 ms SOA	Lag 2 204 ms SOA	Lag 3 306 ms SOA	Lag 6 612 ms SOA	Lag 7 714 ms SOA
Low T2 Contrast-Ratio	74.2 (10.54)aΩ	68.05 (11.10)	48.9 (15.50)bΩ	74.66 (9.35)	80.38 (6.47)aΩ
Intermediate T2 Contrast-Ratio	83.07 (5.53)aΩ	73.86(10.26)	60.52 (12.55)bΔ	84.07 (7.90)	88.8 (6.17)aΩ-
High T2 Contrast-Ratio	95.27 (2.41)aΔ	88.48 (4.27)	73.99 (13.75)b¥	88.65 (7.27)	95.18 (5.08)aΔ-

Note: Mean percentages of T2 performance across factors of Condition and Lag. Standard deviations for each mean value are included in parenthesis. Table 3 only illustrates results of post-hoc comparisons for lags 1, 3, and 7. Mean values in the same row sharing the same designation "a", or "b" *did not* significantly differ according to post hoc test carried out at the .05 level. Means in the same column sharing the same designation "Ω", "Δ", or "¥" *did not* significantly differ. However, means in the same column that *do not* share the same designation "Ω", "Δ", or "¥", but are marked as "-", also *did not* differ at the .05 level.

Subjective T2 Visibility Analyses

T2-Absent Trials: A 3x4x3 mixed factor ANOVA for the within-subjects factors of Condition and Rating-Interval, along with the between-subject factor of Order was carried out. The factor Rating-Interval was constructed by dividing the subjective-visibility scale into four intervals (0–25; 26–50; 51–75; and 76–100). The dependent variable was *number of trials* rated within a given rating interval. This measure was deemed appropriate due to an equal number of T2-absent trials across factors of Condition and Lag. Statistical differences were thus evaluated at the level of *mean number of trials* – i.e., the average number of trials rated within a given interval across participants (e.g., On average participants rated 20 trials within the [0–25] interval). Analysis of T2-absent trials was *only* intended to ensure participants used the lower end of the visibility scale - thus trials were not analyzed as a function of T1-correct/incorrect or lag position.

Results for T2-absent Trials: Mauchly's test showed a violation of sphericity for the repeated measures factor of Rating-Interval. Statistics pertaining to this factor are thus reported with the Greenhouse-Geisser correction. No effects of Condition $F(2, 34) = 1.25$, $MSE = .004$, $p = .29$, or Order $F(2, 17) = 1.19$, $MSE = .004$, $p = .33$, were found. An effect of Rating-Interval was present $F(1.71, 29.17) = 297.67$, $MSE = 6.92$, $p < .001$. The only interaction present was between Condition and Rating-Interval $F(2.48, 42.21) = 58.96$, $MSE = 12.30$, $p < .001$ (See Figure 6). T2-absent trials showed participants did use the lower extremes of the visibility scale. Despite not finding a main effect of Condition, the mean number of trials rated in the [0-25] interval differed significantly between all three conditions – this value increasing as T2 contrast increased. The main effect of Rating-Interval was largely due to the mean number trials rated in the [0-25] interval being significantly greater than all other intervals for intermediate and high contrast conditions. In conjunction with this data trend, the interaction between Condition and Rating-Interval was due to the mean number of trials rated in the [26-50] interval being greater than all other intervals for the low contrast condition. Further discussion these results will take place during the Experiment 1 final discussion. A full summary of visibility ratings for T2-absent trials can be viewed in Figure 6 and Table 4).



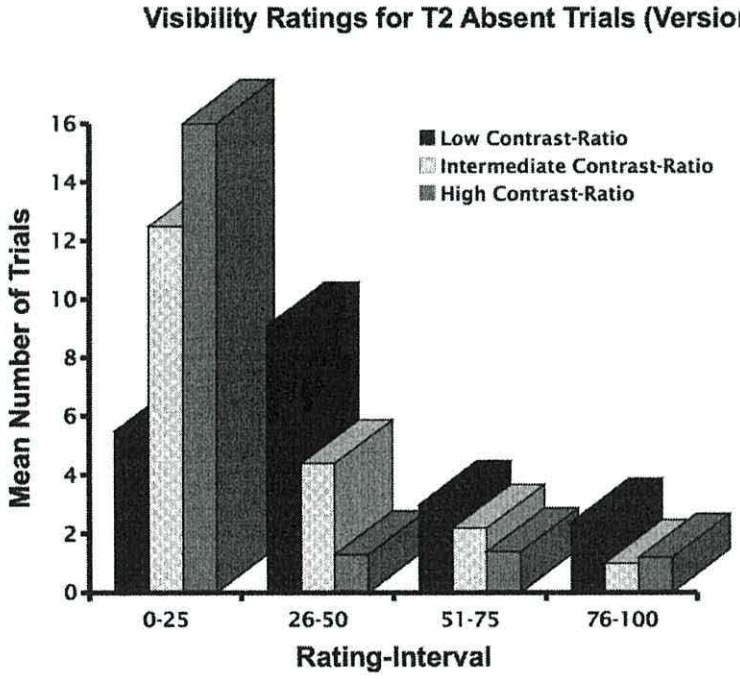


Figure 6: Illustrates the mean number of T2 absent trials rated across the factors of Rating-Interval and Condition. The exact same data is illustrated in two formats (Version 1 and Version 2).

Table 4

Subjective-Visibility Rating for T2-Absent Trials

Condition	[0 – 25]	[26 – 50]	[51 – 75]	[76 – 100]
Low T2 Contrast	5.5 (3.36) a Δ	9.1 (1.53) b Δ	3.0 (1.37) a Δ	2.4 (1.39) a Δ
Intermediate T2 Contrast	12.5 (2.98) a Φ	4.3 (2.63) c Φ	2.2 (1.20) c Δ	1.0 (.00) c Δ
High T2 Contrast	16.0 (1.50) a д	1.3 (.67) b д	1.4 (.78) b Δ	1.3 (.52) b Δ

Note: Mean number of T2-absent trials rated by factors of Rating-Interval and Condition and. Standard deviations are included in parenthesis. Mean values within each row sharing the same designation "a", "b", or "c" did not differ significantly at the .05 level as determined with Tukey's HSD post hoc comparison. Mean values within the same column sharing the same designation Δ, Φ, or д also did not differ at the .05 level.

T2-Present/T1-Correct Trials (AB and No-AB Trials Inclusive): Here, T2-present/T1-correct trials were analyzed with no distinction being made between AB and No-AB trials (i.e., whether participants responded correctly or incorrectly to the T2 identity response was irrelevant). This segment of the analysis was divided into two parts – each aimed at answering the following question. Did all three levels of T2 contrast show bimodal distributions for visibility ratings at all lag positions? Recall that this is the outcome predicted by Sergent and colleagues if in fact awareness for T2 always emerges in an all or none fashion under demands of divided attention (See Figure 1).

Part 1 examined this question at the level of mean differences between ratings intervals. This analysis was carried out with a 3x4x5x3 mixed factor ANOVA for the factors of Condition, Rating-Interval, Order, and Lag. The dependent variable was *number of trials* rated within a given rating interval. This measure was justified by the lack of differences in T1 identity-report accuracy across

factors of Condition and Lag[6] (See Figure 4 and Table 2). Because no significant differences in T1 performance were found, it can be assured that within each level of Condition and Lag the overall number of T2-present / T1-correct trials did not significantly differ. Had significant T1 differences been found between factors, the percentage of trials rated within each interval would have been a more appropriate dependent measure[7].

In order to conclude that bimodal distributions indicative of discreetly different states – i.e., 'seen' vs. 'unseen' – occur regardless of T2 signal-strength, it was determined the data must meet three[8] criteria. These criteria were based on Sergent and Dehaene's 2004 findings (See page 99, 100, and Figure 1 of current work). The first two criteria were meant to determine whether each T2 contrast condition – independently of the other two – yielded a bimodal response distribution similar to that reported by Sergent and Colleagues. *Criterion One:* At all lag positions the mean number of trials rated in the [26–50] and [51–75] intervals must be significantly smaller than for the [0–25] and [76–100] intervals. *Criterion Two:* The mean number of trials rated in the [26-50] and [51–75] intervals must not differ within or across lag positions[9]. The third criterion determined whether intermediate response intervals – i.e., [26–50] and [51–75] – were used to an equal extent across

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[6] The lack of differences in T1 identity-report performance is not only apparent from the lack of statistical differences between mean levels of performance, but also the extremely narrow range of mean performances across factors of Condition and Lag (Minimum = 87.24 / Maximum = 90.23).

[7] Had significantly different numbers of T1-correct trials across factors been present, this could potentially have confounded results produced with a dependent measure of *number of trials* rated within a given interval – differences between rating intervals could have been caused not by how T2 signal-strength impacted visibility ratings, but rather how many T1-correct trials were available to be rated.

[8] At first glance it may seem that a fourth criteria is required – that for each lag position, the mean number of responses rated within the [0 – 25] and [76 – 100] intervals not significantly differ across conditions. This criteria would however be invalid, as it may be possible for increased levels of contrast ratio to increase the frequency of No-AB trials, and yet the difference of T2 awareness between AB and No-AB trials be all-or-none.

[9] "Within" a lag position refers to interval ratings for a single lag position – e.g., the 26-50 and 51-75 intervals did not differ for lag-3. "Across" lag positions refers to interval ratings for all lag positions – e.g., number of trials rated within the 26-50 interval was the same for lags 1, 2, 3, 6, and 7.

conditions. *Criterion Three:* At each lag position the mean number of trials rated in the [26–50] and [51–75] intervals must not differ across conditions – e.g., the mean number of trials rated within the [26 – 50] interval at lag 1 did not differ across conditions.

Meeting the first and second criteria for all three conditions, and the third criterion across conditions, would illustrate not only were responses clustered around two modes[10] – a critical factor in determining that a distribution is indeed bimodal – but that intermediate rating intervals were used with more/less equal frequency across all experimental factors. If awareness of T2 occurs in an all-or-none fashion, intermediate rating intervals should not only be seldom used, but the extent to which they are used should not vary significantly across factors of Condition and Lag.

Importantly, statistical comparisons between the [0–25] and [76–100] intervals were not considered to be theoretically important to the question of bimodality. Regardless of whether 'T2 awareness' emerges in a graded or all-or-none fashion, the number of trials rated in these intervals was expected to differ – recall that dual-task demands become progressively stronger until lag-3 then taper off through lag-7. Assuming as Sergent and colleagues did that a rating of "0" corresponds to conventional AB trials and a rating of "100" to No-AB trials, it follows that the number of trials clustered around these extreme ratings can vary, and yet the bimodality required to support all-or-none bifurcations of consciousness be maintained (See Sergent and Dehaene data – Figure 1 of current work).

Part 2 evaluated *overall* changes in visibility responses across the four rating intervals. To this end, all response distributions – across factors of Condition and

[10] Mode reflects is measure of central tendency – the most commonly used responses.

Lag[11] - were submitted individually to a multiple regression model with two predictors. Here again the dependent variable was number of trials rated within each interval. Model predictors were chosen, which if found to account for a significant amount of response variation, would support the assertion that visibility responses were a discrete combination of 'seen' and 'unseen' states for T2. Following the methods of Sergent and Colleagues (2004, 2005), as predictors I selected the two response distributions that were most strongly skewed toward opposite ends of the visibility scale. For the current data these were the T2-absent responses for the high contrast condition (*predictor-1 one of the model*), and the T2-present / T1-correct responses for lag 7, also from the high contrast condition (*predictor-2 of the model*). To reiterate, if response distributions are indeed heavily bimodal, then *both* predictors should account for a significant degree of response variation.

Part 1 Results: Mauchly's test showed a violation of sphericity for the repeated measures factor of Rating-Interval. Statistics pertaining to this factor are thus reported with the Greenhouse-Geisser correction. No main effects of Condition $F(2, 34) = .33$, $MSE = 4.92$, $p = .71$, Order $F(2, 17) = 1.07$, $MSE = 2.57$, $p = .36$, or Lag $F(4, 68) = .03$, $MSE = 5.90$, $p = .10$, were found. Only a main effect of Rating-Interval was present $F(1.98, 33.81) = 7{,}505.08$, $MSE = 17.00$, $p < .001$. Three interactions were found between factors – Condition (x) Rating-Interval, Lag (x) Rating-Interval, and Condition (x) Rating-Interval (x) Lag (See Figures 7 - 8 & Tables 5 and 6).

As previously indicated, when examining the issue of bimodality at the level of mean differences, three criteria were required in order to conclude increased

[11] "across factors of Condition and Lag" implies that for each condition five response distributions were submitted to the regression model (i.e., one for each lag position) – a total of 15 distributions in all. Each response distribution contained all four rating intervals.

levels of T2 signal-strength *did not* prevent bimodality. Below is a description of how the current data fit these criteria.

Criteria One: For each of three T2 contrast conditions, significantly smaller mean number of trials being rated within the [26-50] and [51-75] intervals than either the [0-25] or [76-100] intervals.

Low Contrast Condition: This first criterion was only met for the low contrast condition. When compared to either the [0–25] or [76–100] interval, a significantly smaller mean number of trials was rated within in the [26–50] and [51–75] intervals – this data trend was present at all lag positions for the low-contrast condition (See Figures 7 - 8 and Table 6).

Intermediate Contrast Condition: As T2 contrast-ratio increased visibility responses began to skew toward higher ends of the visibility scale. For intermediate contrast trials, at lags 1, 2, 6, and 7 the mean number of trials rated within the [0–25] interval was not statistically different from that of the [26–50] and [51–75] intervals. At these lag positions the mean number of trials rated within the [76-100] interval was significantly greater than for the [0-25], [26-50], and [51-75] intervals. Only at lag 3 was a bimodal distribution present – the [26–50] and [51–75] intervals were used significantly less than either the [0–25] or [76–100] intervals (See Figures 7 - 8 and Table 6).

High Contrast Conditions: The extreme impact of increased contrast was most apparent in the high T2 contrast condition. Here all lag positions showed a heavily skewed distribution of visibility ratings with most all trials being rated within the [76 – 100] interval – for all lag positions the mean number of trials rated within this interval was significantly greater than for both the low and intermediate contrast conditions. None of the lag positions yielded bimodal distributions in the high contrast condition. With the exception of lag 3, all lag positions yielded a mean

number of trials rated in the [0 – 25] interval that was not significantly different from that of the [26 – 50] and [51 – 75] intervals. At lag 3 the mean number of trials rated with the [26 – 50] and [51 – 75] intervals was significantly greater than for the [0 – 25] interval (See Figures 7 - 8 and Tables 6).

Criterion Two: Within each condition the [26-50] and [51-75] intervals should not differ within or across lag positions.

This criterion was met for all three conditions (See Figures 7-8 & Table 6).

Criterion Three: For each lag position the mean numbers of trials rated within the [26-50] and [51-75] intervals do not differ across conditions.

The [26-50] interval at lag 3 for high contrast trials was significantly greater than the same intervals at lag 3 for low contrast trials. This particular case was the *only* instance for which this criterion was not met (See Figures 7 - 8 and Tables 6).

Part 1 Results Summary

In summary, only the low T2 contrast condition yielded a bimodal response distribution similar to that reported by Sergent and Colleagues – all lag positions in the low contrast condition met both the first and second apriori criteria. Bimodal response distributions were not found for intermediate and high T2 contrast conditions. For these conditions response distributions were unimodal at all lag positions – excluding lag 3 for the intermediate contrast condition. Moreover, response distributions for these conditions were heavily skewed toward the [76-100] rating interval.

Table 5

Factorial Interaction Statistics for T2-Present / T1-Correct Visibility Ratings

Condition (x) Order	$F(4, 34) = .22$, $MSE = 5.89$, $p = .82$
Rating Interval (x) Order	$F(3.97, 33.81) = .42$, $MSE = 17.00$, $p = .79$
Lag Position (x) Order	$F(8, 68) = .90$, $MSE = 5.90$, $p = .51$
*Condition (x) Rating Interval	$F(2.71, 46.08) = 283.77$, $MSE = 21.43$, $p < .001$
Condition (x) Lag Position	$F(8, 136) = .175$, $MSE = 8.64$, $p = .10$
*Rating Interval (x) Lag Position	$F(4.49, 76.40) = 62.87$, $MSE = 36.91$, $p < .001$
*Condition (x) Lag (x) Rating Int.	$F(5.99, 101.87) = 8.37$, $MSE = 67.38$, $p < .001$

Note: The designation "*" indicates an interaction found to be significant at the .05 level.

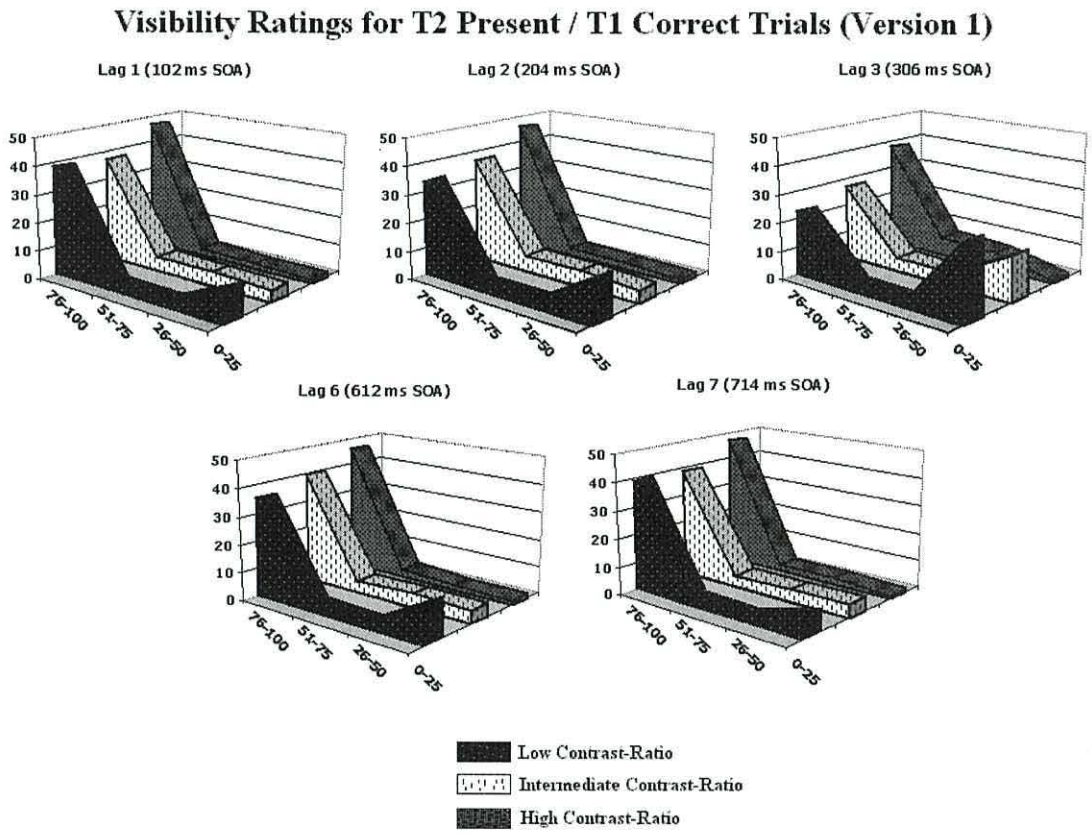

Figure 7: For T2-present / T1-correct trials, illustrates mean number of trails rated by factors of Rating-Interval, Condition, and Lag. The same mean values are illustrated in an alternative format in Figure 8.

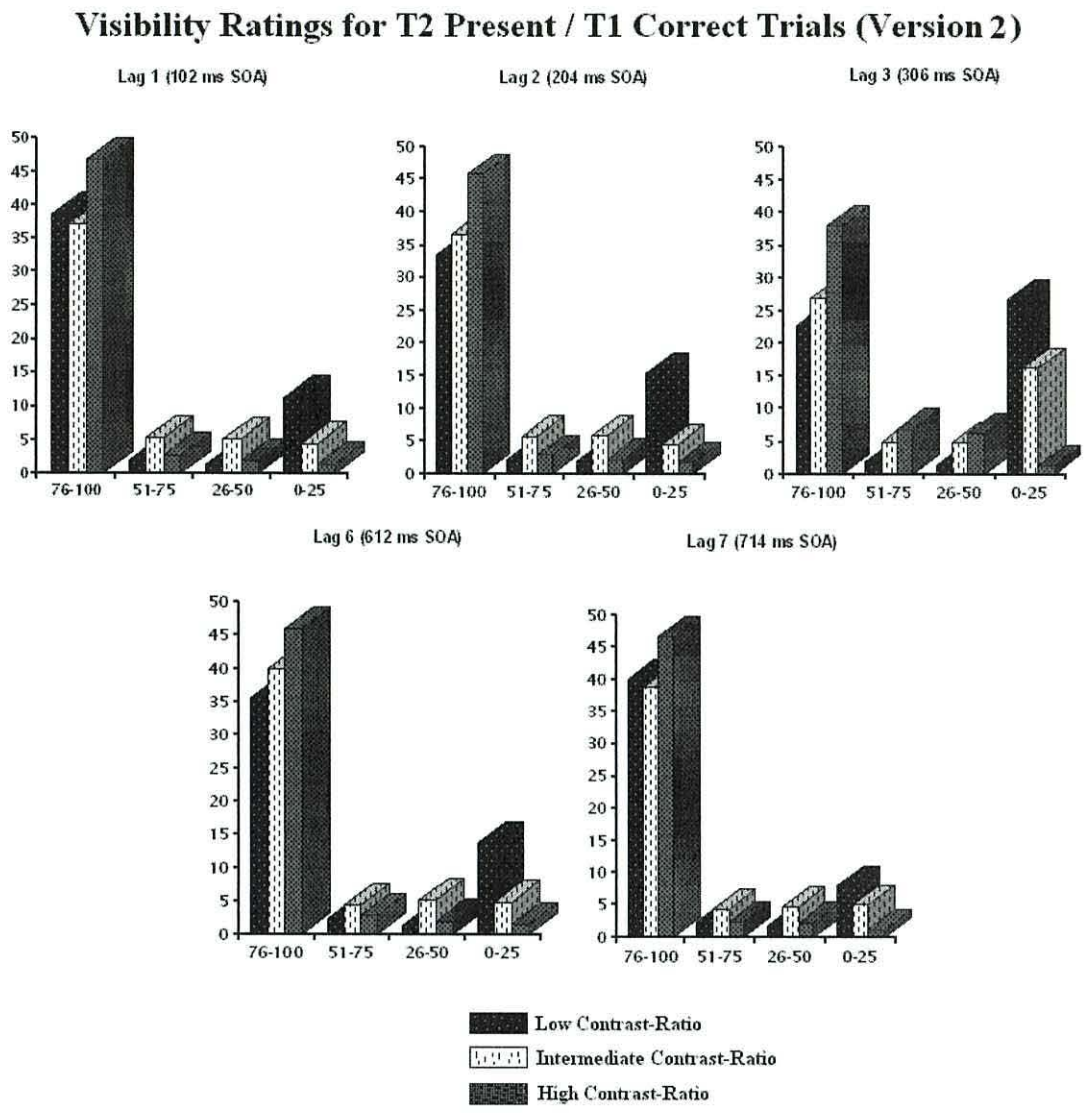

Figure 8. For T2-present / T1-correct trials, illustrates mean number of trials rated by factors of Rating-Interval, Condition, and Lag. The same mean values are illustrated in an alternative format in Figure 7.

Table 6

Subjective-visibility Ratings for T2-Present / T1-Correct Trials – By Lag Position

Condition	Lag 1 (102 ms SOA)	Lag 2 (204 ms SOA)	Lag 3 (306 ms SOA)	Lag 6 (612 ms SOA)	Lag 7 (714 msSOA)
Low T2 Contrast	**0-25** 11.2 (3.7)	**0-25** 15.43 (6.4)	**0-25** 26.87 (6.0)	**0-25** 13.61 (3.3)	**0-25** 8.0 (4.0)
	26-50 1.45 (.60)	**26-50** 1.85 (1.08)	**26-50** 1.59 (.76)	**26-50** 1.44 (.75)	**26-50** 1.84 (1.1)
	51-75 1.90 (.91)	**51-75** 2.0 (.91)	**51-75** 1.9 (1.02)	**51-75** 2.21 (1.05)	**51-75** 2.54 (1.3)
	76-100 38.80 (5.37)	**76-100** 33.63 (7.6)	**76-100** 22.75 (6.5)	**76-100** 35.10 (4.75)	**76-100** 40.00 (6.3)
Intermed. T2 Contrast	**0-25** 4.54 (2.4)	**0-25** 4.62 (3.4)	**0-25** 16.31 (6.1)	**0-25** 4.96 (2.8)	**0-25** 5.0 (2.2)
	26-50 5.11 (2.0)	**26-50** 5.9 (4.0)	**26-50** 4.8 (2.8)	**26-50** 5.15 (1.9)	**26-50** 4.75 (3.3)
	51-75 5.37 (1.8)	**51-75** 5.75(3.12)	**51-75** 5.00 (2.7)	**51-75** 4.51 (3.0)	**51-75** 4.46 (2.4)
	76-100c 37.31 (7.8)	**76-100** 36.75(9.3)	**76-100** 26.9 (5.8)	**76-100** 39.97 (8.0)	**76-100** 38.99 (7.9)
High T2 Contrast	**0-25** 1.45 (.60)	**0-25** 1.72 (.92)	**0-25** 1.36 (.57)	**0-25** 1.62 (.99)	**0-25** 1.2 (.52)
	26-50 1.94 (1.2) b	**26-50** 2.25 (1.5)	**26-50** 6.22 (2.9)	**26-50** 2.05 (1.3)	**26-50** 2.33 (1.1)
	51-75 2.71 (1.7) b	**51-75** 2.9 (1.2)	**51-75** 6.99 (3.3)	**51-75** 2.95 (1.3)	**51-75** 2.57 (1.4)
	76-100 46.8 (7.3)	**76-100** 45.93 (6.4)	**76-100** 39.00 (5.4)	**76-100** 47.90 (8.0)	**76-100** 46.75 (9.6)

Note: Illustrates mean number of trials rated by factors of Rating-Interval, Condition, and Lag – standard deviations are in parenthesis. Significant differences between mean values are not indicated due to the large number of comparisons made. Theoretically significant differences are pointed out in the discussion of results presented below.

Part 2 Results: As stated, all visibility response distribution – across factors of Condition and Lag - were submitted individually to a multiple regression analysis. Response distributions for the two predictors can be seen in Figure 9. Multicolinearity[12] was not found to be an issue for the regression analysis. The mean number of trials rated within the [0 – 25] interval for predictor one was substantially less than the mean number rated within the [76 – 100] interval for predictor two (see Fig. 9). This difference was the result of having less T2 absent trials than T2-present / T1-correct trials. As the results indicated however, this difference did not prevent the model from successfully indicating the presence or absence of bimodality.

For all response distributions the overall[13] model accounted for a significant amount of variance in the dependent measure – range of r^2 values was .78 - .98. Most importantly however, only in the low contrast ratio condition were both predictors found to contribute significantly to the variance accounted for at all lag positions. For the intermediate contrast-ratio condition only at lag 3 were both predictors found to contribute significantly to the model. For all other intermediate contrast-ratio lags positions, and all high contrast-ratio lag positions, only the second predictor (i.e., T2-present / T1-correct responses) contributed significantly to the model. It should be re-emphasized that to indicate bimodality, it was required that both predictors contribute significantly to the degree of variance accounted for by the model. A full summary of results from the multiple regression analysis can be viewed in Table 7.

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[12] Multicolinearity occurs when two independent variables are highly correlated. High levels of intercorrelation among such variables make it difficult to obtain valid regression coefficients. This difficult arises from variables being treated as redundant information by analysis software.

[13] "Overall model" refers to the amount of variance the model accounted for inclusive of both predictors (i.e., independent / explanatory variables). The value is reflected in the r-squared value.

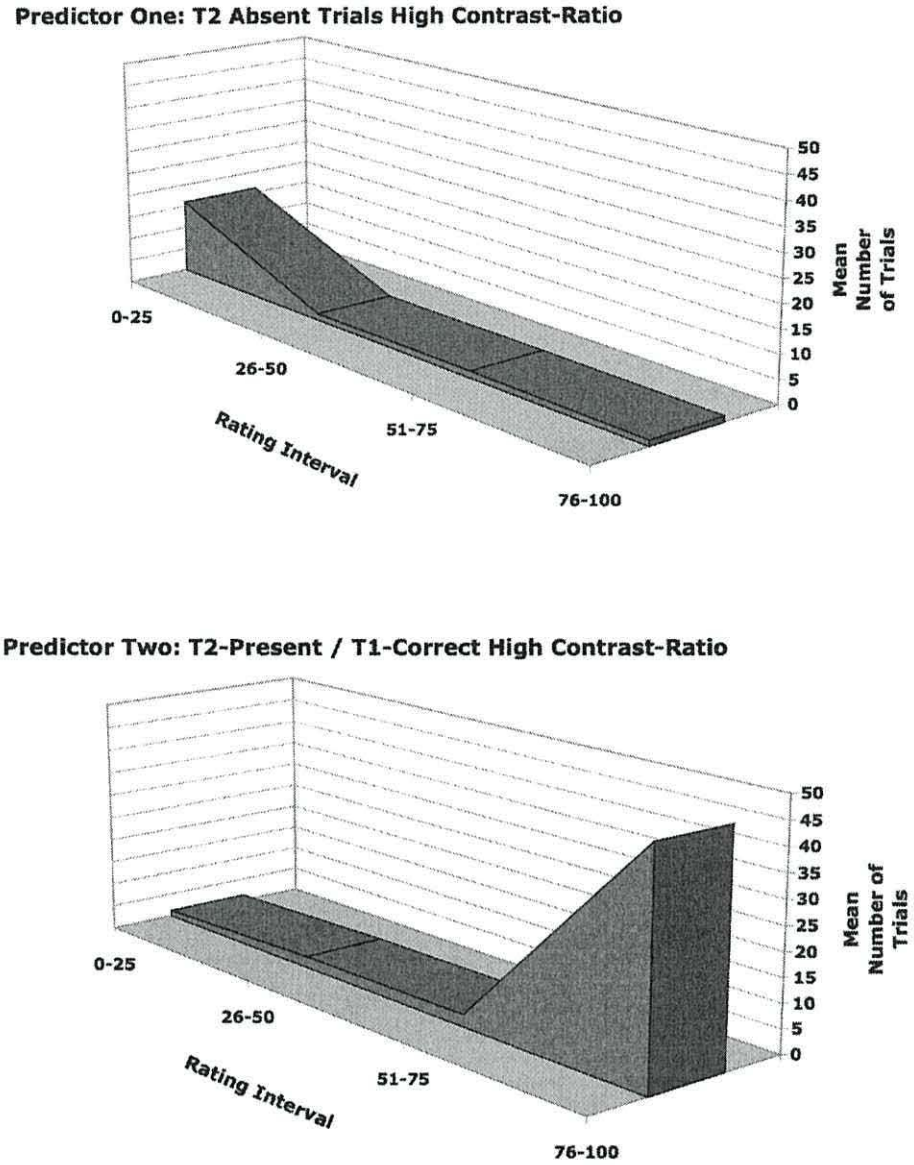

Figure 9. Response distributions for the two predictors used for multiple regression.

Table 7

Summary of Multiple Regression Statistics

Condition	Lag 1 (102ms SOA)	Lag 2 (204ms SOA)	Lag 3 (306ms SOA)	Lag 6 (612ms SOA)	Lag 7 (714msSOA)
Low Contrast-Ratio	$r^2 = .92$ F test < .001 (P1) Absent < .01 (P2) Present < .01	$r^2 = .90$ F test < .001 (P1) Absent < .01 (P2) Present < .01	$r^2 = .87$ F test < .001 (P1) Absent < .01 (P2) Present < .01	$r^2 = .97$ F test < .001 (P1) Absent < .01 (P2) Present < .01	$r^2 = .94$ F test < .001 (P1) Absent < .01 (P2) Present < .01
Intermed. Contrast-Ratio	$r^2 = .95$ F test < .001 (P1) Absent = .46 (P2) Present < .01	$r^2 = .90$ F test < .001 (P1) Absent = .67 (P2) Present < .01	$r^2 = .78$ F test < .001 (P1) Absent < .01 (P2) Present < .01	$r^2 = .93$ F test < .001 (P1) Absent = .87 (P2) Present < .01	$r^2 = .93$ F test < .001 (P1) Absent = .16 (P2) Present < .01
High Contrast-Ratio	$r^2 = .98$ F test < .001 (P1) Absent = .12 (P2) Present < .01	$r^2 = .97$ F test < .001 (P1) Absent = .20 (P2) Present < .01	$r^2 = .92$ F test < .001 (P1) Absent = .48 (P2) Present < .01	$r^2 = .97$ F test < .001 (P1) Absent = .12 (P2) Present < .01	$r^2 = 1.00$ F test * (P1)Absent * (P2)Present *

Note. Statistical summary of the multiple regression analysis across factors of Condition and Lag position. R-squared represents the amount of variance accounted for in the dependent variable for the entire model – inclusive of both predictors. The F-test indicates is the r-squared value is significant. (P1)Absent – i.e., T2 Absent predictor, and (P2)Present – i.e., T1 correct/T2 present predictor, represent the two predictors, and whether they were found to contribute significantly to the amount of variance represented by the r-squared value.

T2-Present/T1-Correct (AB trials only): Here, T2-present / T1-correct /AB Trials were analyzed in order to determine how subjective-visibility ratings were used during AB trials (i.e., when T2 identity was reported incorrectly). To this end, a 3x3x3[14] mixed ANOVA[15] with the factors of Condition, Order, and Rating-Interval was carried out on AB trials only. For this analysis '*number of trials*' was deemed an inappropriate dependent measure. Despite not including the factor of lag in the

[14] Only three levels of Rating-Interval were used in the analysis of AB trials due to a complete absence of responses in the [76 – 100] interval across conditions.

[15] Understanding how visibility ratings for AB trials vary across lag positions was NOT a goal of the current experiment. For this reason the factor of lag was omitted from this analysis.

ANOVA, the total number of AB trials differed dramatically across conditions (See Figure 5 and Table 3). The dependent measure chosen for this analysis was therefore *percentage of trials rated within each interval*. Statistical differences were evaluated at the level of *mean percentage of trials* – i.e., the average percentage of trials rated within a given interval across participants (e.g., on average participants rated 20% of trials within the [0–25] interval). For none of the three contrast-ratio conditions was T2 visibility ever rated within the [76-100] interval on AB trials. For this reason only intervals [0-25], [26-50], and [51-75] were included in this analysis[16].

Results: Mauchly's test showed a violation of sphericity for the repeated measures factor of Rating-Interval. Statistics pertaining to this factor are thus reported with the Greenhouse-Geisser correction. Main effects were found for both Condition $F(2, 34) = 195.02$, $MSE = 26.27$, $p < .001$, and Rating-Interval $F(1.71, 29.06) = 670.66$, $MSE = 33.69$, $p < .001$. No main effect of Order was found $F(2, 17) = .03$, $MSE = 33.06$, $p = .96$. The only significant interaction present was between Condition and Rating-Interval $F(2.46, 41.83) = 506.13$, $MSE = 31.50$, $p < .001$ (See Figure 10 and Table 8 below).

Regarding the main effect of Condition, the mean percentage of trials rated within the [0-25] and [26-50] intervals differed across all three conditions. Percentages of trials rated within the [0-25] interval significantly decreased as an inverse function of T2 contrast-ratio. On the other hand, percentages of trials rated within the [26-50] interval significantly increased as a function of T2 contrast-ratio. These data trends also speak to the interaction between Condition and Rating-interval. As to the main effect of Rating-Interval, and further to the Interaction between Condition and Rating interval, in the low contrast and intermediate contrast

[16] Inclusion of the 76-100 rating interval would have lead to a sever violation of homogeneity of variance between factors. Even with applied corrections for heterogeneity of variance, a total absence of variance for this rating interval would likely have nevertheless biased the ANOVA analysis.

conditions the greatest percentage of AB trials was rated within the [0-25] interval – this value being significantly higher than for the other two intervals. In the high contrast condition the greatest percentage of AB trials was rated within the [26-50] interval.

As indicated in the methods of Experiment 1, participants were instructed to only use the rating of "0" when confident that T2 did not occur in the RSVP stream. Ratings of visibility between 5-100 can therefore be presumed to indicate that participants were able to see – i.e., obtain a conscious percept of – T2. Because rating intervals [26–50] and [51–75] did not include the rating of "0", it can be assumed with a high level of confidence that for all trials rated within these interval a conscious percept of T2 was obtained. As illustrated in Figure 10 and Table 8, 49.15% of AB trials were rated within these intervals for the intermediate contrast-ratio condition and 88.70% for the high contrast-ratio condition. By comparison, only 11.6% of AB trials in the low contrast-ratio condition were rated within these intervals. The analysis of AB trials therefore suggest that it is possible to obtain a conscious representation of T2 yet not be able to correctly report the identity of T2. Furthermore, the probability of obtaining a conscious representation of T2 during an AB trial significantly increases as a function of T2 signal-strength.

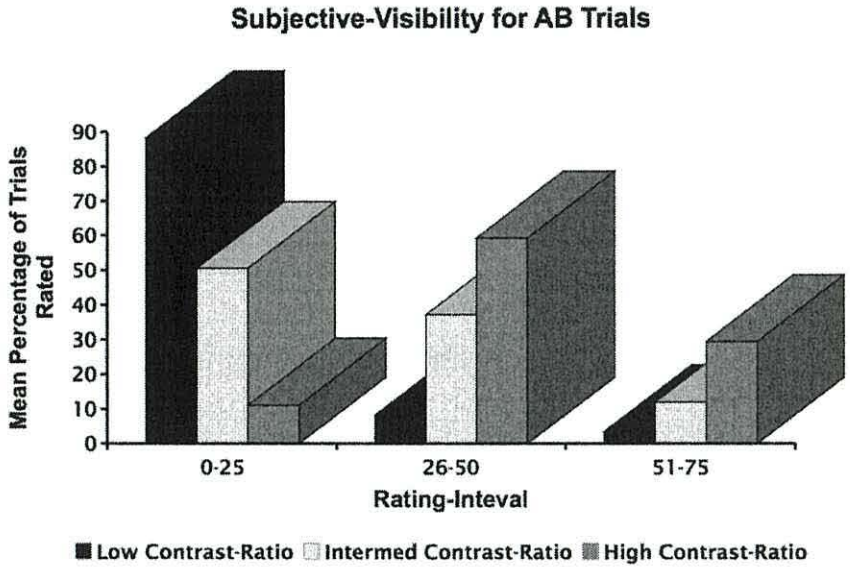

Figure 10: Illustrates mean percentage of AB trials rated by factors of Rating-Interval and Condition.

Table 8

Subjective-Visibility Ratings for T2-Present / T1-Correct Trials – AB Trials Only

	[0 – 25]	[26 – 50]	[51 – 75]
Low T2 Contrast	88.35% (7.55) a Δ	8.2% (4.44) b Δ	3.45% (2.79) b Δ
Intermed T2 Contrast	50.60% (8.83) a Φ	37.15% (5.07) b Φ	12.00% (6.56) c Δ
High T2 Contrast	11.15% (7.38) a д	59.30% (13.35) b д	29.40% (13.89) c Φ

Note: Mean number of AB trials rated by factors of Rating-Interval and Condition – respective standard deviations are included in parenthesis. Mean values within the same row sharing the same designation "a", "b", "c", do not differ significantly at the .05 level as determined with Tukey's HSD post hoc comparison. Mean values within the same column sharing the same designation Δ, Φ, or д also do not differ at the .05 level.

Discussion

To review the results of Experiment 1, the objective measure of identity-report showed similar T1 performance across both factors of Condition and Lag. T2 performance revealed a positive relationship between identity-report accuracy and contrast. As T2-contrast increased so did identity-report accuracy. While this trend is clear at all lag positions (See Figure 5 and Table 3), it is most apparent at lag 3 – where T2 accuracy differed significantly between all levels of contrast. Such a relationship is to be expected given the earlier discussion of signal-to-noise ratio. The stronger a signal the more likely it is to survive a given level of processing interference. T2 stimuli that are easily distinguishable from surrounding RSVP items thus seem more likely to survive dual-task demands of the AB. Also important is that the time course of the AB did not differ between conditions – i.e., the maximum level of accuracy for T2 identity report was obtained at lag 7 for all conditions. This outcome suggests that increasing contrast-ratio of the T2 stimulus does not shorten the duration of time during which T1 processing impacts T2. As the following discussion illustrates however, contrast-ratio does influence whether a conscious percept of T2 can be obtained during the AB interval.

Regarding the measure of subjective visibility, T2-absent trials indicated participants were using the lower extremes of the visibility scale. The fact that low contrast / T2-absent trials were most often rated within the [26–50] interval does not indicate inaccurate use of the visibility scale. Rather, this outcome is congruent with the hypothesis that visibility ratings are affected by T2 contrast-ratio. Recalling that ratings of [26–50], [51–75], and [76–100] were interpreted as indicating that a conscious percept of T2 was obtained, it is no surprise the greatest number of 'false-alarms' (i.e., rating T2 as 'seen' when it never occurred in the RSVP stream)

occurred when T2 signal-strength was the lowest (See Figure 6 and Table 4). In other words, lower levels of T2 signal-strength made it difficult to determine when a T2-absent trial had actually occurred. This assertion is further supported by the fact that the mean number of T2-absent trials rated within the [0–25] interval was greater for the high contrast than the intermediate contrast condition (See Figure 6 and Table 4) – reflecting that increased levels of contrast made T2 absent trials easier to detect.

As to whether heightened levels of T2 contrast allowed for evidence of graded- consciousness during the AB, the answer is definitively "yes". Only in the low contrast condition were bimodal response distributions found for visibility ratings at all lag positions. As predicted, the intermediate and high contrast conditions showed extremely unimodal distributions of visibility responses, which were skewed heavily toward the [76-100] interval. Results from the regression model mapped perfectly on to the ANOVA results comparing mean differences between rating intervals. Only for the low contrast condition did both predictors contribute significantly to the model at all lag positions – an indication of bimodality for visibility response distributions. Finally, the analysis of AB trials demonstrated that conscious perception of T2 occurred on trials when the identity of T2 could not be correctly reported.

In summary, Experiment 1 results suggest the bimodal distributions of visibility ratings reported by Sergent and colleagues (2004, 2005) are valid only for the specific stimulus parameters used in their experiments. Observers *can* be aware of the second target in an AB task and yet not be able to accurately report its identity – a finding that is consistent with the notion of graded consciousness. Before further discussing what the current findings indicate about fate of T2 processing during the

AB, we first turn our attention to Experiment 2. Experiment 2 asked the question: Can awareness for T2 be manipulated as a function of T1 task demands?

Experiment 2

Is the relationship between contrast-ratio and 'T2 awareness' sensitive to T1 task difficulty? Answering this question was the goal of Experiment 2. Past experiments are divided as to whether dual-task interference in the AB is magnified as T1 task difficulty increases. Shapiro et al. (1994) initially reported that T1 difficulty did not affect the magnitude of the AB (i.e., T2 accuracy) with this conclusion later supported by other investigators (e.g., Raymond et al., 1995; Ward et al., 1996, 1997). On the other side of the debate, some researchers reported that T1 difficulty did affect T2 accuracy (e.g., Chun & Potter, 1995; Brehaut et al., 1999; Grandison et al., 1997; Seiffert & Di Lollo, 1997). These researchers operationalised T1 difficulty through the use of masking (i.e., a more effectively masked T1 is a more difficult target to process).

In the experimental condition of Experiment 2 T1 and non-target distracter stimuli were equated for contrast. Relative to a control condition for which T1 contrast was identical to Experiment 1[17], equating contrast between T1 and non-target distracters should not only make T1 detection more difficult, but also increase the influence of backward masking caused by the T1+1 item (Breitmeyer & Ogman, 2006). These two factors combined should increase overall difficulty of the T1 task. Working on the presumption that dual-task interference has a suppressing effect on awareness of T2, the driving hypothesis of Experiment 2 predicted that if in fact T1 difficulty influences the degree of dual-task interference between targets, increasing

[17] Recall that in Experiment 1 contrast-ratio of the T1 stimulus was much greater that for non-target distracters.

T1 difficulty would lessen the potential for stronger T2-signals to produce conscious percepts.

Methods

Participants

Eighteen undergraduate students from Bangor University took part in the experiment. Three participants however failed to attend the second experimental session, and one participant did not meet the minimum requirements for T1 performance. Statistical analyses thus included data from 14 participants (7 males, 7 females: $M = 19.85$; $SD = 1.53$). Students were compensated for participating with either course credit or monetary payment. All participants reported normal to corrected-to-normal visual acuity.

Apparatus

Stimuli were presented on a 1024 by 768 pixel, 32-bit colour 'quality', 17-inch cathode ray tube (CRT) monitor using E-prime version 1.1 experimental software (Psychology Software Tools, Inc., Pittsburgh, PA). All stimuli were presented in intervals of the 17 ms refresh rate of the monitor.

Task Parameters

Experiment 2 consisted of two conditions. In both conditions a RSVP stream of 24 items was presented in the center of a black screen. All RSVP stream items were presented at a rate of ~ 10 items per second (i.e. 17 ms 'on'; 85 ms 'off'). Prior to RSVP onset a red fixation-cross appeared that lasted for 500 ms. After the fixation cross disappeared, a 500 ms blank screen separated offset of the fixation cross and

RSVP onset. All RSVP stimuli were presented in New Times Roman 20-point font. The only difference in stimulus parameters between conditions was T1 luminance. In the *T1-Bright Condition* the T1 stimulus was of a much greater luminance than non-target distracter items. In the *T1-Equal Luminance Condition* luminance of the T1 stimulus was equal to non-target distracter items (See Figure 11 and Table 9). In both conditions non-target distracters were presented as achromatic gray stimuli – non-words containing four consonants. T1 onset occurred between the sixth and twelfth items with its specific position determined randomly. T1 appeared as either "XOOX" or "OXXO". The T1 task was to report whether the two center letters were "XX" or "OO". T2 was always one of three numeric words – four, five, or nine.

In both conditions the T2 task for each trial was simply to detect whether T2 was present or absent during the RSVP stream. For T2-present trials, T2 was presented in one of eight possible levels of luminosity. The same eight levels of T2 luminance were present in both conditions. The T2 response was always provided after T1 response. The temporal relationship between T1 and T2 was held constant across all T2-present trials. T2 appeared in the conventional lag 3 position (i.e., 306 ms post T1 onset). The range of luminance values used for the T2 stimulus was consistent with Experiment 1. The minimum value – 19.69 cd/m^2 – was that of non-target distracter stimuli in both Experiments 1 and 2. The Maximum value – 81.40cd/m^2 – was the luminance value for T2 stimuli in high contrast-ratio trials during Experiment 1. Differences between intermediate luminance values were spaced as equally as possible – the average distance between levels was (M = 8.81 cd/m^2; SD = 0.12). Within each condition the exact value of luminance for T2 was randomly intermixed among trials. T2 absent trials were also randomly intermixed within each condition – see section below for explanation regarding the number of

trials presented. During the instruction phase of the experiment participants were informed that some trials would not contain a T2 stimulus (See Figure 11 and Table 9).

Dual-Session Design and Number of Required Trials

Experiment 2 was designed as a within-subjects experiment. However unlike Experiment 1, participants completed the conditions in two sessions. Session two was carried out exactly one week after the first and at the same time of day. Separate sessions were required due to the large number of trials needed for Experiment 2[18]. One experimental condition was completed in each session. The order conditions were completed was counterbalanced across participants.

Experiment 2 required 950 trials be completed for each experimental condition. For each level of luminance 100 T2-present trials were completed. In order to be included in the analysis, participants were required to show correct T1 performance for a minimum of 70[19] trials at each luminance level. One hundred and fifty T2-absent trials were presented in each experimental condition.

Procedure

Upon arrival participants were given a brief introduction to the task then asked to provide their written consent for participation. They were also informed of their right to withdraw from the experiment at any time and to view their data at a

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[18] Conventional standards for parametric testing of psychophysical response functions – as outlined by Gescheider (1997) – state statistical analysis should contain approximately 100 trials for each of 7 – 8 levels of stimulus strength. Based on participant performance in Experiment 1[18], it was decided the maximum number of trials participants could be expected to finish within a 2.5 – 3 hour period was approximately 960.

[19] While 70 trials does not meet the minimum requirement suggested by Gescheider (1997 – see above footnote), it was determined this was the best that could be done without requiring participants come back for three sessions. If was feared too many participants would fail to show up for three sessions.

later date if they so wished. Each condition was split into three trial blocks (330 trials in blocks 1 and 2; 290 trials in block 3). After the first two blocks participants were asked if they would like to take a 5 minute break, during which time they were free to get up and leave the testing room if needed. At the end of the first session participants were *not* debriefed as to the nature of the experiment. Rather, participants were reminded of their agreements to return one week later to finish the experiment. Two days before each participant was scheduled to undertake the second session, a reminder email was sent to him or her. A full debriefing took place at the conclusions of the second experimental session. Each experimental session lasted approximately 120 – 160 minutes.

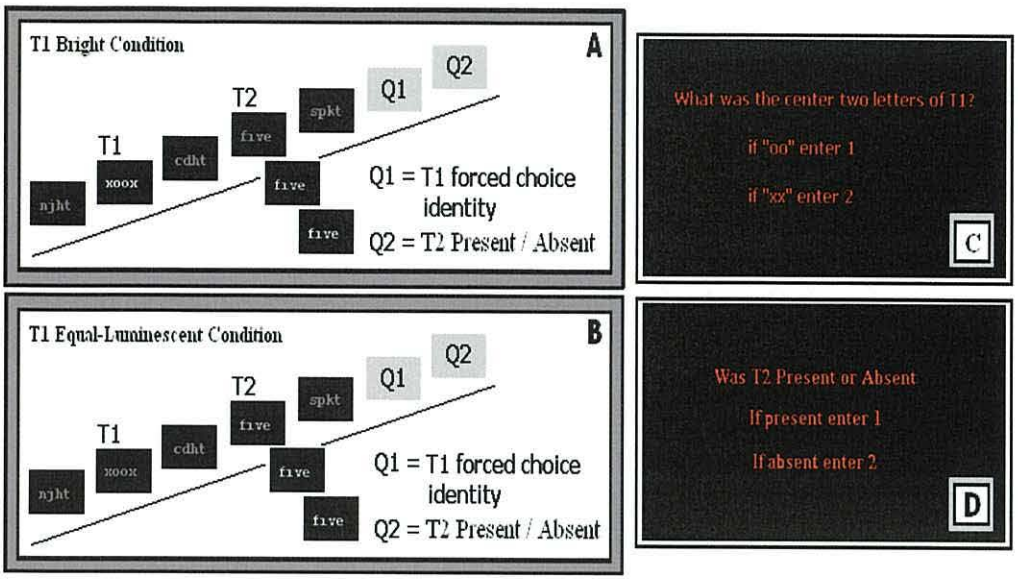

Figure 11. Illustrates the two conditions for Experiment 2. Panel A shows the T1 bright condition for which the visual parameters for the T1 stimulus frame matched that of Experiment 1. Panel B shows the T1 equal-luminescent condition for which visual parameters for the T1 frame match that of non-target distracters. The three T2 frames in Figure 10 are meant simply to illustrate that T2 luminance varied during Experiment 2. Panels C & D illustrate the response frames in Experiment 2.

Table 9-A

Luminance Values, sRGB, and Contrast-Ratio Calculations

Condition	Background		Non-Target Distracters		T1		T1 Contrast Ratios
T1 Bright	Lm = .06cd/m^2		Lm=19.6cd/m^2		Lm=102.3cd/m^2		T1: 1,705:1
	sRGB	R=0	sRGB	R=113	sRGB	R=255	Dist: 326:1
		G=0		G=113		G=255	
		B=0		B=113		B=255	
T1 Equal-Lumin	Lm = .06 cd/m^2		Lm=19.6cd/m^2		Lm=19.6cd/m^2		T1: 326:1
	sRGB	R=0	sRGB	R=113	sRGB	R=113	Dist: 326:1
		G=0		G=113		G=113	
		B=0		B=113		B=113	

Note: Luminance (Lm) was measured in candelas per square meter (cd/m^2). *Red/Green/Blue* values are provided from the standard RGB (sRGB) color gamut used by Microsoft Windows – the operating system used to present stimuli. Numerical representations for R,G, and B represent the proportion of red, green, and blue light contained within a given display of chromaticity. The sRGB gamut produces achromatic displays (i.e., black, white, and gray) by merging equal amount of red, green, and blue light waves. Contrast-Ratio for the T1 and non-target stimulus frames were calculated as follows: {luminance of stimulus / luminance of background}.

Table 9-B

Luminance Values, sRGB, and Contrast-Ratio Calculations Continued

T2 Luminance		T2 Contrast-Ratio
Lm = 19.6 cd/m^2		T2 Frame 326: 1
sRGB	R = 113	Distracter Frame 326: 1
	G = 113	
	B = 113	
Lm = 28.51 cd/m^2		T2 Frame 475: 1
sRGB	R = 127	Distracter Frame 326: 1
	G = 127	
	B = 127	
Lm = 37.33 cd/m^2		T2 Frame 622: 1
sRGB	R = 140	Distracter Frame 326: 1
	G = 140	
	B = 140	
Lm = 46.00 cd/m^2		T2 Frame 766: 1
sRGB	R = 154	Distracter Frame 326: 1
	G = 154	
	B = 154	
Lm = 54.69 cd/m^2		T2 Frame 911: 1
sRGB	R = 168	Distracter Frame 326: 1
	G = 168	
	B = 168	
Lm = 63.60 cd/m^2		T2 Frame 1060: 1
sRGB	R = 182	Distracter Frame 326: 1
	G = 182	
	B = 182	
Lm = 72.41 cd/m^2		T2 Frame 1206: 1
sRGB	R = 196	Distracter Frame 326: 1
	G = 196	
	B = 196	
Lm = 81.40 cd/m^2		T2 Frame 1356: 1
sRGB	R = 209	Distracter Frame 326: 1
	G = 209	
	B = 209	

Note. Shows the eight different intensity of luminosity for which T2 could be presented in Experiment 2. *Red/Green/Blue* values are provided from the standard RGB (sRGB) color gamut used by Microsoft Windows – the operating system used to present stimuli. Numerical representations for R,G, and B represent the proportion of red, green, and blue light contained within a given display of chromaticity. The sRGB gamut produces achromatic displays (i.e., black, white, and gray) by merging equal amount of red, green, and blue light waves. Contrast-Ratio for the T2 and non-target stimulus frames were calculated as follows: {luminance of stimulus / luminance of background}.

Results

Separate 2x8x2 mixed factor ANOVAs were carried out for T1 and T2 performance. Factors included the within subjects factors of T2 Luminance (i.e., the eight levels of T2 luminance) and Condition, as well as the between subjects factor of Order. T2 detection rate – measured by percentage of T2-present trials when T2 was reported as being "present" – was only calculated for T1-correct trials. T2 absent trials were excluded from analysis. All post-hoc tests for T1 and T2 accuracy were carried out using the Tukey's HSD test.

T1 Performance

An overall main effect of Condition was present $F(1, 12) = 61.59$, $MSE = 47.21$, $p < .001$. No main effects of T2 Luminance $F(7, 84) = .23$, $MSE = 48.65$, $p = .97$, or Order $F(1, 12) = .003$, $MSE = 58.69$, $p = .95$, were found. No Interactions were found among variables – this includes the factors of T2 Luminance and Condition $F(7, 84) = .986$, $MSE = 33.77$, $p = .44$. Across all levels of T2 luminance T1 performance was higher for the T1 bright condition than the T1 equal-luminescent Condition. For five out of eight levels of T2 luminance these differences were statistically significant. Therefore, as the main effect of Conditions implies, greater T1 luminance facilitates report of T1 identity (See Figure 12 and Table 10).

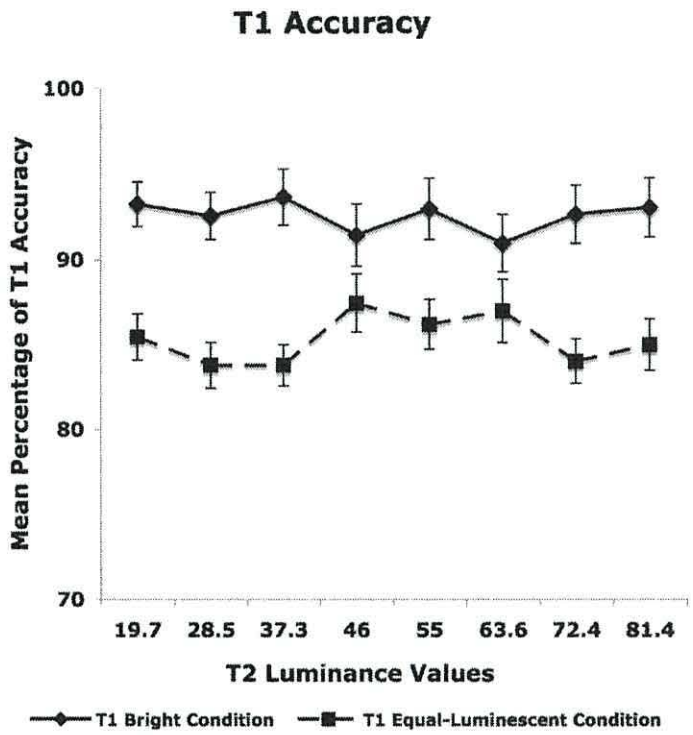

Figure 12. Mean Percentage of T1 correct responses across factors of T2 Luminance and Condition. Error bars represent standard error of the mean. T2 Luminance Values reflect cd/m^2.

Table 10

Averaged T1 Performance

	19.69 cd/m^2	28.51 cd/m^2	37.33 cd/m^2	46.00 cd/m^2	54.97 cd/m^2	63.60 cd/m^2	72.41 cd/m^2	81.40 cd/m^2
T1 Bright	93.25 (4.90) a Ω	92.54 (5.19) a Ω	93.64 (6.17) a Ω	91.42 (6.81) a Ω	92.93 (6.73) a Ω	90.94 (6.28) a Ω	92.61 (6.36) a Ω	93.01 (6.46) a Ω
T1 Equal-Lum	85.47 (5.10) a Δ	83.80 (5.05) a Δ	83.75 (4.52) a Δ	87.44 (6.42) a Ω	86.18 (5.49) a Ω	86.97 (6.87) a Ω	84.03 (4.89) a Δ	84.99 (5.61) a Δ

Note. For each cell the top value represents mean percentage of T1 correct trials across factors of Condition and T2 Luminance – respective standard deviations are included in parenthesis. Means in the same row sharing the designation "a" did not differ at the .05 level. Means in the same column sharing the same designation "Ω" or "Δ" also did not differ at the .05 level.

T2 Performance

Overall main effects of Condition $F(1, 12) = 42.75$, $MSE = 140.48$, $p < .001$, and T2 Luminance $F(7, 84) = 54.07$, $MSE = 41.53$, $p < .001$ were present. No main effect of Order was present $F(1, 12) = 2.69$, $MSE = 135.93$, $p = 12$. An interaction was found between Condition and T2 Luminance $F(7, 84) = 3.01$, $MSE = 180.18$, $p < .01$. No other interactions were present among variables. Although only significantly different for two out of eight luminance levels, a consistent trend of greater T2 detection for the T1 equal-luminance condition was present across all luminance levels – thus leading to the main effect of Condition. The significant differences between conditions at the 19.69 and 28.51 cd/m^2 levels, in conjunction with the significant rise in T2 detection across all eight luminance levels – leading to almost identical T2 performance between conditions for the 72.41 and 81.40 cd/m^2 levels, gave rise to both the main effect of T2 Luminance and the interaction between Condition and T2 Luminance (See Figure 13 and Table 11).

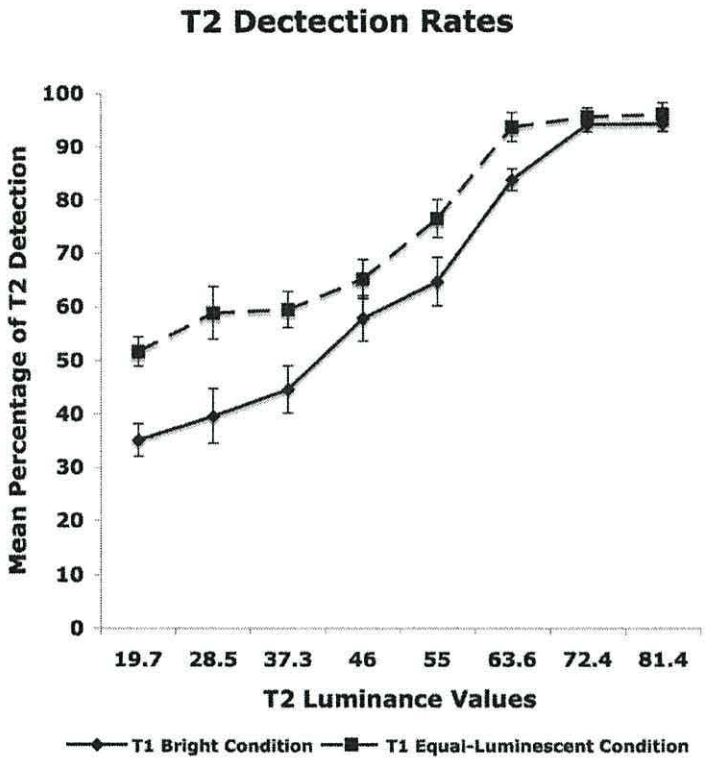

Figure 13. Mean percentage of T2-present trials when T2 was detected (i.e., responded to as "present"). Error bars represent standard error of the mean.

Table 11

Averaged T2 Detection

	19.69 cd/m^2	28.51 cd/m^2	37.33 cd/m^2	46.00 cd/m^2	54.97 cd/m^2	63.60 cd/m^2	72.41 cd/m^2	81.40 cd/m^2
T1 Bright	35.07 (10.33) Ω	39.58 (18.30) Ω	44.54 (12.66) Ω	57.79 (13.57) Ω	64.61 (13.34) Ω	83.72 (10.38) Ω	94.03 (6.29) Ω	94.16 (8.12) Ω
T1 Equal-Lum	51.60 (11.40) Δ	58.80 (18.99) Δ	59.41 (16.44) Ω	65.10 (15.83) Ω	76.40 (16.82) Ω	93.59 (7.50) Ω	95.49 (5.30) Ω	95.96 (5.38) Ω

Note. For each cell the top value represents mean percentage of T2-present trials for which T2 was detected (i.e., responded to as being "present" during the RSVP stream). Standard deviations are included in parenthesis. Significant differences between mean values are only indicated across conditions. Means in the same column sharing the designation "Ω" or "Δ" did not differ at the .05 level.

Discussion

T1 performance was significantly better in the T1-bright condition. This outcome fits well with the logic presented in Experiment 1 that stronger target signals are processed more efficiently. Also in accord with Experiment 1, it was found in Experiment 2 that stronger 'T2 signals' were more likely to produce conscious sensations amidst competitive environmental noise. Unexpected was the outcome that increased T1 task difficulty in the equal-luminescent condition slightly facilitated T2 detection. Although statistically significant differences between conditions only occurred at two of the eight luminance levels, it cannot be ignored that a consistent pattern of increased T2 detection for T1 equal-luminance trials was present at all eight luminance levels - a finding seemingly at odds with previous research demonstrating increased T1 task difficulty exacerbates dual-task interference (e.g., Chun & Potter, 1995; Boucart et al., 1998; Brehaut et al., 1999; Grandison et al., 1997; Seiffert & Di Lollo, 1997).

I propose the results of Experiment 2 may have been confounded by the specific manner in which T1 difficulty was manipulated (i.e., T1 contrast-ratio). For this reason I believe Experiment 2 results are unable to address whether a relationship exists between T1 difficulty, the severity of dual-task interference during the AB, and conscious awareness of T2. Compared to the T1-bright condition, the impact of dual-task interference may have been slightly offset in the T1 equal-luminescent condition by an increased ability to detect differences of luminosity between T2 and surrounding RSVP items. The ability to detect differences in the intensity[20] of two stimuli is known to fluctuate as a function of prior sensory stimulation (Gescheider, 1997). In other words, when presented with

[20] The relationship between prior sensory stimulation and ability to detected differences in stimulus intensity have been shown with various forms of sensory input – e.g., weight, sound, and light (Gescheider, 1997).

the task of detecting differences in the intensity of stimulus (X) and stimulus (Y), our ability to perceive such differences depends upon the intensity (i.e., strength) of sensory input perceived prior to the temporal onset of (X) and (Y). The more intense (i.e., strong) prior stimulation is, the less sensitive our sensory processes are to differences between (X) and (Y). For the conditions of Experiment 2 then, participants may have been less able to detect differences of luminosity between T2 and surrounding distracter items in the T1-bright condition compared to the T1 equal-luminescent condition. Recall that in the T1-bright condition luminance based sensory input prior to T2 was greater than in the T1 equal-luminescent condition[21]. Being more sensitive to differences of luminosity may therefore have underlined the slightly greater rates of T2 detection in the T1 equal-luminescent condition.

This explanation is however tenuous. Previous experiments demonstrating such changes in an observer's ability to detect differences of luminosity use stimulus parameters not comparable to the current Experiment 2. In most cases stimulation preceding (X) and (Y) is viewed by an observer for several seconds to several minutes. The intensity of such stimulation is also often upwards of 10x greater than the luminance values used for T1 in Experiment 2 (Gescheider, 1997). While this does not rule out the potential for such influences in Experiment 2, it does raise questions as to whether T1 luminance was sufficient to induce such effects.

An alternative explanation of Experiment 2 results can be found in the work of Chua (2005). Chua reported that increases in T1 contrast suppressed T2 processing. Chua explained the relationship between T1 contrast and T2 processing by suggesting that attentional disengagement is delayed when contrast is high because target "perceptibility" is prolonged. Delayed attentional disengagement from

[21] In the T1-bright condition the luminance value for T1 was greater than for other RSVP items. In the T1 equal-luminescent condition the luminance value for T1 was equal to other RSVP items.

T1 thus further delaying T2 processing. This explanation also implies that any relationship between T1 task difficulty and consciousness for T2 was likely confounded in Experiment 2 by the manner in which T1 difficulty was manipulated. In other words, the explanation provided by Chua (2005) suggests attention may have been able to disengage from T1 faster in the T1 equal-luminescent condition, thus making attention more assessable at the time T2 was presented.

As a final note, caution must be stressed when applying any interpretation to differences between T1-bright and T1-equal luminescent conditions in Experiment 2. As mentioned, statistically significant differences between conditions were only found for two of the eight levels of T2 luminance. This raises some doubt as to whether processing differences were ever present between the two conditions. More experiments are thus required to properly evaluate the relationship between T1 task difficulty and consciousness for T2. One obvious possibility is to manipulate T1 task difficulty while maintaining a constant level of T1 contrast-ratio across conditions.

General Discussion

As measured by the attentional blink paradigm, graded levels of consciousness are possible under ongoing demands of divided attention. This is the primary conclusion of Experiment 1. The results of Experiment 2 were limited due to potentially confounding influences of the T1 contrast manipulation. For this reason these results will not be incorporated into the following discussion.

Together, the opposing outcomes between Experiment 1 and the work of Sergent and colleagues (2004, 2005) speak to flexibility regarding the fate of T2 processing during AB trials[22] (i.e., when T2 identity is reported incorrectly). As to whether a conscious percept of T2 is obtained during AB trials, a key factor appears to be signal-strength – manipulated in Experiment 1 via contrast-ratio of the T2 stimulus. When the contrast-ratio of T2 is greater than other RSVP items the AB bottleneck is less likely to prevent consciousness. I argue that compared to when T2 contrast is equivalent to non-target distracters, increased levels of T2 contrast allow for stronger competition bias to be established in favor of T2. Increasing T2 contrast makes T2 easily distinguishable from non-target items. In turn, target-defining features associated with T2 are easily detected. As demonstrated by Duncan (1987), establishing competition bias in favor of a target stimulus requires a high degree of perceptual dissimilarity between task-relevant and irrelevant stimuli[23].

Baars (1989) argued that consciousness requires access to a neuronal workspace (i.e., spatial distant regions of the brain responsible for stimulus processing). Importantly, Baar's original conception of a neuronal workspace left the

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[22] Although Sergent and colleagues (2004 and 2005) did not require participants to report T2 identity in their experiments, their interpretation of subjective-visibility ratings and the conclusions they draw, clearly suggests that on traditional AB trials – when participants fail to report T2 identity correctly – no conscious representation of T2 is obtained.

[23] As discussed in Chapter 1 of the current document, Duncan (1987) showed that when a target and non-target stimulus differed only by minor alterations in shape, it was impossible for observers to bias competition on the basis of task-relevance.

question open as to whether consciousness emerges in a graded or all-or-none fashion. In other words, Baars did not reject the notion that the 'quality' of consciousness might gradually improve as more of the workspace is accessed. The concept of a neuronal workspace was only associated with all-or-none consciousness when Dehaene and colleagues (1998) proposed the global neuronal workspace hypothesis. Contrary to the global neuronal workspace hypothesis, Experiment 1 results suggests that under dual-task interference of the AB, consciousness *does not* emerge in an all-or-none fashion once a critical processing threshold has been crossed that allows sudden access to the entire neuronal workspace. If this were true, graded/partial conscious representations of T2 would not have been possible during AB trials. Rather, conscious representations of T2 would only have emerged during No-AB trials. Recall that according to the global neuronal workspace hypothesis, when the entire neuronal workspace is accessed information processing can successfully engage systems involved in operations such as working memory, verbal report, voluntary manipulation, voluntary action, and long-term memorization.

I therefore propose that despite ongoing dual-task interference, the heightened degree of biased competition established for T2 in the intermediate and high contrast conditions allowed more of the neuronal workspace to be accessed by T2 than was possible in either the low contrast condition (Experiment 1), or the experimental conditions used by Sergent and colleagues (2004, 2005). Importantly, despite the strong competitive nature of T2 during intermediate and high contrast conditions, on AB trials the implications of T1 processing nevertheless prevented T2 from accessing the entire workspace. Had the entire neuronal workspace been accessed the resulting conscious percept of T2 would have been of much higher 'quality' – enough so to allow T2 to undergo later stages of processing involved in

operations such as memory consolidation and response selection. This explanation of the results implies that the quality of conscious representations improved as more of the neuronal workspace was accessed – i.e., as more of the neuronal workspace was accessed due to increased levels of T2 contrast, visibility ratings increased.

Notably, the results of Experiment 1 are consistent with the notion put forward by the activation strength hypothesis that stronger levels of signal-strength facilitate conscious awareness (Kanswisher, 2001). Because the current results do not include measures of neurological activation, Experiment 1 cannot speak to the claim that the quality of consciousness is related to 'strength' of neurological activity. However this possibility cannot be ruled out.

Experiment 1 findings may also have implications for the assertion that during AB trials the T2 stimulus is processed to a semantic level. Vogel, Luck, and Shapiro (1998) were the first to demonstrate a N400 component for T2 during AB trials. During AB trials – i.e., when T2 could not be identified correctly – it was found that compared to no-AB trials the N1, P1, and N400 components elicited by T2 were not suppressed. The P3 component for T2 was however nonexistent during AB trials. The key conclusion for these authors was that T2 undergoes a substantial degree of processing despite dual-task demands of the AB. It was left an open question whether the presence of an N400 component indicated that T2 had been consciously perceived on AB trials. It was acknowledged that because their experiment did not measure consciousness directly, it could not be ruled out that a brief conscious representation of T2 emerged that was lost before the time of overt report. However, it was suggested that the complete suppression of a P300 component on AB trials made conscious awareness for T2 unlikely. In support of this idea, these authors cite Hillyard, Squires, Bauer, and Lindsay (1971), who

showed that when observers perform difficult signal detection tasks, a P3 is observed for both hits and false alarms as long as the observer is confident about the response. Hillyard and colleagues interpreted this outcome as indicating that the P3 is more closely related to the observer's ultimate decision that a target has been 'seen' than the actual presence or absence of the target.

I propose that future experiments utilizing methods similar to those in the current Experiment 1 might strengthen the argument that a T2-related N400 component occurs in the absence of consciousness. The strongest possible evidence for such a claim would of course come from a N400 during low-contrast ratio AB trials, accompanied by visibility ratings indicative of an absence of conscious awareness for T2. It is unclear to what degree contrast for the T2 stimulus was different than for other RSVP items[24] in Vogel, Luck, and Shapiro's 1998 study.

Such experiments might also be used to re-examine the claim that on AB trials no clear P300 component is elicited by T2. At present it appears that during AB trials T2 does not undergo late processing stages associated with the P3 component (e.g., memory consolidation – Andreassi, 2005). Recall that Vogel and colleagues (1998) found no P3 component for T2 during AB trials. Perhaps the greater degree of competition bias awarded to T2 during intermediate and high-contrast trials would allow the second target to access enough of the neuronal workspace to produce a P300 even during an AB trial. The work of Hillyard, Squires, Bauer, and Lindsay (1971) suggest a graded conscious representation of T2 would produce a P300, as such experiences carry with them the 'belief' that T2 has

[24] In Vogel, Luck, and Shapiro's 1997 experiments all RSVP items were presented on a grey background. Non-target distracters and T1 were presented as blue stimuli. T2 was a red stimulus. These authors only provide a luminance value for the grey background – 6.7 cd/m^2. Provided for the blue and red stimuli was their coordinates on the 1937 CIE Colour Space – blue (x = .147; y = .067), red (x = .636; y = .344). Even if the red and blue were isoluminant, the difference of chromaticity allowed T2 to 'stand-out' among other RSVP items, thus potentially adding to 'T2 signal-strength'.

been seen. However, because T2 processing is inevitably cut short on AB trials, even if a P300 were found it would most certainly be attenuated in amplitude compared to No-AB trials. This reduction in amplitude would likely relate to the fact that memory consolidation – a key process believed interrupted by the AB – is believed to be associated with the P300.

I propose that when considered in conjunction with the work of Sergent and colleagues (2004, 2005), Experiment 1 results are inconsistent with AB models postulating precise limits on T2 processing imposed by the AB. That the level of awareness for T2 during AB trials can range from "not seen at all" to "seen but unavailable for overt report", suggests that the point in information processing when T2 processing is cut short by dual-task interference can vary[25]. AB models proposing precise limits on T2 processing include the *competition hypothesis* (Shapiro, Raymond, & Arnell, 1994) and the *two-stage model of processing* (Chun & Potter, 1995).

The competition hypothesis postulates that T1, T1+1, T2, and T2+1 items compete with each other during retrieval from a *short-term memory* (*STM*) buffer. Items entering STM are prioritized regarding the order they are to be processed – priority being determined by the order of presentation and how well items match a pre-set target filter. As T1 is the first item to enter STM, the system recognizes it as the highest priority for allocation of processing capacity. Processing of T1 and its subsequent mask is carried out at the expense of T2, which receives a lower priority

[25] Because subjective-visibility responses were divided into four intervals during statistical analysis of Experiment 1, the presentation of data in this chapter does not illustrate the precise frequency for which participants used the rating "0". Rather, Experiment 1 focused on the requirement of bimodality for the distribution of visibility ratings, and the occurrence of AB trials when ratings were given that are indicative of conscious awareness for T2. The work of Sergent and Colleagues however did show a precise frequency of trials rated as "0". The rating "0" is important because it indicates a total absence of awareness for T2. This interpretation of the rating "0" was proposed in Sergent and Colleagues work (2004, 2005) and was incorporated into the instructions given to participants in the current Experiment 1.

rating due to its position in the RSVP stream. T2 is believed to receive too few cognitive resources to effectively compete with other items, and is therefore lost in STM.

The two-stage model proposes differences in capacity limitations for two stages of processing. In a first stage, all stimuli presented are rapidly processed at the level of feature and meaning. A second, capacity limited serial processing stage referred to as a "central processor", completes processing by consolidating stimuli at a level sufficient for report. As the serial nature of the second stage implies, T2 is denied access to the central processor until processing of T1 is complete. It is believed the AB occurs due to the encoded representation of T2 being overwritten by subsequent masking while waiting to enter the central processor (Giesbrecht & Di Lollo, 1998).

When considered within the context of a neuronal workspace (Baars, 1989), the competition hypothesis and two-stage model of processing can be interpreted as suggesting that T2 is able to access a specific amount of the neuronal workspace (Baars, 1989) before processing is terminated. For the competition hypothesis, T2 is able to access as much of the workspace as is required for entry into visual short-term memory. The two-stage model implies T2 can access as much of the workspace as is required for the first stage of processing, which stops short of processes relating to memory consolidation and response selection. Importantly, neither model allows for the type of flexibility required by the explanation of results provided above, which states that when signal-strength of the T2 stimulus is low, dual-task demands terminate T2 processing at an early point before enough of the workspace is accessed to yield a conscious percept, but when signal-strength is high, T2 serves as a stronger competitor for resources and is able to better withstand dual-task demands, thus being processed to a greater degree and accessing more of the neuronal workspace before succumbing

to the AB.

Experiment 1 results, in conjunction with those of Sergent and colleagues (2004, 2005), can be more easily accommodated by models such as the *overinvestment hypothesis* (Olivers and Nieuwenhuis, 2006), the *temporary loss of control model*, (Di Lollo et al., 2005), and the *reactive suppression account* (Olivers, 2007), which make no definitive claims about the ultimate fate of T2 processing. To review, the original version of the overinvestment hypothesis[26] proposes the AB is caused by an overinvestment of attention toward the RSVP stream, which increases the number of non-target distracters that are capable of engaging in competition with T2 for resources. Enhanced competition is said to prevent T2 from reaching "later capacity limited stages of processing", though no definitive claim is made regarding the precise stage at which T2 processing is terminated. The temporary loss of control model proposes that the T1+1 item, due to incompatibility with a target search template, induces a loss of control over monitoring processes. In other words, prior to RSVP onset endogenous top-down mechanisms are set to monitor the stream for certain target defining features. Once T1 occurs and attention is engaged, a following stimulus lacking target-defining features will disrupt monitoring processes. This disruption takes approximately 500 ms to recover from, during which time observers are unable to effectively monitor for additional targets (e.g., T2). The reactive suppression account postulates that the onset of T1 causes a temporary enhancement of attention that reaches its maximum only after the T1+1 item has appeared. Upon determining that task-irrelevant information (i.e., the T1+1 item) is being enhanced, systems of attention respond by strongly suppressing processing of subsequent RSVP items, which includes T2.

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[26] Arend, Johnston, and Shapiro (2006) proposed the AB might be due to an overinvestment in attention toward the T1 stimulus specifically rather than toward the RSVP stream as a whole.

I propose that differences in the amount of processing achieved by a 'strong' vs. a 'weak' T2 stimulus during AB trials can be explained within the context of these models. Such explanations only require that the competitive nature of the T2 stimulus modulate the extent that T2 processing is suppressed during AB trials. For the overinvestment hypothesis, the stronger a competitor T2 is for resources the better it will fair against competing non-target distracters. When T2 is a weak competitor, such as in low contrast-ratio trials, competition from distracter stimuli likely terminates T2 processing very early before enough of the neuronal workspace is accessed to produce a conscious percept. On the other hand, a strongly competitive T2 representation, such as in high contrast-ratio trials, likely withstands competition from distracters for a longer period of time, thus being processed to a greater degree and accessing more of the neuronal workspace before succumbing to the AB. Regarding the temporary loss of control model, the additional 'attention' attracted by a strongly competitive T2 stimulus likely increases the probability that T2 will be detected under conditions when processes responsible for monitoring the RSVP stream are disrupted. Even when T2 is a strong competitor for resources, the disrupted state of monitoring processes may cut short the amount of information encoded from the presentation of T2. As a result, the low quality encoded representation of T2 is likely insufficient for overt report. For the reactive suppression account, the adaptive mechanisms of attention initiated by the T1+1 item are likely to suppress processing of encoded representations of T2 that are weak competitors for resources more than representations of T2 that are strong competitors.

Also important is that increased levels of T2 contrast not only produced graded/partial conscious representations of T2 during AB trials, but also reduced the number of AB trials altogether. In other words, the magnitude of the AB as measured

by accuracy of T2 identity-report was significantly reduced in high and intermediate contrast conditions compared to the low contrast condition. This was most noticeable at lag 3 for which statistically significant differences in accuracy were found between all three contrast conditions. I propose this outcome also speaks to the beneficial influence of increased biased-competition on T2 processing.

It is well understood in the AB literature that the dual-task interference incurred by T1 processing does not always prevent accurate report of T2. Precisely what differences in processing lead to AB vs. No-AB trials is not well understood. Current AB publications, and theoretical models attempting to explain dual-task interference, describe processes that *on average* are more likely to prevent accurate report of T2 during the critical AB interval – approx. 500 ms post T1 onset – than at longer SOAs. Increased levels of biased-competition on behalf of T2, as is suggested to occur when T2 signal-strength is increased, should decrease the likelihood that dual-task demands will ultimately terminate T2 processing before a durable representation is obtained that can be maintained until the time of overt report. Experiment 1 results suggest increased levels of biased-competition on behalf of T2 had just this effect.

Worth noting is that Chua (2005) also demonstrated that increasing T2 contrast facilitates T2 identity-report accuracy. Chua explained his finding not by means of increased biased-competition on behalf of T2 but rather prolonged attentional engagement of T2. Chua proposed that attentional disengagement is delayed when contrast is high because target "perceptibility" is prolonged. Importantly, the notion proposed here that increasing T2 contrast leads to heightened biased-competition and Chua's idea of delayed attentional disengagement are not contradictory. Rather, both ideas not only lead to the same outcome – i.e., facilitation of T2 processing – but also may be linked, as delayed disengagement might be

expected to increase biased-competition on behalf of the T2 stimulus. In light of the fast temporal pace of RSVP presentations, a prolonged period of attentional engagement might have increased the quality of the encoded representation of T2 in Chua's experiment. In turn, a higher quality representation of T2 may have produced stronger signals along neural pathways responsible for encoding the stimulus as task-relevant. Stronger signals along such pathways may therefore have aided in boosting the level of biased-competition established on behalf of T2.

Looking back to Experiment 1, a final concern worth considering is errors when binding the target-defining feature with the to-be-reported target feature. In the low-contract condition these two features were the same – i.e., semantic classification of the T2 item. However, in the intermediate and high contrast conditions these features may have been different from the participants' point of view – i.e., increased luminosity being the target-defining feature while semantic properties being the to-be-reported feature. As demonstrated by Loach, Botella, and Privado (2008), such errors are more common during the rapid sequencing of RSVP presentation. Though the potential for such binding errors cannot be ruled out in Experiment 1, I argue that they were unlikely. Unlike Loach and colleges experiments, in the present Experiment 1 the RSVP item with increased luminosity and semantic meaning was always the same. Furthermore, other RSVP items – excluding T1 for luminosity – had neither.

In conclusion, the existence of graded/partial conscious representations of T2 counter the idea that dual-task interference of the AB is such that access to consciousness is 'closed' to stimuli appearing within approx. 500 ms post T1. Rather, the extent that the AB is capable of denying T2 access to consciousness varies depending upon stimulus properties. This presents a dynamic and flexible picture of

the fate of T2 processing during AB trials. Theoretical models of processing attempting to describe mechanisms underlying the AB must account for this by allowing for flexibility as to the exact point at which T2 processing is terminated. To explain differences in limitations between AB and No-AB trials, it may be necessary to designate an ultimate point in processing that T2 never reaches during AB trials, yet acknowledge that T2 processing may be terminated at multiple earlier stages of processing depending upon factors such as the competitive nature of the T2 stimulus. Examples of a points in processing that T2 likely never reaches during AB trials are stages of memory consolidation and response selection, which are often suggested to be interrupted by the AB (e.g., Chun & Potter, 1995, Jolicoeur & Dell' Acqua, 1998, Marcantoni et al., 2003).

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Chapter Four: Does Failure to Mask T1 Cause Lag-1 Sparing in the Attentional Blink

Chapter 4

Does T1 Masking Modulate Lag-1 Sparing in the Attentional Blink

The human information processing system is limited in its capacity to process multiple units of rapid sequential information. One method for studying this limitation is the *attentional blink* (*AB*). This attentional phenomenon demonstrates that, when instructed to detect or identify two masked targets - commonly presented within a rapid serial visual presentation (RSVP) stream - the *second target* (*T2*) is frequently unable to be reported correctly when presented 200-500 ms post onset of the *first target* (*T1*; Raymond, Shapiro, & Arnell, 1992). At present, three different accounts of the AB have been proposed, though there is overlap among them (cf. Shapiro, Arnell, & Raymond, 1997). Resource-depletion accounts, such as the interference model proposed by Shapiro, Raymond, and Arnell (1994), suggest ongoing processing of T1 leaves insufficient resources available for individuating T2 from other items entering a short-term memory buffer. On the other hand, bottleneck accounts such as Chun and Potter's (1995) two-stage model as well as Jolicoeur and Dell' Acqua's (1998) PRP model, propose T2 is unable to proceed to later stages of processing until an earlier stage is released from processing T1. Both accounts suggest the dual-task bottleneck of the AB occurs at the point of transferring a momentarily active target into a more durable representation. More recently it has been proposed the AB is due to a temporary loss of control over top-down processes related to the monitoring of incoming stimuli to match a target template (Di Lollo, Kawahara, Ghorashi, & Enns et al., 2005).

A particular outcome, known as 'lag-1 sparing' has been the focus of considerable empirical investigation due to its relevance to hypothesised accounts of

the AB. Lag-1 sparing refers to an absence of processing deficit when T2 is presented approximately 100 ms after T1 onset (i.e., the typical lag 1 position; Raymond et al., 1992). Lag-1 sparing was initially explained in terms of the *attentional gate hypothesis* (Shapiro et al., 1994; Chun & Potter, 1995), which postulates that a "gate like" ballistic processing mechanism opens upon presentation of T1 and remains open for 150-200ms. During this brief temporal window, T2 gains access to the same resources used to process T1 by integrating both targets into a single perceptual 'episode'. Since initially proposed, the conception of this integration mechanism has evolved to include additional parameters such as a 'gate filter', which requires T1 and T2 to appear in the same spatial location and have similar task requirements (Visser, Bischof, & Di Lollo, 1999; Juola, Botella, & Palacios, 2004), and recently has been applied to computational accounts of the AB (Bowman & Wyble, 2007). The present report suggests gating accounts of lag-1 sparing neglect to recognize the important role T1 masking plays in the AB. We return to this issue later.

In a recent line of research considering what traditionally have been viewed as opposing theories of lag-1 sparing, Hommel and Akyürek (2005) sought evidence to support either the attentional gate hypothesis as described above, which advocates integration of T1 and T2, or an alternative hypothesis suggesting that, when in the lag 1 position, T2 *competes* with T1 for attentional resources (Potter, Staub, & O'Connor, 2002). As the idea of resource competition implies, the latter hypothesis argues lag-1 sparing is the product of increased T2 processing at the expense of T1. Hommel and Akyürek concluded that integration and competition accounts of lag-1 sparing should not be viewed as opposing interpretations of the same cognitive mechanism; rather both are possible outcomes, either of which can occur depending upon perceptual factors.

Specifically, these authors suggest whether T1 and T2 are integrated into the same episode, or compete for resources while being processed in discrete episodes, depends on their visual "discriminability". On trials where T1 and T2 were equally discriminable, evidence was found for target integration. Although targets were identified with a high degree of accuracy, information regarding the order of target presentation appeared to have been lost. Such confusion of temporal order has previously been reported to accompany lag-1 sparing, and has been attributed to the overlapping processing of targets integrated into a single perceptual episode (Chun & Potter, 1995; Shapiro et al., 1994). This processing 'overlap' has been corroborated neurophysiologically in an AB task by the presence of merged M300 T1/T2 waveforms at the junction of the left temporo-parietal-frontal lobes (TPF; Kessler et al., 2005a).

When T1 and T2 differed in discriminability, on the other hand, Hommel and Akyürek found the more discriminable target was identified with a higher degree of accuracy. On this basis, these authors concluded that greater discriminability was responsible for one target "winning out" in a competition for resources. Perhaps even more importantly than the conditional support for both integration and competition accounts, Hommel and Akyürek's findings, among others, demonstrates that the lag-1 sparing phenomenon can be a 'window' into understanding the consequences of (T1) target processing in the AB paradigm. Given that the observation of lag-1 sparing has been a cornerstone of various theoretical accounts of the AB, a more thorough understanding of the cause of the lag-1 sparing phenomenon is warranted.

The rationale for the present series of experiments begins with two simple observations: First, masking of T1 (as well as T2) is a requirement for producing the AB, though the nature of the T1 mask is flexible (Raymond et al., 1992; Seiffert & Di

Lollo, 1997). Second, in an AB paradigm T2 has the potential to act as the T1 'mask' when it occurs in the lag 1 position. Thus when T2 occurs in the lag 1 position it assumes not only the role of the second target, indexing the occurrence of the AB, but importantly the additional role of T1 'mask'. The present report seeks to unconfound these two roles by examining how the lag-1 sparing phenomenon responds to the presence of a T1 mask prior to the conventional lag 1 position.

Akyürek and Hommel (2005) propose lag-1 sparing depends not on the presence or absence of T1 masking, but on the observer's estimation, aggregated over trials, of the duration of an attentional 'episode' as established by the T1-T2 interval. Importantly, although the authors did investigate the same question as in the present report by presenting a mask (i.e., black letter) between T1 and T2 (i.e., black digits), they did so by inserting the T1 mask in the conventional Lag 1 position (i.e., approximately 100 ms after T1 onset) where T2 normally occurs. This does not allow the role of masking to be investigated when T2 occurs in the canonical lag 1 position as is investigated in the present experiments.

Another attempt to examine the role of T1 masking on lag-1 sparing was accomplished by Nieuwenhuis, Gilzenrat, Holmes, and Cohen (2005). These investigators masked T1 prior to the conventional lag 1 position (as do we) yet still found lag-1 sparing; a result in direct contrast with the present report. However, critical methodological differences between their procedure and our own likely account for the different outcome. Although Nieuwenhuis et al. presented an interruption pattern mask between T1 and the conventional lag 1 position, conventional AB tasks present successive stimuli with an intervening inter-stimulus interval (ISI). Nieuwenhuis and colleagues presented T1, the T1 mask, and T2 (i.e., lag 1) without an intervening ISI (i.e., all three items were presented within 150 ms, each for a duration of 50 ms). With

no perceptual break between stimulus presentations, the extremely close temporal proximity of these three critical items may have caused them to be perceptually "chunked" and thus more easily identified (cf. Kellie & Shapiro, 2004).

Perhaps the most convincing examination of this issue was carried out by McLaughlin, Shore, and Klein (2001). Although these authors' primary goal was to examine the theoretically important issue of the relationship between T1 difficulty and the AB, the paradigm they employed did insert a T1 mask prior to the lag 1 position as does the present series of experiments. T1 difficulty was manipulated by varying reciprocally the ratio of the duration of the target to its mask. The levels of T1 difficulty were Hard (i.e., 15 ms T1 – 15 ms ISI – 75 ms T2), Medium (30 ms T1 – 15 ms ISI – 60 ms T2), and Easy (45 ms T1 – 15 ms ISI – 45 ms T2). T2 and its respective mask were held constant at 45 ms each. The authors concluded that, while the varying levels of T1 difficulty were found not to significantly affect T2 performance, Lag-1 sparing was obliterated in all three difficulty conditions. At first glance it may seem the issue we wish to investigate has been resolved. However, whereas McLaughlin, Shore, and Klein (2001) make an important contribution to the understanding of lag-1 sparing and its relationship to T1 masking, their use of a non-canonical, i.e., skeletal[1] RSVP paradigm leaves important questions unanswered.

Recent research using electrophysiological evidence to compare the canonical full-stream Vs. skeletal paradigms suggests that target stimuli may undergo significantly different processing in each. Using a single-target paradigm, Craston, Wyble, and Bowman (2006) report two such distinct differences between the skeletal and full RSVP paradigms. First, the P300 component occurs with an accelerated onset

1. The skeletal paradigm employs only four items: Two targets, both masked, separated by a varying SOA (cf. Ward, Duncan, and Shapiro, 1996). Targets and their respective masks can occur in different spatial locations (as in Ward et al., 1996) or in the same spatial location.

and latency in the skeletal compared to the full RSVP paradigm. This is interpreted as reflecting the differences with which targets are defined in the two procedures: Targets in the skeletal paradigm are defined simply by their (first item) onset, which bypasses the need to search for a target-defining feature. Second, the amplitude of the N1 and P1 waveforms are significantly reduced in a full compared to a skeletal paradigm. Craston et al. attribute this finding to the difference in the continuity of visual perception, as the full RSVP paradigm presents targets in more temporally regular pattern.

We do note that McLaughlin, Shore, and Klein (2001; Experiment 3) conclude that the skeletal and full RSVP streams are significantly correlated, which is interpreted by McLaughlin et al. to suggest that the two methods reflect similar underlying mechanisms. Nevertheless, as McLaughlin and colleagues did not assess the skeletal vs. full RSVP paradigm in specific relation to lag-1 sparing, we believe it is important to study the role of the mask in the conventional AB paradigm as we do in the present two experiments. The different pattern of results we found in contrast to McLaughlin et al. further underscores the importance of the present report.

Experiment 1

Methods

Participants

Twenty undergraduate psychology students (8 males; 12 females) from the University of Wales, Bangor with a mean age of 22 volunteered to participate. All participants reported normal or corrected-to-normal visual acuity and signed a consent form before completing the experiment.

Apparatus

Stimuli were presented on a 1024 by 768 pixel, 32-bit colour quality, 17-inch cathode ray tube (CRT) monitor using E-prime version 1.1 experimental software (Psychology Software Tools, Inc., Pittsburgh, PA). All stimuli were presented in intervals of the 17ms refresh rate of the monitor.

Stimuli

A RSVP stream of 25 letters was presented in the center of a grey screen at a rate of 10 – 11 items per second (i.e., 17 ms 'on'; 85 ms 'off'). During the 85ms ISI only the grey background was present. All but two of the items in the stream (T1 and T2) were black. All stimuli were presented in New Times Roman 18-point bold font. T1 and T2 were distinguished as white letters; T1 always preceded T2. Non-target distracter items were drawn randomly from a subset of the alphabet excluding B, G, S, X, K, and Y. The letters B, G, and S were randomly presented as T1 items; X, K, and Y were randomly presented as T2 items. T1 presentation occurred randomly during the RSVP stream varying between the sixth and twelfth items. The lag-position of T2 onset also varied randomly appearing amongst lag-positions 1, 2, 3, 6, and 7. The numerical representation of lag-position represents the varying SOA between targets of 102 ms (lag 1) to 714 ms (lag 7). Note that temporal references to 'lag-positions' do not include the T1 mask inserted prior to 102 ms post T1 onset. This was done to prevent confusion between the event of T1 masking and the theoretically significant lag 1 position (See Figure 1).

Procedure and Design

Two experimental and one control condition, completed in separate trial blocks, were tested in a within-subjects design. In both experimental conditions, on every trial T1 was always masked prior to the conventional lag 1 position (i.e., before 102 ms post T1 onset). The two experimental conditions differed in that the SOA of the T1 mask was either 34 ms or 68 ms after T1 onset (see Figure 1). In the lag-1 sparing control, i.e., 'typical' AB condition, no T1 mask appeared prior to the lag 1 stimulus presentation. All conditions were dual-task requiring participants to identify both T1 and T2 at the end of each trial. The order of conditions was counterbalanced across all participants.

With one exception, the number of trials was held constant across conditions (30 trials per lag-position). In the 34 ms SOA experimental T1 mask condition 40 trials were given per lag-position. This alteration to the number of trials was implemented on the basis of pilot data which, in accord with previous research (Brehaut, Enns, & Di Lollo, 1999), indicated the short interval between T1 and its mask (i.e., 34 ms SOA) resulted in a reduction of T1 accuracy. The addition of 10 extra trials per lag-position allowed for scoring of all conditions to be based on a sufficient number of trials (15) for which T1 was identified correctly. Figure 1 illustrates the temporal format of stimulus presentation for experimental and control conditions. To begin each trial participants pressed the keyboard spacebar. Prior to the first item of the RSVP stream a black fixation cross appeared for 500 ms, followed by a 500 ms blank interval. Participants were prompted for a three alternative forced choice response to the identity of T1 and T2 at the end of each trial. It should also be noted that the instructions participants were given clearly

stated that T1 presentation would always precede that of T2. Furthermore, participants were also prompted for their T1 response first.

Operationally Defining Lag-1 Sparing

The distinction between the presence and absence of lag-1 sparing was first delineated by Visser, Bischof, & Di Lollo (1999), who proposed that to eliminate lag-1 sparing, second target performance at lag 1 must not exceed the lowest point of the AB by more than 5%. In other words, the typical U-shape function must become more linear than quadratic with lag 1 performance being within 5% of lag 3, which is typically the deepest point of the blink occurring at approximately 300 msec post T1.

Although the Visser et al. (1999) definition is useful in so far as it establishes a highly conservative criterion for lag-1 sparing, we propose to relax this criterion for the present experiments as it prevents us from examining theoretically important differences arising from our experimental manipulations. Therefore, rather than attempt classify lag-1 sparing as present or absent by such a stringent criterion, instead we focus on the degree of attenuation at lag 1 between masked vs. unmasked T1 conditions, as well evaluate the difference between lag 1 performance and a T2 'baseline' as established by T2 performance at lag 7 where the SOA between targets is sufficient to enable an estimate of T2 unaffected by T1.

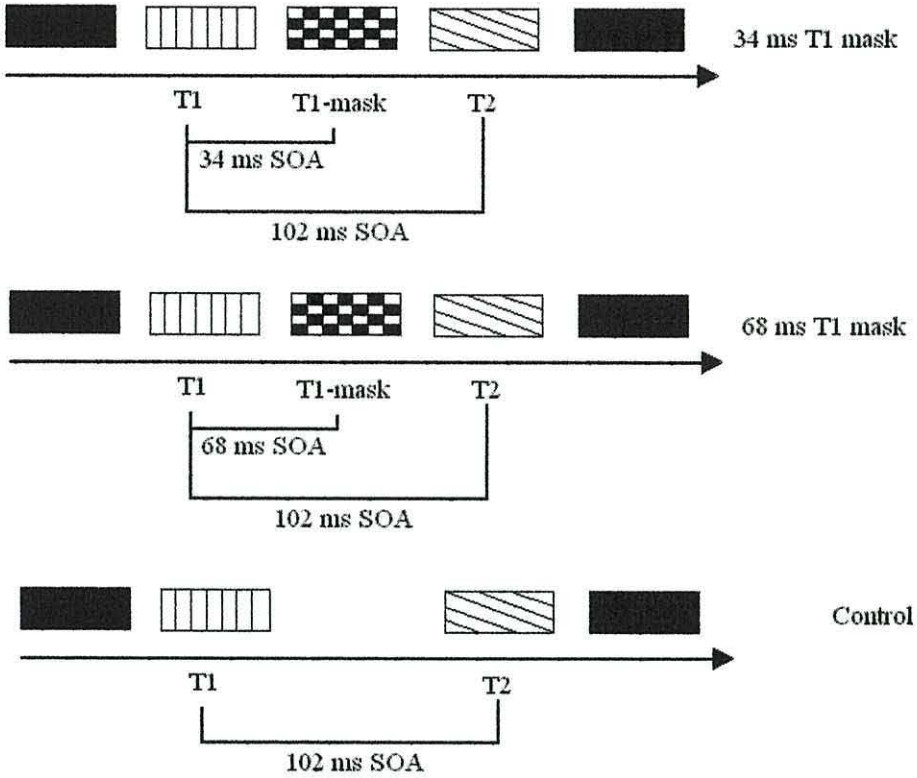

Figure 1: The top two panels show the 34ms and 68 ms experimental conditions, respectively, indicating when the new T1 mask was inserted. The bottom panel represents the canonical (control) AB task.

Data Analysis

Performance was indexed by the percentage of correct T2 detections on trials when T1 was identified correctly. As common to AB experiments, this procedure was adopted on the grounds that when the first target is identified incorrectly, the source of error for any incorrect T2 responses cannot be accounted for. For the dependent measures of T1 and T2 (conditional, i.e., T2 given T1 correct), separate 3 x 5 x 4 three-way mixed analysis of variance (ANOVAs) were conducted with the within-subject factors of condition (i.e., 34ms T1 mask, 68ms T1 mask, and lag-1 sparing control) and lag (i.e., 102 ms, 204 ms, 306 ms, 612 ms, and 714 ms), along with the between-subjects factor of order [2] (i.e., the order in which participants

2. In Experiment 1, although the three conditions could have been completed in six possible orders, only four such orders were implemented during data collection and subsequent analyses.

completed the three conditions). The third variable, order, was analysed for possible interactions with other variables not only to determine if there were order effects, *per se*, but also to determine if strategic factors may have affected T2 accuracy as previously suggested by Akyürek and Hommel (2005). For all statistical tests the criterion for significance was set at an alpha level of .05. To examine the pattern of reported main effects, pair wise comparisons were calculated using the Bonferroni correction for multiple comparisons.

Results

T1 Performance

Analysis revealed a significant omnibus effect for condition $F(2, 32) = 29.470$, $MSE = 1.161$, $p < .001$. Both the overall effects of lag $F(4, 64) = .079$, $MSE = 8.838$, $p = .988$, and order $F(3,16) = .332$, $MSE = 1.336$, $p = .802$ were non-significant. There were no interactions among variables at the .05 level of significance. Pair wise comparisons revealed the significant main effect of Condition on T1 performance to be as follows: 68ms T1 mask, ($M = 81.72\%$, $SD = 11$); 34ms T1 mask, ($M = 73.3\%$, $SD = 18.01$); and lag-1 sparing control, ($M = 95.19\%$, $SD = 7.20$). Figure 2 shows the mean percentages of correct T1 responses as a function of lag for each condition. It is no surprise that all three conditions were found to differ significantly in this respect, due to the effect of increased masking interference resulting from the close temporal proximity of T1 and its respective mask in the experimental conditions (Brehaut et al., 1999). As no interaction occurred between lag and condition, we find no evidence of competition between targets with T2 in the lag 1 position as suggested by Potter, Staub, and O'Connor (2002). According to

these authors such competition would be manifest as a reduction in T1 performance as the temporal interval between T1 and its mask decreased.

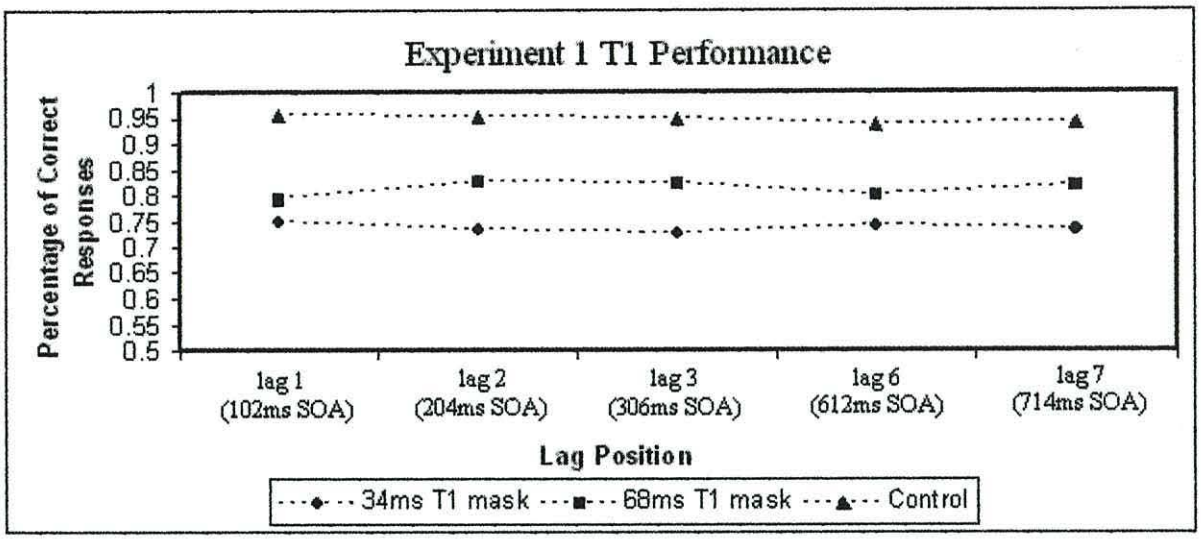

Figure 2: Mean percent correct T1 responses for all T2 lag-positions for each of the three conditions of Experiment 1. Standard Error bars are not shown in Figure 2 due to the low range of values between .009 and .028.

T2 Performance

Analysis revealed no significant omnibus effect of condition $F(2, 32) = .601$, $MSE = 1.486$, $p = .554$, although a significant effect of lag was present $F(4, 64) = 63.190$, $MSE = 1.447$, $p < .001$. Importantly, a significant interaction between lag and condition was found $F(8, 128) = 6.16$, $MSE = 8.23$, $p < .001$. No significant effect of order was present $F(3, 16) = 1.984$, $MSE = .130$, $p = .157$. As neither condition nor lag interacted significantly with the variable of order, we conclude our experimental design did not facilitate the adoption of any particular response strategy. A detailed treatment of this issue is presented in the discussion of Experiment 1. Figure 3 and Table 1 show the mean percentages of correct T2 responses as a function of nominal lag for each condition.

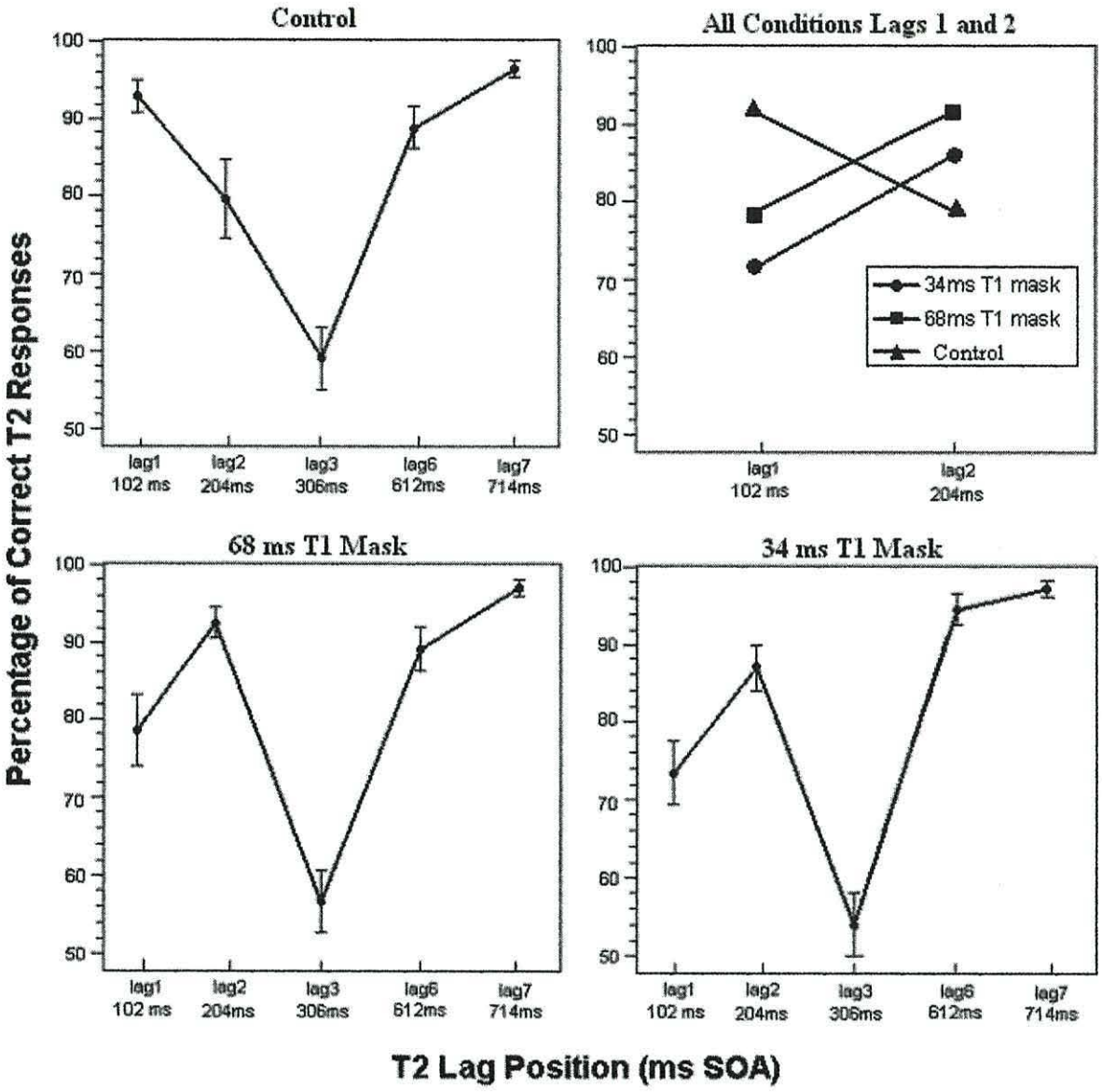

Figure 3: Mean percent correct T2 responses (contingent on correct T1 responses) for all lag-positions for each of the three conditions in Experiment 1. Error bars represent standard error of the mean. The upper right panel shows an overlap of performance across all conditions at lag positions 1 and 2.

Table 1

Mean Percentages of Correct T2 Responses (Experiment 1)

Condition	Lag 1 102ms SOA	Lag 2 204ms SOA	Lag 3 306ms SOA	Lag 6 612ms SOA	Lag 7 714ms SOA
Lag-1 Sparing Control	94.05 (6.52)	79.80 (12.38)	59.10 (15.71)	88.42 (15.30)	96.35 (6.46)
34 ms T1 Mask	73.80 (13.25)	86.75 (13.11)	53.60 (21.39)	94.80 (8.24)	96.75 (4.75)
68 ms T1 Mask	78.05 (12.42)	92.15 (7.59)	56.75 (18.30)	89.35 (15.47)	97.25 (5.05)

Note: The standard deviation of each mean value is listed in parenthesis.

Lag-1 Sparing

That lag-1 sparing occurred in our control condition was confirmed, as T2 performance at lag 1 did not differ significantly from lag 7. Lag-1 sparing can also be classified as having occurred according to the conservative criteria set by Visser et al. (1999), i.e., lag 1 performance was more than 5% larger than the lowest point of the AB. Examination of the interaction between lag and condition revealed lag 1 performance to be significantly attenuated in the 34 ms and 68 ms T1 masking conditions compared to the control condition. The 34 ms and 68 ms masking conditions did not differ significantly from each other at lag 1 but both conditions exhibited significantly worse performance than that shown at lag 7.

Lag-2 Sparing

Although not statistically significant, an unexpected boost in performance at lag 2 occurred in both the 34 ms and 68 ms T1 mask conditions relative to the control condition (See Figure 3 and Table 1). Within each experimental condition

performance at lag 2 was not significantly different than lag 7. Performance at lag 2 also did not differ between the two experimental masking conditions.

Discussion

The results of Experiment 1 suggest in a canonical AB paradigm masking T1 with a non-target prior to the lag 1 position significantly attenuates lag-1 sparing. This finding supports the original notion of Raymond et al. (1992) that adequate masking of T1 is required to cause an attentional blink. Importantly, our results suggest that processing of T1, by itself, in the canonical AB paradigm does not cause a time-dependent lapse of attention, as would be concluded on the basis of reports by Akyürek and Hommel's (2005) and Nieuwenhuis et al. (2005). Instead, it suggests that the cause of the AB is event-dependent, that event being the occurrence of at least a non-target (mask) uninterruptedly following T1.

As previously indicated, the lack of any interaction effects pertaining to the order participants completed conditions allows us to discount an alternative account proposed by Akyürek and Hommel (2005). According to these authors, participants keep the target integration window open for variable intervals of time depending on the temporal rate at which stimuli are presented. Such a strategy, if present in Experiment 1, would undermine our conclusions regarding the theoretical basis of lag-1 sparing. Such an order effect might have reflected a shortened integration window being adopted each time a respective mask was shifted closer to T1 offset. It should be noted however that certain parameters used by Akyürek and Hommel, e.g., long-duration T1 targets, may have inadvertently contributed to the use of such strategies in their experiments.

Although we maintain such an integration strategy did not take place in our own experiment, recent work by Akyürek et al. (2007) reports electrophysiological evidence further supporting the assertion that participants are strategically able to leave integration windows open for variable lengths of time. In their experiment a "slow" and "fast" RSVP stream was presented to participants. In the fast condition stimulus durations were held constant at 30 ms with ISI of 70 ms. The slow condition presented stimuli at durations of 70 ms with ISI of 30 ms. These authors interpret the presence of distinct ERP modulations isolated to the fast condition as reflecting the creation of a separate "event" for T2 not required in the slow condition – the integration window was maintained long enough to incorporate T2 in the slow, but not the fast condition. Assuming this interpretation of the electrophysiological data is correct, this would, as the authors suggest, imply that global task expectations can guide attention. Whereas Akyürek and colleagues demonstrate such a strategy can take place in certain circumstance, we maintain this strategy was not adopted in our experiment.

In regard to the unexpected occurrence of lag-2 sparing, we attribute this outcome to a potential 'capture of attention' resulting from a perceived increase in rate of stimulus presentation (i.e., a short transient event). Put another way, the inclusion of the new T1 mask altered the intervening ISI between stimuli for a brief three-item portion of the stream relative to the regularity occurring from RSVP stream onset. The otherwise 85 ms ISI became 17 ms between T1 and the 34 ms mask, and 54 ms between T1 and the 68 ms mask. Furthermore, the ISI between the 34 ms mask and the lag 1 item was 51 ms, while the same ISI for the 68 ms mask was 17 ms.

A review of the literature reveals considerable debate as to whether abrupt stimulus onsets alone are sufficient to guarantee attentional capture (Jonides & Yantis, 1988; Yantis & Jonides, 1984; 1990) or whether, instead of specific stimulus properties, the critical factor is the observer's attentional control setting (ACS) as calibrated by task demands (Folk, Remington, & Johnston, 1992, 1993; Folk & Remington, 1998). Specifically, Folk and colleagues propose that attentional capture depends on whether the features of the capturing stimulus are included in the ACS. If stimulus features are not task-relevant (i.e., not part of the ACS), then they will not capture attention.

In our view, the specific point in time at which an observer begins to evaluate each stream item is no doubt related to the temporal regularity of the RSVP stream itself. As this applies to targets and non-target alike, the expected temporal rhythm (i.e., regularity of stimulus onsets) is likely included in the ACS. Although it is not the goal of the present work to systematically evaluate the relationship between exogenous and endogenous determinants of engaging attention, we believe attentional capture a likely mechanism underlying our unanticipated finding of lag-2 sparing.

Experiment 2

The results of Experiment 1 suggest that the lag-1 sparing phenomenon is not a ballistic process set in motion by the occurrence of T1 alone and is significantly attenuated when a non-target stimulus occurs between the T1 and the (T2) stimulus normally appearing in the lag 1 position of the canonical AB paradigm. The question that remains to be addressed, however, is the requirement of this intervening stimulus to produce this outcome. Given that lag-1 sparing is typically revealed by a

second target (T2) appearing in the lag 1 position, in Experiment 2 we investigated whether the occurrence of T2 in the same temporal position as the T1 mask in the previous experiment would similarly attenuate lag-1 sparing. Moreover, this design enables us to investigate the outcome of changing the temporal regularity of the stream, as was effected in Experiment 1 by the introduction of the new mask and which revealed lag-2 sparing. Finally, Experiment 2 was designed to enable a replication of the main outcome of Experiment 1.

Methods

With the exception of a new sample of participants (n = 15), and the addition of 30 trials during which T2 was presented 34 ms post T1 onset (See Figure 4), all methods were the same as in the 34 ms condition of Experiment 1. Specifically, T2 could occur 34 ms following T1 or in any one of the canonical lag positions 1 to 7. When T2 occurred in the canonical lag positions, a non-target (mask) was presented 34 ms following T1 as in Experiment 1.

Data Analysis

T1 and T2 performance were analysed separately with a one-way ANOVA for the within-subjects factor of lag-position. As in experiment 1 pair wise comparisons were carried out with the Bonferroni correction with .05 set as the criteria for significance.

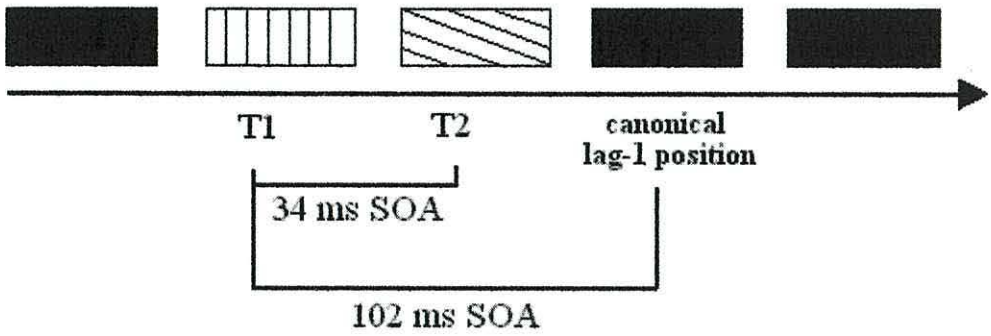

Figure 4: Temporal parameters for the 30 experimental trials presenting T2 at 34ms post T1 onset.

Results

T1 Performance

No significant effect for the within-subjects factor of lag-position was found $F(5, 70) = 1.041$, $MSE = 4.55$, $p = .401$. A summary of T1 and T2 performance by lag-position can be viewed in Table 2.

T2 Performance

One-way ANOVA analysis revealed a significant effect of the within-subjects factor of lag-position for T2 performance $F(5, 70) = 18.519$, $MSE = 3.53$, $p < .001$. Pair wise comparisons revealed T2 performance was not impaired (i.e., it was 'spared') when presented 34 ms after T1 onset, as T2 performance on these trials was not significantly different than for trials at lag 7. Replicating the results of Experiment 1, T2 performance at the canonical lag 1 position was attenuated as significant differences emerged when compared with lag 7 as well as T2 performance at 34 ms SOA.

Discussion

In Experiment 1 masking T1 with a non-target during the ~100 ms T1-T2 interval attenuated the lag-1 sparing effect. In Experiment 2 this finding was replicated (see canonical lag 1 position Figure 5 and Table 2). However, lag-1 sparing remained when T2 was presented 34 ms post T1-onset, placing it in the same temporal position as a non-target occurred in Experiment 1. Experiment 2 thus further supports our assertion that the insertion of a non-target T1 mask prior to the canonical lag 1 position, and not the resulting alteration in temporal parameters, is responsible for the attenuation of lag-1 sparing revealed in Experiment 1. Finally, despite the exceptionally close temporal proximity between targets, no competition trade-offs between T1 and T2 were observed; T1 performance with T2 at 34ms post T1 onset was not significantly lower at the .05 level than with T2 presented at later lags (See Table 2). We return to this issue in the General Discussion.

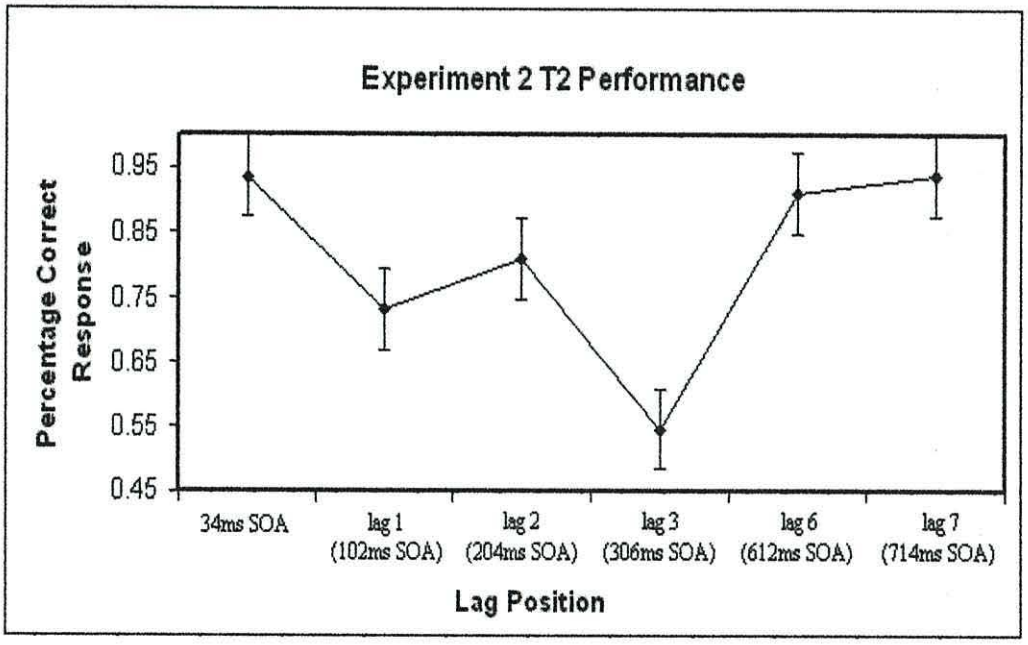

Figure 5: Mean percent correct T2 responses (contingent on correct T1 responses) for all temporal positions of T2 in Experiment 2. Error bars represent standard error of the mean.

Table 2

Mean Percentages of Correct T1 and T2 Responses (Experiment 2)

T1 Performance

34ms Post T1 SOA	Lag 1 102ms SOA	Lag 2 204ms SOA	Lag 3 306ms SOA	Lag 6 612ms SOA	Lag 7 714ms
95.13 (4.59)b	96.87 (4.37)b	97.40 (5.00)b	93.00(6.64)b	97.20 (8.13)b	94.67 (8.29)b

T2 Performance

34ms Post T1 SOA	Lag 1 102ms SOA	Lag 2 204ms SOA	Lag 3 306ms SOA	Lag 6 612ms SOA	Lag 7 714ms
93.70 (5.93)a	73.00 (7.53)b	80.08 (9.28)b	54.54(15.42)c	91.04 (25.5)a	93.82 (6.69)a

Note. The standard deviation of each mean value is listed in parenthesis. Means in the same row that do not share the same designation "a", "b", or "c" differ at $p < .05$ with the applied Bonferroni correction for multiple comparisons.

General Discussion

Experiments 1 and 2 suggest lag-1 sparing does not result solely from the close temporal proximity of targets *per se* in the AB paradigm, but rather is to a great extent due to the absence of T1 masking. We are the first to definitively demonstrate the importance of T1 masking for lag-1 sparing while maintaining the canonical AB paradigm and parameters, notably the temporal position of the lag 1 item in a full RSVP stream. Although similar results were reported by McLaughlin, Shore, and Klein (2001) using a skeletal RSVP stream, the considerable interest in the literature on the lag-1 sparing phenomenon necessitates a full evaluation of the phenomenon. As emphasised in our introduction, Craston, Wyble, and Bowman (2006) suggest the clear differences in detection and ensuing processing of targets in the skeletal Vs.

full RSVP stream procedures underscores the need for a full evaluation of the lag-1 sparing phenomenon.

We now know that despite these differences, T1 masking plays a important role in lag-1 sparing for both skeletal and full RSVP AB paradigms. As to why masking T1 did not cause lag 1 performance to fall within 5% of the lowest point of the AB – as was the case in McLaughlin, Shore, and Klein's (2001) skeletal experiment – the most likely answer lies in the fundamental difference between the two methods. In a skeletal RSVP stream, the first item to appear is T1. As reported by Craston, Wyble, and Bowman (2006), the P300 component for a single target in a single-target AB paradigm occurs with accelerated onset and latency for skeletal relative to full RSVP method. Thus we argue that the appropriation of attention triggered at T1 onset was greater in McLaughlin, Shore, and Klein's experiment compared to our own.

We cannot fully evaluate whether integration or competition is operating at lag 1 in our experiment as participants' foreknowledge of target order, along with restrictions placed on T1 Vs. T2 responses, prevented us from observing order reversals. Rather than a weakness, however, we believe this approach provides an opportunity to obtain a 'pure' measure of lag 1 performance unconfounded by T2 report errors resulting from order reversals. We do note, however, that although our approach prevented *report* of order reversals, it does not prevent the perception of order reversals. For most experiments investigating the lag-1 sparing phenomenon it is impossible to tell what proportion of T2 errors reflect target order reversals or the attentional blink, *per se*. Assuming as most research has that lag-1 sparing is always the product of either integration or competition, our results support integration. To

reiterate, in neither experiment did T1 analysis reveal evidence of competition trade-offs between targets as proposed by Potter, Staub, and O'Conner (2002).

Turning to the issue of lag-2 sparing, we propose this to be simply a by-product of an unexpected ISI value resulting from our T1 masking manipulation. This mid-stream alteration of presentation rate likely induces attentional capture (see Experiment 1 discussion), which is capable of temporarily overriding the AB bottleneck. Within the framework of traditional AB models with their emphasis on resource limitations (e.g., Chun and Potter, 1995; Shapiro et al., 1994) such a 'capture' of attention could easily be said to summon additional attentional resources for target processing. For example, such resources could prevent the representation of T2 from decaying before it gains access to the second stage of Chun and Potters 1995 two-stage model.

The present results are congruent with the conclusion drawn from the first AB study (Raymond et al., 1992) that masking is required to yield an AB. Importantly, along with McLaughlin et al. (2001), we are able to conclude that Lag-1 sparing is at least in part an epiphenomenon of the failure to adequately mask T1. We consider our work to be congruent with Di Lollo et al. (2005) in regard to distinctly different responses that arise to a 'non-target-' vs. a 'target-' mask in the T1+1 position. Di Lollo and colleagues argue the AB occurs as a result of a temporary loss of control over endogenous search processes. Specifically, when the T1+1 item fails to match an endogenously set target template, processes involving search become disrupted, resulting in a reduced ability to process subsequent targets. As the non-target T1 mask we inserted in our Experiment 1 would have failed to match any endogenously set target template for T1, our findings are congruent with Di Lollo's account.

As reference to the temporary loss of control model has become common in the AB literature, it is important to point out that the theory is not incongruent with more traditional AB models. Such models, e.g., Chun and Potter, 1995; Shapiro et al., 1994, argue that sufficient perceptual aspects of the second target are recognised to determine whether it is a target or a non-target but that resource limitations prevent access to conscious awareness. The notion of 'temporary loss of control' is arguably another way of describing the process by which information not matching a (T1) target template strains limited resources.

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Chapter Five: Attentional Capture and the Attentional Blink: A Dissociation of Spatial and Temporal Discontinuity

Chapter Five

Attentional Capture and the Attentional Blink: A Dissociation of Spatial and Temporal Discontinuity

Introduction

William James (1890) noted long ago that it is human nature for many events to capture our attention, including "strange things, moving things, wild animals, bright things, pretty things, metallic things, words, [and] blood." James carefully delineated the multiple roles that such attention-demanding events play in altering our mental processes (James, 1890). For instance, he noted that if an event captures attention, the mind becomes more prepared, in a very general way, to process information than it was prior to the occurrence of capture. Modern cognitive scientists refer to this as the *alerting* function of an attentional cue (Fitch, Kiefer, Hankey, & Kleiner, 2007; Ross & Ross, 1977; Sharot & Phelps, 2004)

James (1890) also discussed what happens when attention is captured *during* an ongoing task, in particular, a task that depends on a good match (or fit) between the internally generated expectations and the perceptual features of the task events. If the capturing event focuses attention on information that matches the internal expectations (i.e., task-relevant features), then attentional capture *benefits* performance. If however, the capturing event alters the match between the internal expectations and the target features - a performance *cost* will ensue. The present study reports three experiments that explore this interaction between attentional capture and task performance in the context of the attentional blink, a task in which participants attempt to identify two targets in a rapid sequence of items (Shapiro, Arnell & Raymond, 1997).

Many modern studies examining attentional capture during an ongoing task have used visual search, a task in which attention is distributed widely over space in order to detect features that can help to locate and identify a target item. The results show that if a capturing event appears in the field of view during the presentation of a search array, search time is dependent on whether this new event is the target. If it is the target, search is very rapid and accurate. This suggests that capture immediately focuses attention on the target when it appears and the ensuing alerting benefits processing. On the other hand, if the new event is not the target, then search is slow and effortful. Such increases in search time are taken as evidence that the alerting function of capture was not able to benefit processing - likely because attention is slow to disengage from the capturing event (Jonides & Yantis, 1988; Lamy, 2005; Lamy & Egeth, 2003; Theeuwes, 1992).

In contrast to the many studies to date of attentional capture in the context of tasks in which attention must be distributed over *space*, relatively few investigations have examined tasks in which attention must be allocated across *time*. Of course, spatial search itself takes some time, but it is notable that the time course of search over space seems to be an order-of-magnitude faster than the time course of attention from one item to the next when items appear successively in the same region of space. That is, each additional potential target item in a spatial search increases search time on the order of 5 to 50 milliseconds, even when the search is quite difficult because the target is defined by a conjunction of features. In contrast, detecting the first of two targets in a rapid serial visual presentation (RSVP) of items can occupy attention for as long as 500 ms (Duncan et al., 1994). This fact alone suggests that the interaction between task

demands and attentional capture may operate differently in tasks that are primarily temporal vs. spatial in their demands on attention. The present report focuses on the nature of this interaction in the temporal domain.

Prior to describing the present experiments, we will first give a brief overview of the attentional blink (AB) task and its main result. In a typical AB experiment, visual items are presented serially, in the same location, at a rate of 10 items per second. Embedded in this temporal stream are two target items that have been defined for the observer in advance. The observer's task is to detect and/or identify these target items. The common finding – indeed, the one after which the task has been named – is that following the successful detection or identification of the first target (T1) there is a period of approximately 500 ms during which the second target (T2) cannot be reported accurately. Various theories have been offered to account for this outcome (cf. Shapiro, 1997), but most attribute reduced T2 accuracy to a late processing bottleneck caused by the processing of T1.

As is true for the visual search task, capture during the attentional blink task has the potential to either benefit or impede target processing. Moreover, just as in visual search, the outcome seems contingent on whether the capturing event focuses attention on information needed to complete an ongoing task or diverts attention away from it. For example, Shapiro, Caldwell, and Sorensen (1997) reported a beneficial effect of capture in a visual version of the classic auditory cocktail party effect: When T2 was the observer's own name, rather than someone else's name, the AB was significantly reduced, suggesting that personally relevant information added a 'capturing' component to T2. Because the capturing event was also the information needed to complete the

task (i.e., the second target), processing of T2 was enhanced relative to when no capturing event (someone else's name) was presented.

Other experiments have revealed the opposite outcome – a cost – when the capturing event directs attention *away* from task-critical information. To illustrate this outcome a single-target variant of the AB is typically used with both a capturing stimulus and to-be-identified target presented within an RSVP stream (Arnell, Killman, & Fijavz, 2007; Egeth et al., 2001; Jolicoeur, Sessa, Dell'Acqua, & Robitaille, 2006; Spalek, Falcon, Di Lollo, 2006). In one such example, Maki and Mebane (2006) presented a target word at varying lag intervals following a to-be-ignored-stimulus. Both the target and to-be-ignored stimuli were presented within an RSVP stream of false-font distracters. Recall of the target word was significantly suppressed only when the to-be-ignored stimulus contained letters – as opposed to false fonts or digits. There are two important conclusions that can be drawn. First, exogenous mechanisms can override instructions to ignore stimuli that contain target-defining features – letters in this case. Second, as also demonstrated by visual search experiments; attentional capture by a task-irrelevant stimulus will delay attention from being directed toward targets occurring later in the stream.

Even more relevant to the approach used in the present experiments, the deleterious effect on target processing caused by task-irrelevant capture has been demonstrated in a conventional two-target AB task. Wee and Chua (2004) presented a square frame around a distracter item occurring between T1 and T2. In accord with the findings from single-target experiments described above, these authors concluded that attention was unable to disengage from the square frame in time to process T2.

Finally, Martin and Shapiro (2008) recently raised the possibility that a capturing event could perform a general alerting function, in the context of an AB task, without diverting attention away from the task at hand. These investigators were studying one the phenomenon of lag-1 sparing in the AB (Visser, Bischof, & Di Lollo, 1999), when they serendipitously discovered that inserting an additional distracter item into the temporal gap that normally occurs between T1 and the subsequent item had a significant influence on the AB. Specifically, adding the item resulted in an 18% increase in T2 accuracy when T2 appeared in the second possible lag position following T1 (i.e., a lag of 204 ms). Martin and Shapiro (2008) speculated that the addition of this item to the otherwise temporally regular stream had a general alerting effect simply because it was an abrupt deviation from an expected temporal pattern or rhythm.

Scope of the Present Study

To summarise to this point, the extant literature on attentional capture paints a picture of a mutual interaction between capture and task performance. Capture occurring during an ongoing task can either benefit or impede performance, depending on task demands. If a capturing event directs attention toward task-critical items the alerting functions of capture benefits processing. If a capturing event directs attention away from task-critical items – toward non-target items - then attention will be slow to disengage from the capturing event. Moreover, it is even possible that capture may benefit performance when attention is directed neither toward nor away from task-critical items, instead causing a general increases in readiness and preparedness to process (Martin & Shapiro, 2008).

The present experiments explore the possibility of opposing outcomes of attentional capture in the context of the AB task. To this end we compared the influence of sudden disruptions in the stream by either a *spatially-* or *temporally-defined* discontinuity in a typical AB task, namely one in which two spatially defined targets (letter shapes) must be selected and identified among a stream of non-targets (other letter shapes). Because the observer engages in a *spatial* identification task, we hypothesized that *spatial discontinuity* in the temporal stream (i.e., a sudden variation in the size of letter distracters) would both *capture* and *divert* the observer's attention toward the capturing items (the different-sized distractor letters). In contrast, we hypothesized that merely creating a *temporal discontinuity* in the stream (i.e., a sudden variation in the temporal pattern) would serve to *capture* the observer's attention, but would not *divert* attention away from their primary task of letter identification, simply because the temporal discontinuity in itself provided the participant with no alternative spatial pattern to attend. Without attention being diverted from the spatially-defined target items we anticipated the alerting functions of capture would benefit target accuracy through a general increase in alertness (readiness to process information).

Experiment 1

Experiment 1 tested the hypothesis that spatial discontinuity impedes target processing by *diverting* the observer's attention away from the task-critical items (targets) and toward non-target items. Spatial discontinuity was introduced by randomly altering the font size of non-critical distracter stimuli across the RSVP stream.

Method

Participants

Sixteen undergraduate psychology students (12 females; 4 males; mean age of 21) from the University of Wales, Bangor volunteered to participate. All participants reported normal to corrected-to-normal visual acuity.

Apparatus

Stimuli were presented on a 1024 by 768 pixel, 32-bit colour quality, 17-inch cathode ray tube (CRT) monitor using E-prime version 1.1 experimental software (Psychology Software Tools, Inc., Pittsburgh, PA).

Task

On every trial a RSVP stream of 24 letters (New Times Roman 18-point font) was presented in the centre of a grey screen and participants attempted to identify two targets. All items in the stream were black with the exception of the two white target items (T1 and T2). Non-target items were drawn from a randomly alternating sequence of the entire alphabet with the exceptions of B, G, S, X, K, and Y. The letters B, G, and S were used as randomly selected T1 items; X, K, and Y were used as randomly selected T2 items. All items in the RSVP stream were presented at a rate of ~ 10 items per second (i.e., 17 ms 'on'; 85 ms 'off'). T1 was presented randomly between the sixth and twelfth items. The temporal position (i.e., lag-position) of T2 onset also varied randomly, appearing 1, 2, 3, 6, or 7 items after T1.

Two critical conditions were compared; an experimental condition with variation in the font size of the items (spatial discontinuity) and a comparison condition in which font size was held constant (standard). The standard font size was 18-point, with the varying font sizes selected randomly from 16, 18, 20, or 22 - point[1]. The two exceptions to the random selection of fonts in the spatial discontinuity condition concerned (1) the mask item (T + 1) that followed each target: these were made equal to the target size in all cases, and (2) the items occurring after the T2+1 position: these were all 18-point font, under the assumption that items following the mask have no influence on target accuracy (See Figure 1).

[1] Variation in font size did not vary uniformly around the mean in Experiment 1 (18-point font), but did in Experiment 3. The similarity in results across experiments suggests that this had no effect on the outcome.

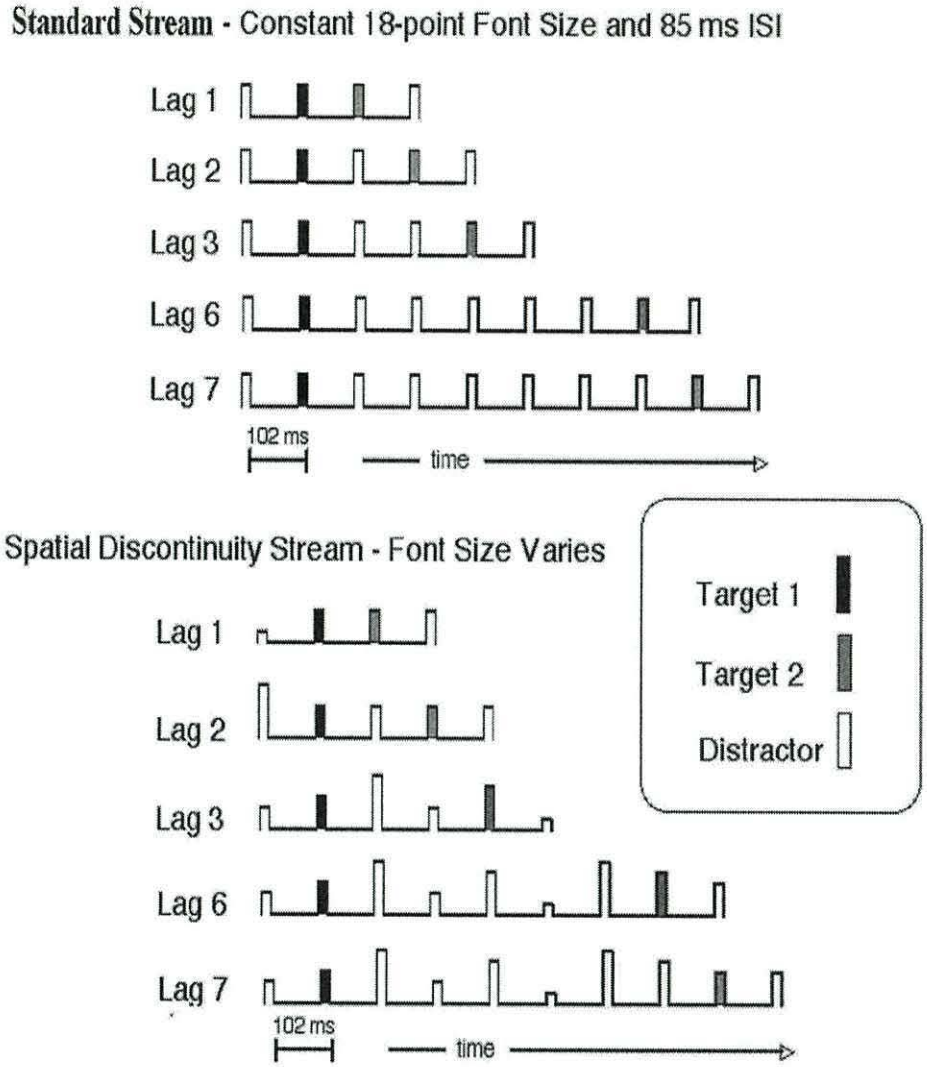

Figure 1: Spatial and temporal parameters for both spatial discontinuity and standard AB conditions in Experiment 1.

Procedure

Participants were tested on a total of 400 trials; 200 in each of the two conditions in a counterbalanced order, with 40 trials representing each of the lags within a condition. To begin each trial, participants pressed the keyboard spacebar. This initiated a black fixation cross in the centre of the screen for 500 ms, followed by a 500 ms blank interval, and then the RSVP stream. Participants indicated the identity of the two targets by pressing "B", "G", or "S" to indicate the identity of T1, and pressing "X", "K", or

"Y" to indicate T2's identity. As is common practice, T2 accuracy was calculated only for trials on which T1 was identified correctly, in order to ensure that attention was fully devoted to at least the first target on every trial.

Results

Target accuracy was examined separately for the first and second targets (Figure 2) with a 2 (conditions) x 5 (lags) x 2 (orders) mixed-factor ANOVA. All post-hoc tests were carried out using the Bonferroni correction for multiple comparisons. All statistical tests were deemed significant at .05 level.

T1 Accuracy. Spatial discontinuity *reduced* first target accuracy relative to the standard condition. This outcome was reflected by a significant main effect of Condition $F(1, 14) = 274.05$, $MSE = 46.89$, $p < .001$, and Lag $F(4, 56) = 5.44$, $MSE = 20.01$, $p < .01$. The interaction between Condition and Lag was not significant $F(4, 56) = 1.53$, $MSE = 26.20$, $p = .20$, nor was the main effect of Order $F(1, 14) = .84$, $MSE = 19.96$, $p = .37$. Interactions between Order and Condition $F(1, 14) = .213$, $MSE = 46.89$, $p = .65$, and Order and Lag $F(4, 56) = 1.29$, $MSE = 20.01$, $p = .28$, were also not significant. Post hoc comparisons revealed T1 performance differed between conditions at all T2 lag positions.

T2 Accuracy. Spatial discontinuity also *reduced* second target accuracy relative to the standard condition. This outcome was reflected by a significant main effect of Condition $F(1, 14) = 88.25$, $MSE = 86.16$, $p < .001$, and Lag $F(4, 56) = 101.43$, $MSE = 43.69$, $p = .001$. The interaction between Condition and Lag was not significant, $F(4, 56) = 1.89$, $MSE = 60.72$, $p = .12$, nor was the main effect of Order $F(1, 14) = .001$,

MSE = 38.53, *p* = .97. Interactions between Order and Lag *F*(4, 56) = .74, *MSE* = 43.69, *p* = .56, and Order and Condition *F*(1, 14) = .14, *MSE* = 86.16, *p* = .70, were also not present. Post hoc comparisons indicated a significant *reduction* in accuracy in the discontinuity condition at every lag and a significant increase in accuracy from lag 3 to lag 7, indicating the typical attentional blink effect, in each condition (Table 1).

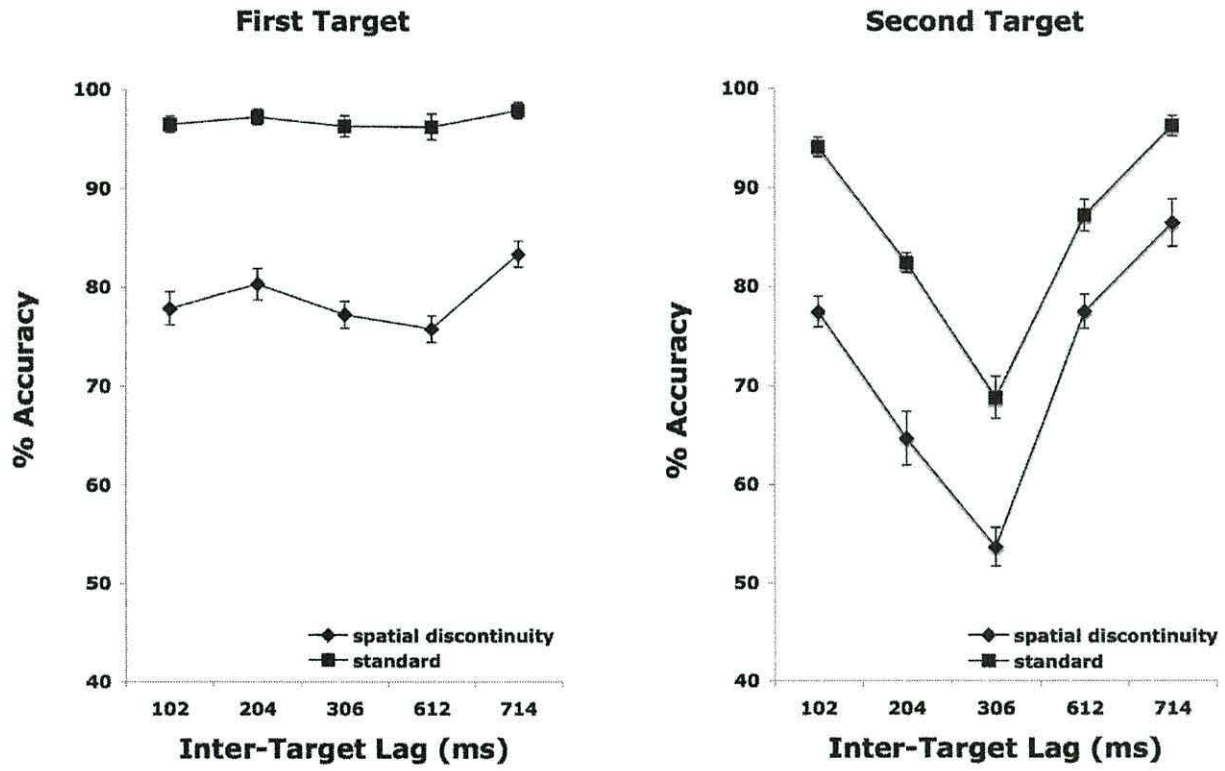

Figure 2: Average T1 (Box A) and T2 (Box B) performance in Experiment 1 across factors of condition and lag. Error bar represent standard error of the mean. In Box A, Error bars for the standard AB condition are not visible due to the extremely small degree of measurement error on these trials.

Table 1

Experiment 1. Mean T2 Accuracy (standard deviations in parentheses) for the standard and spatial discontinuity conditions.

	Lag 1 (102ms)	Lag 2 (204ms)	Lag 3 (306ms)	Lag 6 (612ms)	Lag 7 (714ms)
Standard	94.06 (4.2)	82.37 (3.9)	68.81(8.4)*	87.18 (6.4)	96.25(4.1)*
Spatial Discontinuity	77.43 (6.2)	64.68(10.8)	53.68 (7.9)*	77.50 (6.9)	86.43 (9.6)*

Note. Mean accuracy was significantly greater in the standard condition at each lag (column effects). Accuracy differences within a condition (row effects) were limited to those indicated with asterisks.

Discussion

These results show that font size variation (spatial discontinuity) in an RSVP stream has a deleterious effect on participants' ability to identify each of two targets presented in succession. This experiment, however, gives no indication of whether the temporal position of the discontinuity plays any role in this reduction in target accuracy. We will return to this question after we first compare the effects of introducing temporal discontinuity to the RSVP stream in an analogous way to these spatial discontinuities in Experiment 2.

Experiment 2

Experiment 2 tested the hypothesis that temporal discontinuity *improves* target processing because it *alerts* the observer without *diverting* the observer's attention away from the task-critical items (targets). Temporal discontinuity was introduced by randomly varying the interval between items in the RSVP stream in an analogous way to how we varied the font-size of non-target items in Experiment 1.

Method

All details regarding participants and procedures were identical to the previous experiments, with the exception of the participant sample (n = 16; 6 females; 10 males; mean age 20.4) and the procedural details described below.

All items in both the experimental (temporal discontinuity) and standard conditions were a constant size (18-point) and of constant frame duration (17 ms). The critical difference between conditions was therefore the temporal interval between items, which was selected randomly from the set: 34, 51, 68, 85, 102, 119, 153, 204, 221 ms, with the constraints that (1) the interval between each target and its mask (off time) was held constant at 85 ms, (2) the lag between the first and second target was fixed to be equal to the lags in the standard condition, and (3) the items following the second target mask (T2 + 1) had a constant inter-item interval of 85 ms, on the assumption that events following the second mask had no influence on target accuracy (See Figure 3).

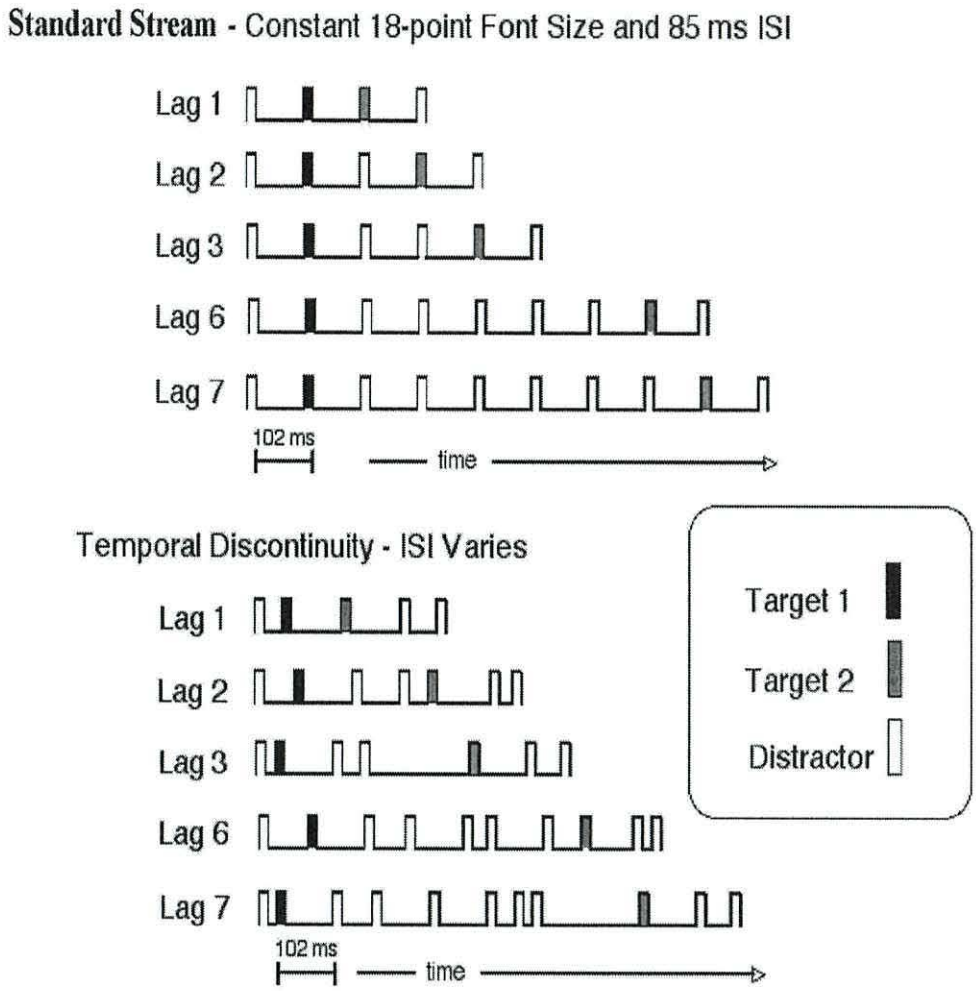

Figure 3: Temporal parameters for both the temporal discontinuity and standard AB conditions in Experiment 2.

Results

Target accuracy was examined separately for the first and second targets (Figure 4) with a 2 (conditions) x 5 (lags) x 2 (orders) mixed-factor ANOVA and post-hoc tests were carried out in the same way as Experiment 1.

T1 Accuracy. Temporal discontinuity had no influence on first target accuracy, as indicated by a null effect of Condition $F(1, 14) = .60$, $MSE = 58.51$, $p = .45$. No other

effects were significant in the first target accuracy data either: Lag $F(4, 56) = 1.57$, $MSE = 33.73$, $p = .19$; Order $F(1, 14) = .82$, $MSE = 37.14$, $p = .48$; Condition and Lag $F(4, 56) = .83$, $MSE = 30.07$, $p = .51$; Condition and Order $F(1, 14) = 1.31$, $MSE = 58.51$, $p = .27$; Lag and Order $F(4, 56) = 1.18$, $MSE = 33.73$, $p = .32$ (See Figure 4).

T2 Accuracy. Temporal discontinuity *increased* second target accuracy relative to the standard condition, as reflected by significant main effects of Condition $F(1, 14) = 7.68$, $MSE = 195.39$, $p = .01$, Lag $F(4, 56) = 42.23$, $MSE = 65.95$, $p < .01$, and a significant interaction of Condition and Lag, $F(4, 56) = 18.69$, $MSE = 68.33$, $p < .01$. There were no significant effect of Order $F(1, 14) = 3.16$, $MSE = 210.13$, $p = .09$, nor interactions of Order and Condition $F(1, 14) = 2.72$, $MSE = 195.39$, $p = .12$, nor of Order and Lag $F(4, 56) = 2.09$, $MSE = 65.95$, $p = .09$. Post hoc comparisons indicated a significant increase in accuracy (mean= 28%) in the discontinuity condition at lag 3 (Table 2).

Order Effects: It is no surprise that target accuracy in the two conditions was equivalent at lags 1 and 7 – lag-1 sparing and AB recovery would prevent such differences. Lags 2 and 6 however – occurring at intermediate points of AB severity – show only minor benefits attributable to temporal discontinuity. Despite not finding main effects of order, it is possible that completing the temporal discontinuity condition first could influence performance in the standard condition at these lags. To answer this question, an additional mixed ANOVA with the within-subjects factor of Lag and the between-subjects factor of Order, was carried out for the standard condition alone. An effect of Order $F(1, 14) = 6.00$, $MSE = 197.02$, $p < .05$, Lag $F(4, 56) = 48.13$, $MSE = 76.15$, $p < .001$, as well as an interaction between Lag and Order $F(4, 56) = 4.44$, $MSE =$

76.15, $p < .01$, were present. Post hoc comparisons following up the two-way interaction revealed completing the temporal discontinuity condition first lead to significantly better control performance at lags 2 only (See Figure 5 and Table 3). Interestingly however, it appears the carry-over effect was not strong enough to affect the AB at its strongest point (i.e. lag-3).

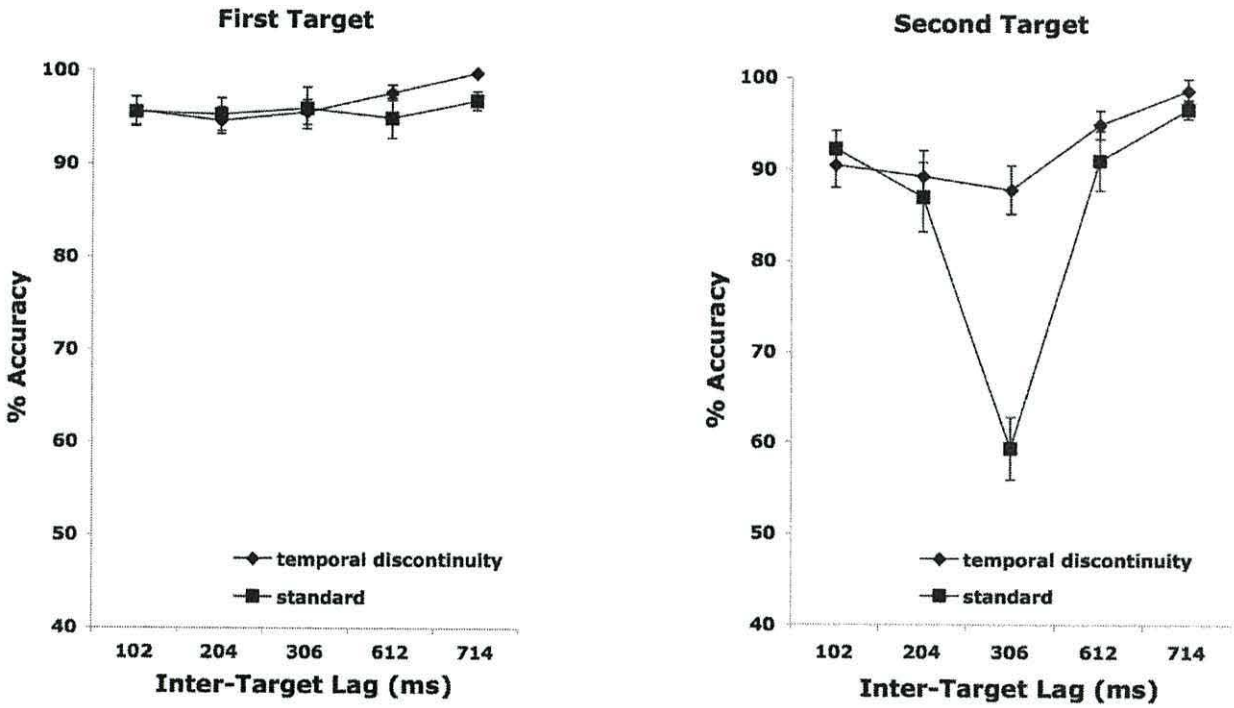

Figure 4: Average T1 (Box A) and T2 (Box B) performance in Experiment 2 for each condition across lag positions. Error bars represent standard error of the mean.

Table 2

Experiment 2. Mean T2 Accuracy (standard deviations in parentheses) for the standard and temporal discontinuity conditions.

	Lag 1 (102ms)	Lag 2 (204ms)	Lag 3 (306ms)	Lag 6 (612ms)	Lag 7 (714ms)
Standard	92.3 (7.9)	87.0 (15.1)	59.3 (13.7)*	91.0 (12.9)	96.8 (4.1)*
Temporal Discontinuity	90.5 (9.7)	89.3 (11.2)	87.8 (10.6)*	94.9 (6.2)	98.7 (4.8)*

Note. Mean accuracy was not significantly different between conditions for any lag (column effects). Accuracy differences within a condition (row effects) were limited to those indicated with asterisks.

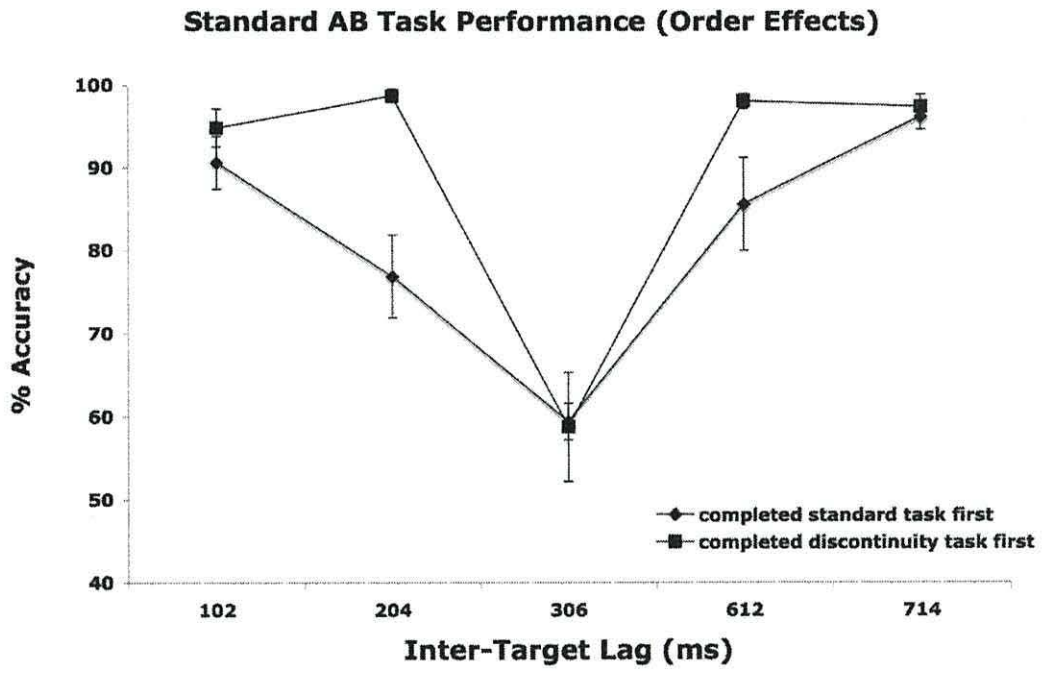

Figure 5: Illustrates carry-over effects of temporal discontinuity at lags 2 and 6 for second target performance in Experiment 2. Error bars represent standard error of the mean.

Table 3

Experiment 2. Mean T2 Standard Accuracy (standard deviations in parenthesis) reflecting order effects at lags 2 and 6

Order of Completing	Lag-2 (204ms)	Lag-6 (612ms)
Temporal Discontinuity First	98.75 (2.31) a	98.50 (2.58) b
Standard First	76.87 (14.44) a	85.62 (15.90) b

Note: Mean values are provided with respective standard deviations in parenthesis. Means within each column sharing the same designation "a" or "b" differ at the .05 level with the Bonferroni correction for multiple comparison.

Discussion

In stark contrast to the interfering effect of spatial discontinuity in Experiment 1, temporal discontinuity in Experiment 2 significantly improved second target accuracy, sharply attenuating the second-target deficit that has become the hallmark of the AB. This is consistent with our hypotheses that attentional capture by a temporal discontinuity will only have an alerting function on a spatially-defined target search, whereas attentional capture by a spatial discontinuity may disrupt the optimal match between the participant's internal expectations with regard to the target and the target-relevant features of the stream.

Yet not all aspects of Experiments 1 and 2 indicated symmetrical effects of the alerting (temporal discontinuity) and diverting (spatial discontinuity) aspects of attentional capture. For instance, the effects of these two types of discontinuity on first target accuracy were quite different, with spatial discontinuity (Experiment 1) sharply reducing first-target accuracy at all lags whereas temporal discontinuity (Experiment 2) did not show any general benefits (though there were hints of a small benefit in the last two lags, see Figure 4). This asymmetry in effects may only reflect the artificial limitations of a ceiling effect in first-target accuracy (already over 95%), or any one of

the small procedural differences between Experiments 1 and 2, or even the fact that different individuals participated in the two experiments. But it may also point to an important difference between the consequences of general alerting and attentional capture. We will return to this issue following Experiment 3, in which we compare the two types of discontinuity against a common baseline condition and with the same participants.

A second difference in the outcomes in the two experiments concerns the effects on second target accuracy. Spatial discontinuity reduced second target accuracy at all lags (Experiment 1) whereas temporal discontinuity increased second target accuracy only at intermediate lags (Experiment 2). Once again, this could reflect the limitations of ceiling levels of performance (over 90% accurate at short and long lags), subtle differences in procedure between the two experiments, inherent differences between the two participant groups, or an important difference between the consequences of general alerting and attentional capture. Experiment 3 will address this question.

Finally, the present two experiments leave unresolved the question of how the temporal position of the discontinuity in the stream is related to the influences on target accuracy. One possibility is that the discontinuity must occur in advance of the first target in order to exert its effect on second target accuracy. Another possibility is that the discontinuity is critical when it occurs between the two targets, as suggested in the preliminary data of Martin & Shapiro (2008). This issue too will be taken up in Experiment 3.

Experiment 3

Experiments 1 and 2 provide support for our main hypothesis that introducing a discontinuity in the otherwise regular pattern of items in an RSVP stream can have differential effects on target accuracy, depending on whether the discontinuity only has an attentional alerting function or whether it also diverts attention away from target items and on to non-target items. However the question remains as to *when* in the RSVP stream spatial and temporal discontinuity are exerting their effects. In Experiment 3 we addressed this question by creating discontinuity in either the spatial and temporal domains during different temporal segments of the RSVP stream: either before the first target, between the first and second target, or in both temporal positions.

Methods

All details regarding participants and procedures were identical to the previous experiments, with the exception of the participant sample (n = 21; 15 females; 6 males; mean age 19.7) and the procedural details described below.

As in Experiments 1 and 2, we introduced discontinuity to either the temporal or the spatial domain, but this time we systematically varied the temporal location of the discontinuity in of three conditions: in pre-T1 items only, between the T1+1 item and T2, and in both pre-T1 and pre-T2 items. A condition with no discontinuity served as the comparison for the 2 (spatial, temporal) x 3 (pre T1, between T1 and T2, and both) conditions. Each participant completed all seven conditions in one of seven Latin Square counterbalanced orders intended to randomize any carry-over effects between

conditions. An RSVP stream of 24 or 25[2] letters was presented in the centre of a grey screen. T1 always appeared as the 12th item in the stream, in order to equate the amount of discontinuity prior to the first target. Twenty trials were completed for each of three possible lag position of T2: lag 2 (i.e. 204 ms elapsed between the onset of T1 and T2), lag 3 (i.e. 306 ms interval), and lag 7 (714 ms interval). Each participant completed a total of 420 trials.

The standard condition (with neither spatial nor temporal discontinuity) was identical to Experiments 1 and 2, with the exception of the three lag positions tested and font size all items (i.e. 20-point New Times Roman Font). The three temporally discontinuous conditions (pre T1, between T1 and T2, and both) are illustrated in Figure 6. The average interval between item onset in these conditions was identical to the standard condition (102 ms). Discontinuity in one of the three critical RSVP periods was created by selecting from a uniform distribution of inter-item intervals (i.e., 'off' time of 17 – 51 – 85 – 119 – 153 ms). For all periods an inter-item interval of 85 ms was used.

The three spatially discontinuous conditions (pre T1, between T1 and T2, and both) are illustrated in Figure 7. Here the average font size was identical to that used in the standard condition (i.e., 20-point). Discontinuity in one of the three critical periods was created by selecting font sizes for items from a uniform distribution of sizes (16, 18, 20, 22, or 24-point). The font size for targets and their respective masks was held constant at 20-point font, as was the size of items that followed the T2+1 item.

[2] As in Experiment 1 two items occurred between T1 and the lag-2 item – for trials presenting T2 in the lag-2 position - to allow for temporal flexibility. In Experiment 3 this extra item was only present in trials manipulating temporal discontinuity.

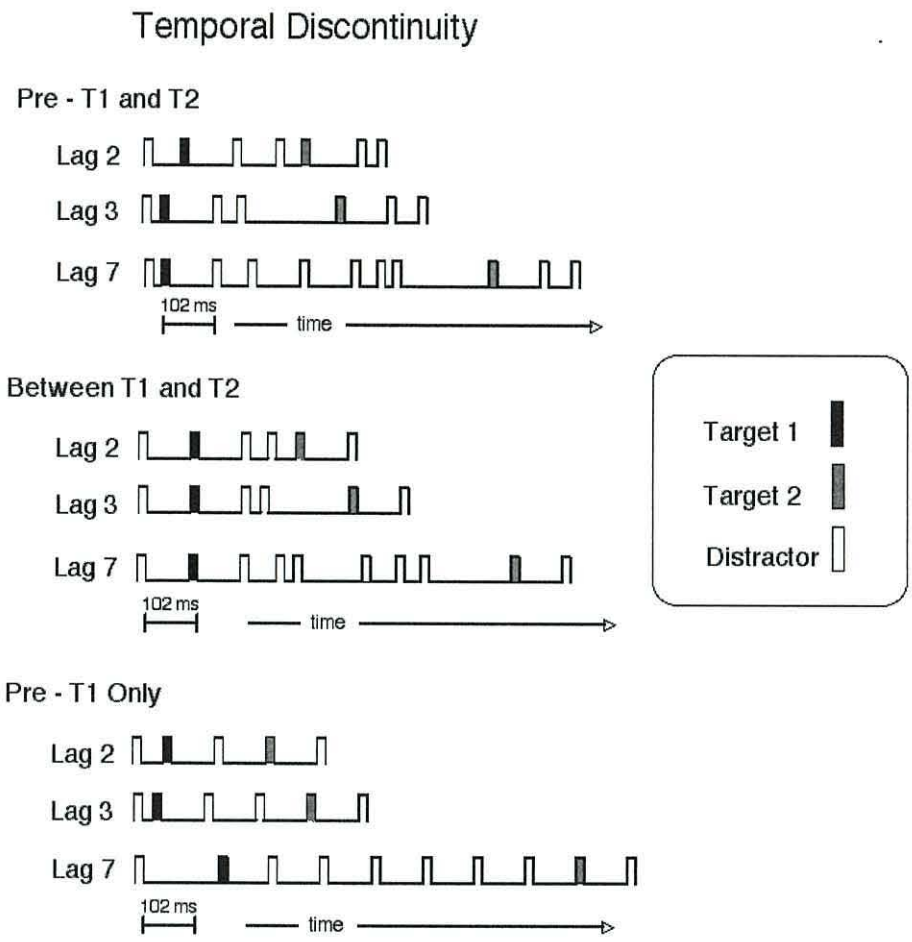

Figure 6: Experiment 3 stimulus parameters implementing temporal discontinuity in three conditions.

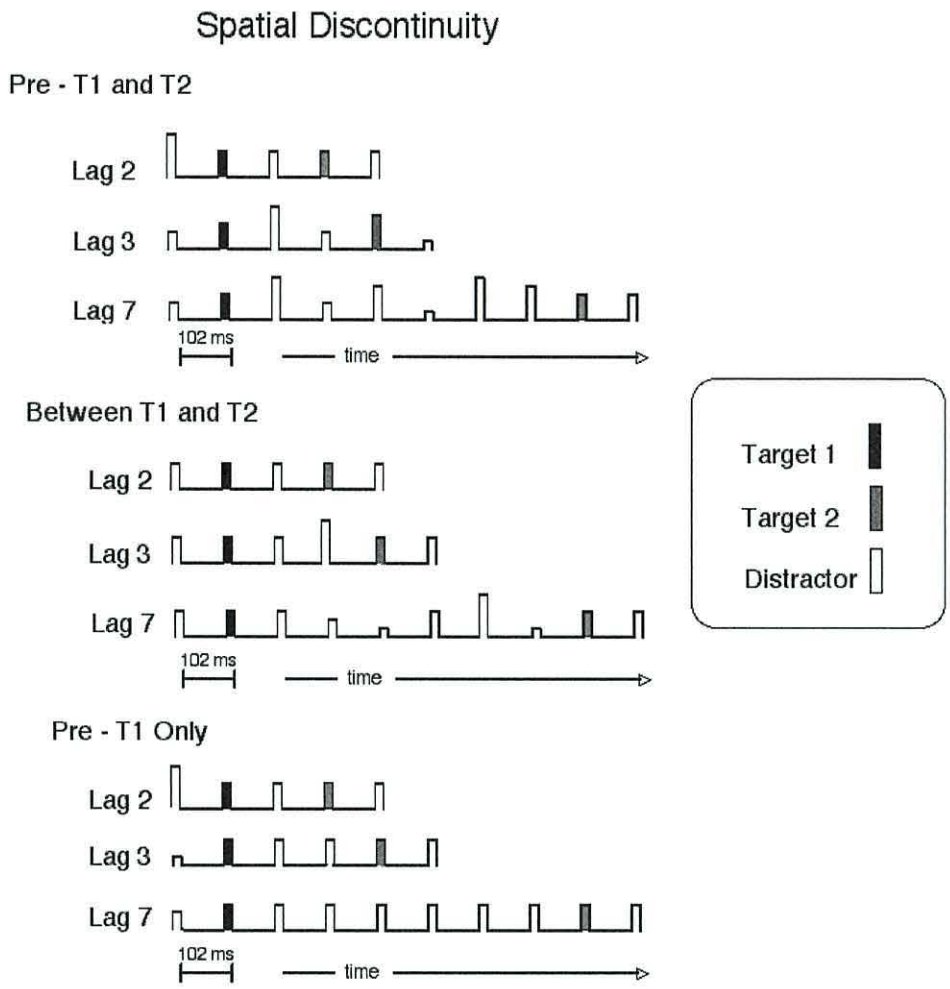

Figure 7: Experiment 3 stimulus parameters implementing spatial discontinuity in three conditions.

Results

Target accuracy was examined separately for the temporally discontinuous (Figure 8) and spatially discontinuous conditions (Figure 9) and for each target in these conditions, with a 4 (conditions) x3 (lags) x 7 (orders) mixed-factor ANOVA. All post-hoc tests were carried out using the Bonferroni correction for multiple comparisons. All statistical tests were deemed significant at .05 level.

Temporal Discontinuity

T1 Accuracy. Temporal discontinuity generally led to *increases* in first target accuracy, as reflected by a significant main effect of Condition $F(3, 42) = 17.45$, $MSE = 45.33$, $p < .001$. There was no effect of Lag $F(2, 28) = 2.77$, $MSE = 50.14$, $p = .08$, nor interaction between Condition and Lag $F(6, 84) = .53$, $MSE = 61.06$, $p = .78$, nor were there any effects of Order $F(6, 14) = .45$, $MSE = 65.17$, $p = .82$, or interactions between Order and Condition $F(18, 42) = .90$, $MSE = 45.33$, $p = .57$, or Order and Lag $F(12, 28) = .95$, $MSE = 50.14$, $p = .50$. Post hoc comparisons revealed that relative to the standard condition, T1 accuracy *benefited* from pre-T1 discontinuity (See Table 4 and Figure 8) but not from discontinuity that occurred between T1 and T2.

T2 Accuracy. Temporal discontinuity also led to *increases* in second target accuracy, as reflected by a significant main effect of Condition $F(3, 42) = 43.45$, $MSE = 36.33$, $p < .001$, Lag $F(2, 28) = 122.53$, $MSE = 44.99$, $p < .001$, and an interaction between Condition and Lag $F(6, 84) = 10.69$, $MSE = 34.19$, $p < .001$. There was no effect of Order $F(6, 14) = 1.22$, $MSE = 38.65$, $p = .35$, nor interactions of Condition and Order $F(18, 42) = .97$, $MSE = 36.33$, $p = .50$, nor of Lag and Order $F(12, 28) = .30$, $MSE = 44.99$, $p = .98$. Post hoc comparisons revealed that relative to the standard condition, T2 accuracy was significantly improved by each increase in temporal discontinuity at Lag 3 (See Table 5 and Figure 8).

T1 and T2 Correlations. Table 6 shows the correlations between first and second target accuracy at all lags. The statistically significant correlation was at lag 7 for pre-T1 discontinuity trials.

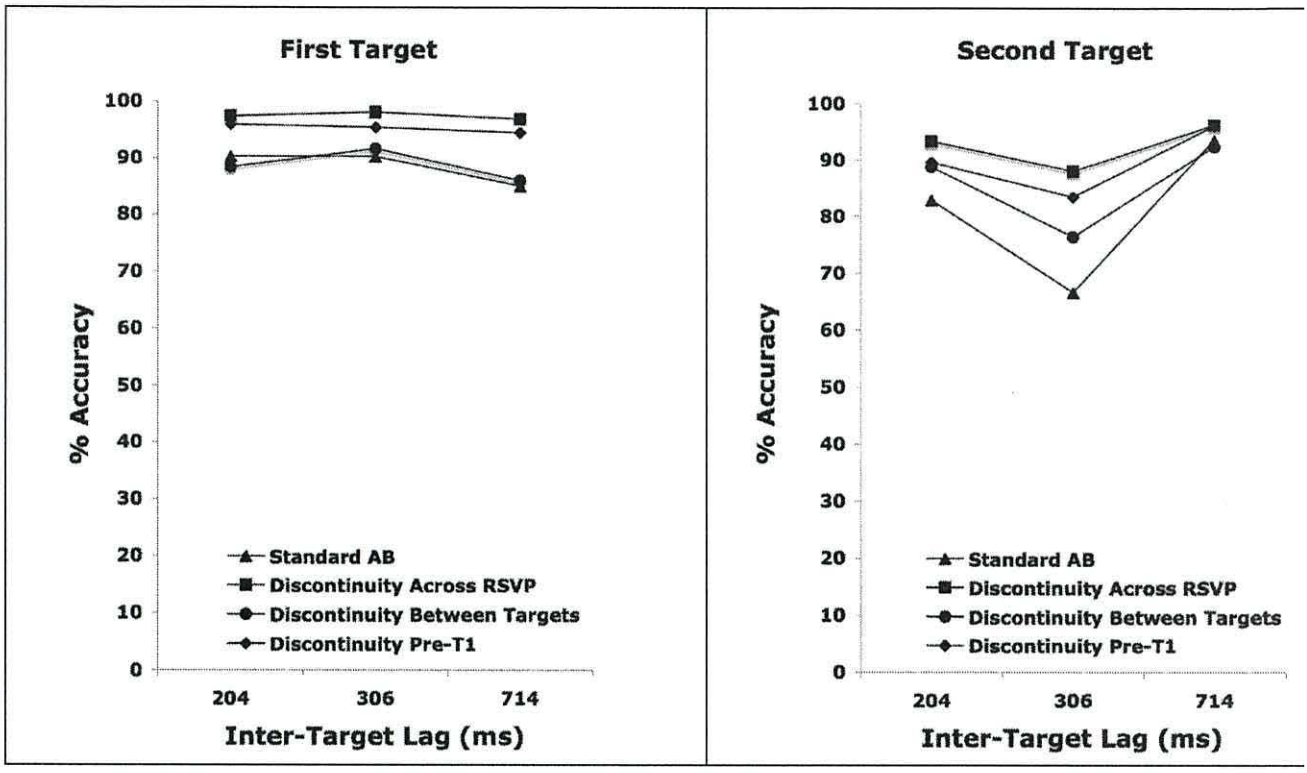

Figure 8: Average T1 (Box A) and T2 (Box B) performance for Experiment 3 across factors of condition and lag. Shown are those conditions that manipulate temporal discontinuity as well as standard AB trials. As mentioned in Experiment 3 results, no error bars are shown due to a large number of intersecting error bars. Respective measurements of variance are shown in Tables 4 and 5 in the form of standard deviations.

Table 4

Experiment 3. Mean T1 Accuracy (standard deviations in parenthesis) for Standard and Temporal Discontinuity Conditions

	Lag-2 (204 ms)	Lag-3 (306 ms)	Lag-7 (714 ms)
Standard	90.24 (8.72)	90.25 (9.54)	85.00 (10.12)
Discontinuity Pre-T1 and Pre-T2	97.34 (4.64)a	98.10 (4.36)a	96.90 (5.11)a
Discontinuity Pre-T1 only	95.95 (7.00)	95.48 (6.50)	94.52 (7.73)
Discontinuity Btw T1+1 and T2	88.33 (9.53)	91.67 (7.47)	85.95 (6.24)

Note: Mean values are provided with respective standard deviations in parenthesis. Within each column, mean values with the signification "a" differed from standard AB trials at the .05 level with the Bonferroni correction for multiple comparisons.

Table 5

Experiment 3. Mean T2 Accuracy (standard deviations in parenthesis) for Standard and Temporal Discontinuity Conditions

	Lag-2 (204 ms)	Lag-3 (306 ms)	Lag-7 (714 ms)
Standard	82.90 (9.04)	66.56 (4.80)	93.53 (4.80)
Discontinuity Pre-T1 and Pre-T2	93.34 (4.88)a	88.91 (8.14)a*	96.27 (4.57)
Discontinuity Pre-T1 only	89.58 (5.73)	83.50 (4.31)a	96.05 (4.44)
Discontinuity Btw T1+1 and T2	88.70 (5.52)	76.26 (6.43)a*	92.40 (4.57)

Note: Mean values are provided with respective standard deviations in parenthesis. Within each column, mean values with the signification "a" differed from standard AB trials at the .05 level with the Bonferroni correction for multiple comparisons. Also within each column, means sharing the designation "*" also differ at the .05 level.

Table 6

Experiment 3 Correlations Between First and Second Target Performance

Condition	Pearson Correlation Two-Tailed		
Temporal Discontinuity Between T1+1 and T2	Lag 2 $r = .39, p = .80$	Lag 3 $r = -.082, p = .72$	Lag 7 $r = .27, p = .23$
Temporal Discontinuity Pre-T1 Only	Lag 2 $r = -.03, p = .90$	Lag 3 $r = .09, p = .67$	Lag 7 $r = .47, p = .03$*
Spatial Discontinuity Between T1+1 and T2	Lag 2 $r = -22, p = .32$	Lag 3 $r = -.49, p = .02$*	Lag 7 $r = -.15, p = .51$
Spatial Discontinuity Pre-T1 Only	Lag 2 $r = .43, p = .04$*	Lag 3 $r = .56, p < .01$*	Lag 7 $r = .07, p = .74$

Note: Two-Tailed Pearson Correlations Between First and Second Target Performance. The designation "*" indicates a significant correlation relationship.

Spatial Discontinuity

T1 Accuracy. Spatial discontinuity generally led to *decreases* in first target accuracy, as reflected by a significant main effect of Condition, $F(3, 42) = 62.80$, $MSE = 53.24$, $p < .001$. There was no effect of Lag $F(2, 28) = 2.42$, $MSE = 63.39$, $p = .10$, nor was there any interaction between Condition and Lag $F(6, 84) = 1.05$, $MSE = 59.29$, $p = .39$, nor of Order $F(6, 14) = 2.69$, $MSE = 35.11$, $p = .05$, nor interactions of Order and Condition $F(18, 42) = 1.56$, $MSE = 53.24$, $p = .15$, or Order and Lag $F(12, 28) = 1.02$, $MSE = 63.39$, $p = .52$ were found. Post hoc comparisons revealed that relative to the standard condition, T1 accuracy was *reduced* by pre-T1 discontinuity (See Table 7 and Figure 9) but not from discontinuity that occurred between T1 and T2.

T2 Accuracy. Spatial discontinuity also led to *decreases* in second target accuracy, as reflected by a significant main effect of Condition, $F(3, 42) = 71.30$, $MSE = 45.29$, $p < .001$, Lag $F(2, 28) = 387.92$, $MSE = 52.44$, $p < .001$, and the interaction between Lag and Condition $F(6, 84) = 4.06$, $MSE = 32.52$, $p < .001$. There was no effect of Order $F(6, 14) = .519$, $MSE = 24.95$, $p = .78$, nor interactions of Condition and Order $F(18, 42) = .76$, $MSE = 45.29$, $p = .72$, nor of Lag and Order $F(12, 28) = .71$, $MSE = 52.44$, $p = .73$. Post hoc comparisons revealed that relative to the standard condition, T2 accuracy was significantly improved in each condition involving spatial discontinuity at Lag 3 (See Table 8 and Figure 9).

T1 and T2 Correlations. Table 6 shows the correlations between first and second target accuracy at all lags. There were significant positive correlations at lags 2 and 3 in the pre-T1 spatial discontinuity condition indicating T1 and T2 accuracy rising and falling together. Moreover, there was a significant negative correlation at lag 3 when

spatial discontinuity occurred between T1 and T2 condition. The implications of these correlations are presented in the General Discussion.

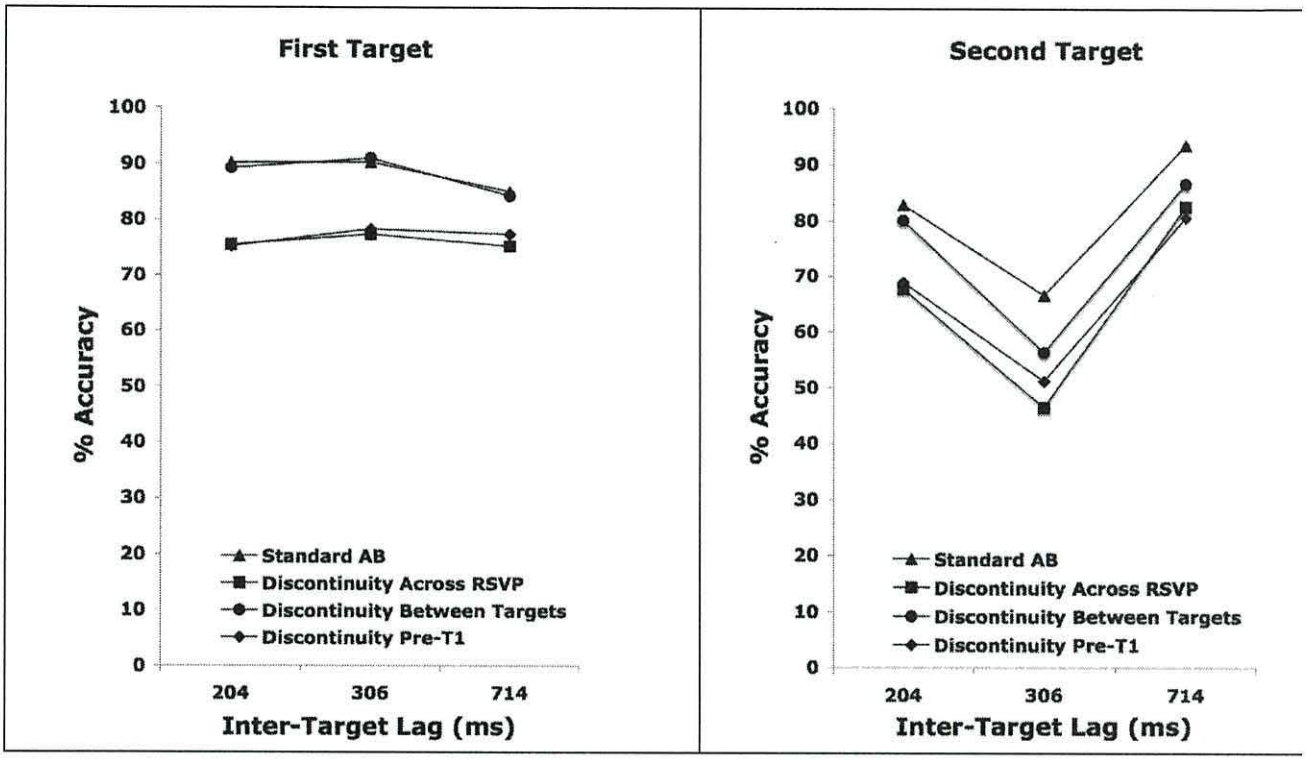

Figure 9: Average T1 (Box A) and T2 (Box B) performance for Experiment 3 across factors of condition and lag. Shown are those conditions that manipulated spatial continuity as well as standard AB trials. As mentioned in Experiment 3 results, no error bars are shown due to a large number of intersecting error bars. Respective measurements of variance are shown in Tables 6 and 7 in the form of standard deviations.

Table 7

Experiment 3. Mean T1 Accuracy (standard deviations in parenthesis) for Standard and Spatial Discontinuity Conditions

	Lag-2 (204 ms)	Lag-3 (306 ms)	Lag-7 (714 ms)
Standard	90.24 (8.72)	90.25 (9.54)	85.00 (10.12)
Discontinuity Pre-T1 and Pre-T2	75.48 (7.22)a	77.38 (7.68)a	75.24 (8.58)
Discontinuity Pre-T1 only	75.24 (7.15)a	78.33 (6.19)a	77.38 (8.60)
Discontinuity Btw T1+1 and T2	89.29 (6.39)	90.95 (6.63)	84.29 (6.76)

Note: Mean values are provided with respective standard deviations in parenthesis. Within each column, mean values with the designation "a" differed from standard AB trials at the .05 level with the Bonferroni correction for multiple comparisons applied.

Table 8

Experiment 3. Mean T2 Accuracy (standard deviations in parenthesis) for Standard AB and Spatial Discontinuity Conditions

	Lag-2 (204 ms)	Lag-3 (306 ms)	Lag-7 (714 ms)
Standard AB	82.90 (9.04)	66.56 (4.80)	93.53 (4.80)
Discontinuity Pre-T1 and Pre-T2	67.66 (4.47)a/b	46.37 (7.57)a/b	82.46 (3.45)a
Discontinuity Pre-T1 only	68.93 (8.40)a/b	51.10 (5.45)a	80.55 (4.55)a
Discontinuity Btw T1+1 and T2	80.05 (6.42)	56.20 (6.17)a	86.70 (5.46)

Note: Mean values are provided with standard deviations in parenthesis. Within the same columns mean values with the designation "a" differed from standard AB trials with correction for multiple comparisons applied. Means with the designation "b" differed from trials manipulating synchrony between targets – during the inter-target-interval.

Discussion

Relative to a common baseline in this experiment (standard condition), temporal discontinuity in the RSVP stream benefited target accuracy, whereas spatial discontinuity impeded it. With regard to the primary motivation for this experiment – concerning the relationship between the RSVP interval during which discontinuity occurred and its effect on AB magnitude – we found that temporal and spatial discontinuity in all three RSVP intervals exerted effects on second target accuracy, with discontinuity occurring throughout the stream, i.e., both before T1 and between T1 and T2, being roughly equal to the combined size of the each of these effects when they occurred in isolation. In both spatial and temporal conditions discontinuity had a greater effect on both first and second target accuracy when it occurred prior to T1, compared to when discontinuity occurred between T1 and T2.

General Discussion

The opposing consequences of temporal and spatial discontinuity on the ability to identify targets in a rapid sequence – the 'attentional blink' task – suggests that the capture of attention during this task plays two dissociable roles. When the capturing event varies in a dimension task-relevant to the target (spatial size), then the capturing event competes with target processing. For example, if the target identification task requires spatial analysis – as was the case in each of the present experiments – then capturing events that vary in their spatial characteristics (i.e., the *spatially* discontinuous distracters in Experiments 1 & 3) must be engaged and then disengaged before subsequent target items can be processed. Attentional disengagement takes time. If targets appear before attention disengages from previous stimuli, then target processing suffers. This finding is consistent with previous research demonstrating the deleterious effects of capturing events that occur immediately prior to target onset (Arnell, Killman, & Fijavz, 2007; Dalton & Lavie, 2006; Egeth et al., 2001; Jolicoeur, Sessa, Dell'Acqua, & Robitaille, 2006; Jonides & Yantis, 1988; Lamy, 2005; Lamy & Egeth, 2003; Spalek, Falcon, Di Lollo, 2006; Theeuwes, 1992; and Wee and Chua, 2004).

On the other hand, when a capturing event does not share properties with task-critical items, as was the case in the *temporal* discontinuity in Experiments 2 & 3, then there is no competition, allowing the alerting function of attentional capture to exert its facilitating effects on target identification. This relationship between increased arousal and improved information processing has been demonstrated previously, within the framework of Posner's 'alerting network' (Posner, Inhoff, Friedrich, & Cohen, 1987). According to these investigators, a heightened state of arousal causes the information

processing system to process stimuli more efficiently via either executively-modulated reallocation of cognitive resources, or by adjustments in goal directives (e.g., change in search parameters). In the present experiments, the general increase in preparedness brought about by a capturing event (a discontinuity) benefited performance only when it was not defined by a stimulus dimension relevant to the primary task of identifying targets, that is, when attention was not diverted away to distractor items differing unpredictably along the task critical dimension of spatial size. The ensuing benefits in T2 accuracy that occurred for temporal discontinuity were therefore likely the result of modulations in resource allocation.

T1/T2 Correlations and Implications

In the between T1 and T2 temporal discontinuity conditions, there was no relationship between T1 and T2 accuracy at any lags. In the pre-T1 temporal discontinuity condition, the only relationship found between T1 and T2 accuracy occurred at lag 7, which is outside the AB. The absence of correlations between T1 and T2 for temporal discontinuity conditions may reflect either the theoretically interesting conclusion that temporal events do not impact first and second target processing in the same way, or the more mundane conclusion that variation in T1 accuracy was limited by a 'ceiling effect' on performance.

The spatial discontinuity conditions, on the other hand, yielded a number of significant T1/T2 correlations. Positive correlations observed at Lags 2 and 3 in the pre-T1 condition indicated that discontinuity caused T1 and T2 accuracy to rise and fall together. As the amount of attention available was reduced for T1, it was also reduced

for T2. This relationship can be interpreted as support for a 'two-stage' model, where the second target cannot advance until later stages have completed processing the first target (Chun & Potter, 1995). More specifically, as a result of the capturing events, less available attention causes T1 processing to take longer in turn causing the processing of T2 to wait until sufficient processing resources are available. Such processing delays allow more time for the encoded representation of T2 to decay as a result of interference from the subsequent mask.

The negative T1/T2 correlation at Lag 3 in the between-target condition speaks to a similar role for masking and discontinuity. As reported by Kessler et al. (2005), the disruption in T1 processing caused by the T1 mask triggers a protected state of processing of T1, as revealed by an earlier M300 component for a masked, relative to an unmasked, T1. Here we propose the disruption caused by discontinuity occurring post T1 adds to this effect by further accelerating T1 processing. Simultaneously, spatial discontinuity causes T2 to be adversely affected by the competition between attentional capture and target processing yielding the negative correlation.

Theory and research concerning the relationship between T1 and T2 processing has a long history. Shapiro et al. (1994) initially reported that T1 difficulty did not affect the magnitude of the AB (i.e., T2 accuracy) with this conclusion later supported by other investigators (e.g., Raymond et al., 1995; Ward et al., 1996, 1997). On the other side of the debate, some researchers reported that T1 difficulty did affect T2 accuracy (e.g., Chun & Potter, 1995; Brehaut et al., 1999; Grandison et al., 1997; Seiffert & Di Lollo, 1997). These researchers operationalised T1 difficulty through the use of masking (i.e., a more effectively masked T1 is a more difficult target to process).

Following these studies, the topic has been further examined but in other contexts. For example, Potter et al. (2002) and Hommel and Akyürek (2005) have looked at a specific case of the T1/T2 relationship in the context of the outcome known as 'Lag-1 sparing', when T2 occurs in the lag position immediately following T1 thus acting as both the second target as well as the mask on T1. These investigators find a trade-off in T1/T2 processing and, although interesting in its own right, does not directly bare on the issue presently under discussion. Before concluding the discussion of this issue, it is worth noting that various investigations into the underlying neural basis of T1/T2 trade-offs in the context of both the Lag-1 sparing issue (Kessler et al., 2005) and the resource allocation model (Shapiro et al., 2006) have been conducted with evidence found to support the notion that T1 and T2 accuracy are significantly correlated as is supported by the results of the present study.

Capture and The Attentional Blink

We believe our results can provide an alternative way to view the results of recent experiments examining the effects of peripheral[3] task-irrelevant activity on the AB. Continuous presentation of non-contingent visual (Arend et al., 2006) or auditory (Olivers & Nieuwenhuis, 2005) stimuli was found to significantly attenuate the AB. Both sets of investigators explain their findings within the framework of a hypothesis of 'overinvestment'. They propose task-irrelevant activity reduces the amount of attention invested toward the RSVP stream, particularly with regard to the first target task. These

[3] "Peripheral" refers to stimuli presenting simultaneous with, but outside the RSVP stream. The original Olivers study had participants listen to music while completing the AB task. Arend and colleagues presented a moving star field that surrounding the RSVP stream.

'reserved' attentional resources are then able to be redeployed toward the second target, yielding a reduced AB. The effects of temporal discontinuity reported here suggest Olivers' and Arend et al.'s findings may be interpreted in a different way, i.e., to reflect capture and alerting to a non-task relevant event. By this account peripheral task-irrelevant activity simply could be capturing attention and alerting the system, in turn creating a heightened state of processing. To test this hypothesis, it would be interesting to see if peripheral task-*relevant* information produced an outcome similar to that produced by spatial discontinuity in the present set of experiments. In a similar vein, Sheppard et al. (2002; Experiment 4) developed a temporal AB task, requiring judgement of the duration of a target letter, rather than the typical judgement of its identity. As this manipulation produced an AB, it would be interesting to see if combining a temporal judgement with the same two types of discontinuity as in the present experiments produces a reversal in the pattern of results. Based on our hypothesis, we predict the temporal discontinuity condition would yield a larger AB relative to the standard condition, whereas spatial discontinuity would produce less of an AB.

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Chapter Six: Establishing and Confirming Object-Hypotheses in the Presence of Multiple Task-Relevant Features

Chapter Six

Establishing and Confirming Object-Hypotheses in the Presence of Multiple Task-Relevant Features

Introduction

Visual masking is a popular method for studying the time-course of object perception. Traditionally, visual masking has been viewed as interfering with target processing during the initial feed-forward progression through early stages of information processing. During these stages target and mask are thought to compete for cognitive resources causing the target signal to be inhibited by the mask. As a result, target processing is viewed as being terminated at a pre-categorical level (Scheerer, 1973; Turvey, 1973; Breitmeyer & Ogman, 2006). In the current chapter this is referred to as the *traditional view* of visual masking. Although not denying that feed-forward processing plays a critical role in visual masking, recent publications have proposed an important role for reentrant (i.e., feed-back) processes as well (Di Lollo, Enns, & Rensink, 2000; Enns & Di Lollo, 1997; Enns & Di Lollo, 2000; Enns & Oriet, 2007).

Authors of these publications base their arguments upon inconsistencies between the traditional view and neurophysiological measures of masking. Contrary to the traditional view, neurological evidence has emerged suggesting that target signals are *not* inhibited or 'suppressed' by masking. Most revealing are experiments demonstrating that target-related P1, N1, and N400 ERP components are identical under conditions when masking is and is not present. Similar outcomes regarding these ERP components have been found for *pattern interruption masking*[1] (Vogel,

[1] *Pattern Interruption Masking* occurs when target and mask spatially overlap, but target offset occurs before mask onset. This is different from *pattern integration masking*, when mask onset occurs before target offset.

Luck, & Shapiro, 1998) and *metacontrast masking*[2] (Bridgeman, 1980; von der Heydt et al., 1997). Most troublesome for the traditional view is the idea that visual masking does not prevent the occurrence of a target-related N400 component. This ERP component is viewed as indicating that the target stimulus has been processed at a semantic level[3] (Besson, Kutas, & Van Petten, 1992; Kutas & Hillyard, 1980; Kutas, Van Petten, & Besson, 1988; Osterhout & Holcomb, 1995; Rugg, 1984). Target-related N400 components occurring under conditions of masking stand in diametrical opposition to the traditional view, which asserts that target processing is terminated at a pre-categorical level.

In order to reconcile neurophysiological measures of masking with behavioural outcomes that indicate target processing *is* negatively influenced by visual masking, Enns and Colleagues have proposed replacing the concept of inhibitory interactions between target and mask (i.e., the traditional view) with that of multi-directional connections between the same neurons across various stages of processing. To this end Enns and colleagues have proposed two theories relating to visual object processing, both being inherently linked in the ideas they propose. These theories are the *reentrant theory of perception* and the *reentrant theory of successful backward masking (Di Lollo, Enns, & Rensink, 2000; Enns, 2004; Enns & Di Lollo, 1997; Jiang & Chun, 2001a, 2001b; Lleras & Moore, 2003; Lleras & Enns, 2004; Neill, Hutchison, & Graves, 2002). Backward masking* occurs when the temporal onset of a mask occurs after the temporal onset of a target – i.e., presentation of the mask trials the target stimulus in time (e.g., Breitmeyer, 1984).

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[2] *Metacontrast Masking* occurs when contours of the target stimuli are completely surrounded by the mask. Target and mask do not spatially overlap in metacontrast masking.

[3] The N400 component is highly sensitive to the degree of semantic mismatch between a word and a previously established context.

According to the reentrant theory of perception, obtaining perceptual awareness of an object requires both feed-forward and reentrant processes. The initial feed-forward progression through visual processing is viewed as occurring in two stages. In stage one, geometrically simple and spatially local receptive-fields are activated for lower-level visual neurons. Based on these activations higher-level visual neurons are activated that are sensitive to larger regions of the visual field and correspond to complex properties such as patterns and shapes. Amongst these higher-level neurons, those receiving the strongest signals from lower level visual cortex represent what is referred to as an *object hypothesis*. The object hypothesis can be viewed as the most probable representation of an object based on the information obtained during the initial feed-forward sweep through visual processing.

To alleviate ambiguity with alternative object representations corresponding to other higher-level neurons, the object hypothesis must be confirmed via reentrant processes. Reentrant processes attempt to match the hypothesis with an updated representation of sensory information. This updated representation is thought to be available after object-related information has been integrated (i.e., bound) into a single unified representation. Critically, this theory insists that the hypothesis must be successfully confirmed before a conscious representation of the object can emerge.

The reentrant theory of successful backward masking proposes that the mask appears before the hypothesis formulated for the target can be confirmed. Onset of a mask is believed to set in motion a process known as *object updating*. Object updating is a process whereby newly sampled information is integrated with an existing stimulus representation, resulting in an updated version. Within this

updated version information relating to target and mask is erroneously bound into a single representation. Successful masking occurs when confirmation of the target-object hypothesis[4] fails due to a mismatch with the updated representation of sensory information resulting from object updating. Failure to confirm the target-object hypothesis prevents a conscious representation of the target from emerging, at which point another object-hypothesis is established based on the most recent activation of lower level neurons – i.e., activation corresponding to the mask. Establishing a new object hypothesis after abandoning the target-object hypothesis is referred to as *object substitution.* Correctly identifying a target in the presence of backward masking thus requires unbinding target and mask information after the two displays have been integrated into a single representation through the process of object updating. Only after such information has been unbound can the target-object hypothesis be confirmed by establishing a match with an updated representation of sensory information relating to the target stimulus.

Enns and Oriet (2007) proposed that object hypotheses are influenced by ongoing goals of the observer. According to this idea, when an observer is instructed to carry out a particular task relating to the target stimulus – e.g., make specific judgements about target features – the target-object hypothesis is formulated and confirmed with heavy emphasis being placed on task-relevant information. To support this idea these authors cited previous publications suggesting that based on an observer's intentions to detect or identify certain target features – i.e., those features that are task-relevant - a search filter is established prior to stimulus onset (e.g., Di Lollo et al., 2000). Search filters are thought to be configured to expectations of task-relevant information, and have been proposed to amplify neural

[4] The designation "target-object hypothesis" is used in the current chapter to make reference to the object-hypothesis established for the target stimulus – i.e., the stimulus that precedes the mask.

signals elicited by task-relevant information while attenuating neural signals to task-irrelevant information (e.g., Duncan, 2006). Enns and Oriet proposed that such a filter serves the purpose of ensuring that the target-object hypothesis is formulated with heavily weighted importance for task-relevant information. As a result, establishing a match for task-relevant information between the target-object hypothesis and updated sensory information was thought to be more important for confirming the hypothesis than a match for task-irrelevant information.

Enns and Oriet tested this idea by manipulating similarity between target and mask for task-relevant and task-irrelevant features. It was predicted that when target and mask contained similarity for a given feature – e.g., both containing the colour blue – the likelihood of successfully unbinding target/mask information relating to that feature would be reduced[5]. The added difficulty in unbinding was expected to arise from being unable to determine what information relating to the matching feature belonged to the target vs. the mask. It was hypothesised that if task-relevant information plays a dominant role in the formulation and confirmation of object-hypotheses, then similarity between target and mask for a task-relevant feature should influence target processing more than similarity for a task-irrelevant feature.

Presenting only a target and its mask, these authors used the technique of backward metacontrast masking. In their critical experiment four different images could appear as the target or mask – i.e., 2 shapes (diamond or square) x 2 colours (blue or red). The mask stimulus contained a star shaped hole large enough to hold the target image (See Figure 1). Task instructions were divided between two groups of participants - one group reported the shape of the target while another group reported the target colour.

[5] Recall that correctly identifying a target in the presence of backward masking requires unbinding target and mask information after the two displays have been integrated into a single representation through the process of object updating.

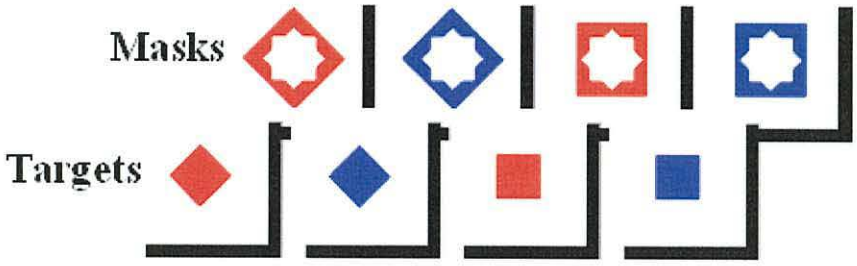

Figure 1. Reproduction of the target and mask stimuli used in Experiment 2 of Enns and Oriet's 2007 publication.

Similarity between target and mask for the task-relevant (i.e., to-be-reported) feature exacerbated masking interference for both participant groups. In other words, when reporting target colour, accuracy was lower when target and mask were the same as opposed to different colours. Likewise, when reporting target shape, the same data pattern was found when target and mask were the same as opposed to different shapes. For both the shape group and colour group, accuracy was not influenced by whether target and mask were matched or mismatched for the task-irrelevant feature.

In accord with their experimental hypothesis, Enns and Oriet concluded that object-hypotheses are biased toward task-relevant information. Masking interference was only influenced when target and mask held similarity for the task-relevant feature. This outcome was interpreted as suggesting that confirming the target-object hypothesis did *not* require matching target-related *task-irrelevant* information with updated sensory information. Were this not true, the influence of visual masking should have fluctuated as a function of target/mask similarity for the task-irrelevant feature.

In Enns and Oriet's experiment there was only one task-relevant target feature[6]. In the current Experiment 1 the question was asked: *When instructed to report upon two task-relevant features from the same target stimulus, do observers attempt to establish and confirm two distinct object-hypotheses (i.e., one hypothesis for each task-relevant feature) – or – is one object-hypothesis established that includes both task-relevant features?* Recall that the reentrant theories of perception and successful backward masking state that when an object-hypothesis fails to be confirmed, the object-representation corresponding to that hypothesis never reaches consciousness. It follows then that if a single object-hypothesis were established on behalf of two task-relevant features, failure to confirm that hypothesis on the basis of either feature would cause the entire hypothesis to fail, resulting in a lack of conscious awareness for the entire object, and thus an inability to report either target feature accurately. Alternatively, if two separate hypotheses are established – one for each task-relevant feature – then failure to confirm the hypothesis for one feature is unlikely to prevent successful confirmation of the other.

Experiment 1 thus required observers to report upon two features of a single target object (colour and spatial orientation). Varying which task-relevant feature was held similar between target and mask, I was able to manipulate whether a target-object hypothesis was more likely to be confirmed on the basis of colour or orientation. In other words, it was anticipated that information relating to the feature held similar between target and mask would be more difficult to unbind from the processes of object updating than would information relating to the feature held dissimilar. If multiple object-hypotheses are established, significant differences in

[6] As indicated, in Enns and Oriet's (2007) experiment task instructions were divided between two groups. One group was instructed to report target colour while the other was instructed to report target shape – thus for each group there was only one task-relevant feature (colour or shape).

report accuracy should emerge between target features held similar vs. dissimilar with a mask.

In Experiment 2 I inserted a masking manipulation similar to the one used in Experiment 1 as the second of two targets (i.e., T2) in an *Attentional Blink* (*AB*) task. In the introduction to Experiment 2 it is explained how a temporary absence of attention, as occurs during the AB, may be capable of influencing Experiment 1 results in two ways. The goal of Experiment 2 was to support one of these two possible outcomes. Surprisingly, neither of the potential outcomes proposed in Experiment 2 were supported by the data. The results are discussed accordingly. Combined, Experiments 1 and 2 were intended to determine whether processes involved in establishing object-hypotheses work flexibly when varying levels of processing demands are placed on the information processing system. When discussing the results of Experiment 1 and 2, it is explained how establishing multiple object-hypotheses for a single target stimulus may serve as an advantageous strategy for object processing.

Experiment 1

As indicated, Experiment 1 was intended to determine whether observers formulate one or two object-hypotheses when required to report upon two features from the same target. Both task-relevant features should be incorporated within the visual search filter that is set prior to target onset. Because it is information matching this search filter from which hypotheses are formulated and confirmed (Enns & Oriet, 2007), I proposed that if a single object-hypothesis were established on behalf of both task-relevant features, confirming this hypothesis would require establishing matches for both features with available sensory information. If a match failed to be

established for either feature the entire hypothesis would fail to be confirmed. As a result, a conscious representation of the target object would not be obtained and thus neither target feature would be reported on correctly.

Alternatively, if two object-hypotheses were established – one for each task-relevant feature – then confirming each hypothesis would only require establishing a single match with available sensory information. Because each hypothesis contains information about a different task-relevant feature, failure to confirm one hypothesis would be unlikely to influence confirmation of the other. When one hypothesis is confirmed and the other is not, observers may be able to obtain a partial conscious representation of the target – a representation that allows accurate report of the target feature tied to the hypothesis that was successfully confirmed.

To test whether observers establish one or two object-hypotheses, I asked participants to report upon two features of a target stimulus (colour and spatial orientation). The target stimulus was followed within close temporal proximity by a backward pattern interruption mask. The primary manipulation in Experiment 1 involved the contents of this mask. By varying whether target and mask possessed similarity[7] for either colour or orientation, I was able to manipulate for which task-relevant feature the target-object hypothesis would fail to be confirmed. To phrase another way, if target and mask possessed similarity for colour only, then reentrant processes would be less likely to confirm a match with sensory information relating to colour than information relating to orientation – i.e., target-related information

[7] Like in Enns and Oriet's (2007) experiment, task-relevant "similarity" refers to target and mask possessing an exact match for the task-relevant feature – e.g., both containing blue when the task-relevant feature is colour.

regarding orientation would be easier to unbind from the mask than would colour information[8].

To maximise the influence of this manipulation, in trials when target and mask possessed similarity for only one feature (i.e., *the masked feature*), the mask contained no information relating to the other feature (i.e., *the non-masked feature*). For example, in *colour only masked trials* (See Table 1) when the target stimulus contained the colour blue and a right oblique orientation, the trailing mask also contained the colour blue but possessed no information relating to orientation. It was anticipated that a total absence of masking information relating to the feature held dissimilar between target and mask would further promote confirmation of a target-object hypothesis for this feature. While unbinding target/mask information is most difficult when both stimuli contain an exact match for the task-relevant feature (Enns & Oriet, 2007), I suspected that unbinding might be least difficult when information regarding the task-relevant feature is totally omitted from the mask – even less difficult than when target and mask contain different versions of the task-relevant feature (e.g., target and mask containing different colours).

To explain, having target and mask 'match' for a task-relevant feature – e.g., both containing the colour blue – may make the unbinding process more difficult not because it is "difficult to determine" what information relating to this feature belongs to target and mask[9], but rather because the same neurons (e.g., those coding for blue) are important for both stimuli. When target and mask contain different versions of a

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[8] Recall that according to the *Reentrant Theory of Successful Backward Masking*, successfully reporting the identity of a target feature requires unbinding target and mask information after being erroneously integrated across the two stimulus displays (object updating). Only after successfully unbinding target and mask information can a match be established between the target-object hypothesis and a updated representation of sensory information relating to the target stimulus.

[9] As described at an earlier point in this chapter, the reentrant theory of successful backward masking suggest unbinding target/mask information after the process of object updating is complicated by similarity between target and mask because similarity "makes it more difficult to determine what information belongs to the target vs. the mask".

task-relevant feature – e.g., target being red while the mask is blue – different but closely adjacent neurons are active for each stimulus. Closely adjacent neurons easily influence one another through processes of excitation and inhibition. Unbinding target information relating to a specific task-relevant feature from the process of object updating may then be easiest when the specific neurons that process that feature, and those neurons closely adjacent to them, are not required to process the mask. Because colour analysis is carried out predominately along ventral stream pathways in striate and extrastriate visual cortex while orientation is processed predominately along dorsal stream pathways (e.g., Goodale & Milner, 1992), a significant amount of spatial distance and functional independence can be achieved on behalf of the neurons coding for masked and non-masked task-relevant target features in Experiment 1. Thus, when information relating to the non-masked feature is omitted from the mask, unbinding target information for this feature from the process of object updating should be easy, as neither the same nor closely adjacent neurons are important for processing the mask.

My specific hypotheses for Experiment 1 were as follows. If observers establish a single target-object hypothesis for both task-relevant features then failure to confirm this hypothesis on the basis of either feature should result in a lack of conscious awareness for the entire object. This should result in an equally low level of report accuracy for colour and orientation responses regardless of which task-relevant feature is held similar between target and mask. Alternatively, if two separate target-object hypotheses are established, failure to confirm one hypothesis should not interfere with confirmation of the other. This should result in a significantly lower level of report accuracy for the task-relevant feature held similar

between target and mask (i.e., the masked feature) relative to the feature held dissimilar between stimuli (i.e., the non-masked feature).

Methods

Participants

Fourteen undergraduate psychology students (mean age 24.6 years; 5 females, 9 males) from the Bangor University volunteered to participate. All participants reported normal to corrected-to-normal visual acuity.

Visual Apparatuses

Stimuli were viewed on a twenty-inch CRT monitor – IIyama Vision Master Model 506. During the session participants were seated approximately 62 centimetres from the screen. Stimuli were projected with E-prime Version 1.1 experimental software (Psychology Software Tools, Inc., Pittsburgh, PA.).

Task Parameters

A target and a mask were presented in each trial in the centre of a black screen. At the beginning of each trial a red fixation cross appeared for 2000 ms in the centre of the screen, which turned white during the last 500 ms as a final warning that the trial was about to begin. Following offset of fixation cross a blank interval appeared for 500 ms. At the end of this 500 ms interval the target appeared and was present for 34 ms. Mask onset occurred at 85 ms SOA (51 ms ISI). The mask was also present for 34 ms.

The observer's task was to identify the colour and orientation of the target stimulus. In total there were 12 possible targets that were sampled randomly across all trials. As illustrated in Figure 2, for the target image there were three possible colours (x) four possible spatial orientations. The experimental manipulation in Experiment 1 varied contents of the trailing pattern interruption mask. As summarised in Table 1 there were four trial types. For *both-feature masked trials* the mask contained information relating to colour and orientation. In *colour-only masked trials* the mask contained colour information but no orientation information. In *orientation-only masked trials* the mask contained orientation information but no colour information. Critically, when both target and mask contained either colour or orientation, the mask always contained the specific colour or orientation contained in the target. For these trials target and mask both contained only one orientation. For colour however, the mask contained three colours – i.e., the colour contained in the target plus two more. The colours contained in the mask were those that could potentially occur within the target (Red, Green, and Blue). The use of multi-coloured masks was based on the results of pilot testing[10]. For the fourth trial type – *no-feature masked trials* - the target +1 stimulus contained neither colour nor orientation. These trials were meant to serve as a control measure reflecting participants' ability to report both target features in the absence of masking

[10] A pilot test was carried out (n = 15) for which target and mask *both* contained only a *single* colour and orientation. The pilot test consisted of only a single trial-type – both target and mask contained an identical colour and orientation. The colour and orientation of the target and mask did randomly change between trials. Participants were required to report the colour and orientation of the target. Accuracy was at ceiling for the colour judgement but significantly lower for orientation. These results seemed to suggest that without the influence of additional trials when target and mask contained different colours – like in Enns & Oriet's (2007) experiment – participants were able to develop a strategy allowing them to perceive target and mask as simply a repetitive presentation of the same information (i.e., colour). Such a strategy then undermined the effects of task-relevant similarity for target masking as suggested by Enns & Oriet. Why participants were unable to adopt a similar strategy for orientation was unclear. Using a multi-colour mask in the current Experiment 1 was expected to allow for task-relevant similarity of colour – e.g., target and mask both contain blue – yet prevent the same strategy from being adopted as in the pilot study.

interference. Thus, the stimulus following the target was not anticipated to serve as an effective mask. In addition to not possessing task relevant features, the multi-dot pattern used in these trials was spatially diffused. That is to say, only a small portion of the target overlapped spatially with the dot pattern. A large degree of spatial overlap between target and mask is a requirement for pattern masking (e.g., Breitmeyer & Ogman, 2006). The multi-dot pattern also was not expected to serve as a meta-contrast mask. As already indicated, meta-contrast masking requires that a mask surround the contours of a target (e.g., Enns & Oriet, 2007). While the multi-dot pattern was larger than the target, large segments of the target contour were not outlined. As illustrated along with other target/mask stimuli in Figure 2, *colour-only masked trials* also contained a multi-dot pattern. However, this dot pattern was much more spatially compact than the pattern used in *no-feature masked trials*. For this reason the colour dot pattern was expected to serve as an effective backward pattern interruption mask. Colour and luminance information for target and mask stimuli can be viewed in Table 2.

In order to insure a complete spatial overlap between stimuli, target stimuli were 4 cm in width and 8 cm in length. Mask stimuli possessing one of the four spatial orientations were 6 cm in width and 10 cm in length. The multi-dot pattern used in *colour-only masked trials* was approximately 8 cm in diameter. The target+1 stimulus used in *no-feature masked trials* was approximately 12 cm in diameter. After mask offset a 500 ms blank interval appeared before participants were prompted to respond. Separate response screens were used to prompt for target colour and spatial orientation. For all trials participants were prompted for the orientation response first and the colour response second. Responses were entered by pressing keys corresponding to 1,2,3, or 4 on the keyboard. Each number represented

a choice illustrated on the response screen (See Figure 2). The task was completed in a within-subjects design with a grand total of 200 trials – 50 trials for each of four trial types. Trial types were intermixed randomly across the 200 trials.

Procedure

Once participants arrived they were provided with a brief description of the task and asked to give their informed consent. A short 5-trial practice set was provided during which questions could be asked. The actual experiment was completed in two identical 100 trial blocks. Between each block a 2-minute break was offered. The entire experiment lasted between 45 and 60 minutes varying across participants.

Table 1

Four Configurations of Target/Mask Contents used in Experiment 1 & 2

	Target Contents	Mask Contents
Configuration 1 **(Both-Feature Mask Trials)**	Colour and Orientation	Colour and Orientation
Configuration 2 **(No-Feature Mask Trials)**	Colour and Orientation	Neither Colour no Orientation
Configuration 3 **(Colour-Only Mask Trials)**	Colour and Orientation	Colour with no Orientation
Configuration 4 **(Orientation-Only Mask Trials)**	Colour and Orientation	Orientation with no Colour

Note: Table 1 list the four configurations for target/mask contents used in Experiment 1 & 2 of the current chapter. For Experiment 2 these manipulations refer to the T2 stimulus and its mask within an Attentional Blink task. When discussing these experiments, results will be referred to as occurring for either *Both-Feature Mask Trials*, *No-Feature Mask Trials*, *Colour-Only Mask Trials*, or *Orientation-Only Mask Trials*.

Table 2

Luminance and Chromaticity Values for Experiments 1 & 2

	Luminance	CIE Colour Space		SRGB Gamut		
Red	46.5 cd/m^2	x = .615	y = .338	R = 253	G = 0	B = 0
Blue	46.5 cd/m^2	x = .203	y = .172	R = 94	G = 94	B =255
Green	46.5 cd/m^2	x = .295	y = .550	R = 0	G =142	B = 0
Gray	46.5 cd/m^2	----------		R = 192	G =192	B = 192
Black	.06 cd/m^2	----------		R = 0	G = 0	B = 0

Note: Luminance (LM) was measured in candelas per square meter (cd/m^2). *Red/Green/Blue* values are provided from the standard RGB (sRGB) color gamut used by Microsoft Windows – the operating system used to present stimuli. Numerical representations for R,G, and B represent the proportion of red, green, and blue light contained within a given display of chromaticity. The sRGB gamut produces achromatic displays (i.e., black, white, and gray) by merging equal amount of red, green, and blue light waves. X and Y coordinates are also provided for the CIE Colour Space.

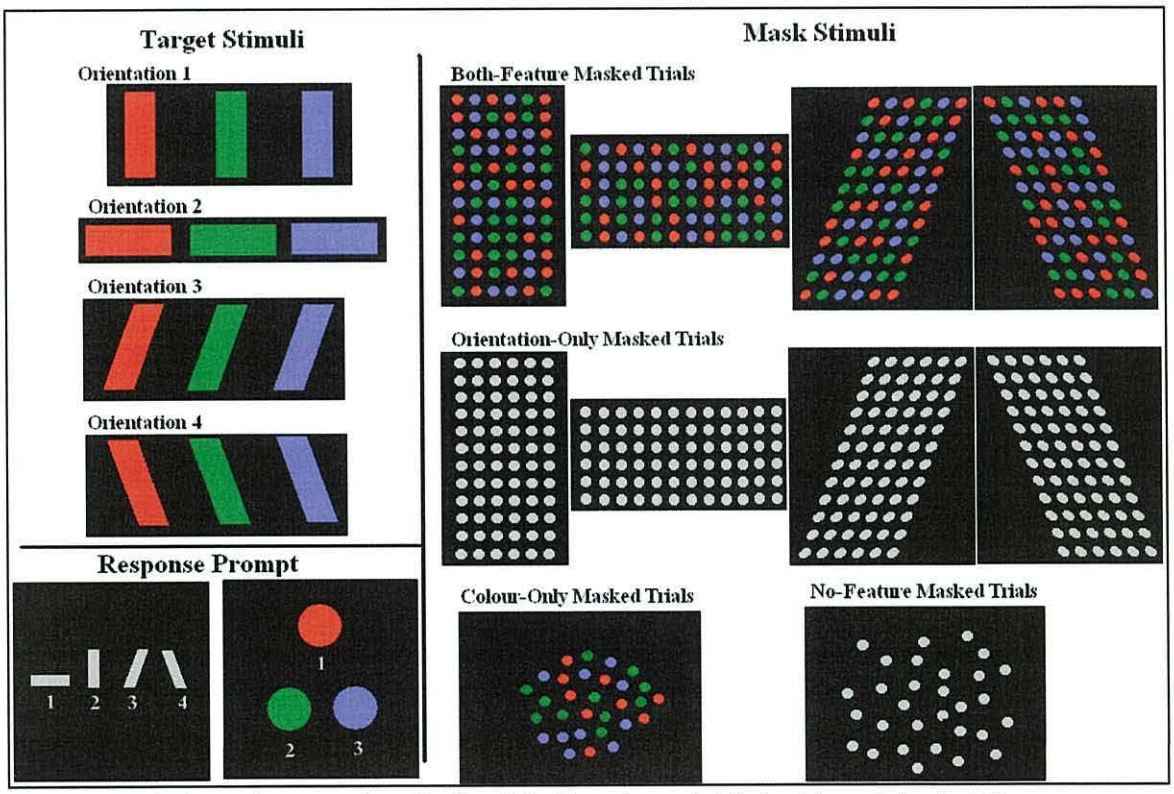

Figure 2: Variations of target and mask stimuli for Experiment 1. Mask with spatial orientations consisted for 72 individual dots. Mask with orientation and colour consisted of 24 red, 24 blue, and 24 green dots. Mask with no orientation consisted for 30 individual dots. The mask with colour but no orientation consisted for 10 dots in each of the three colour.

Results

A within-subjects multivariate analysis of variance (MANOVA) was carried out to assess main effects of the factor Trial-Type (version of mask) across the two dependent variables (orientation and colour accuracy). Follow-up single-factor univariate ANOVAs were then carried out for each dependent variable separately. Post-hoc comparisons were carried out using the Tukey's HSD test. All statistical tests were deemed significant at the .05 level.

The initial multivariate analysis revealed that manipulating task-relevant feature similarity between target and mask significantly influenced report accuracy, as a main effect was found for Trial-Type, *Wilk's Lamda* = .017, $F(6, 8) = 75.69$, $p < .001$. Univariate analysis revealed this effect to be significant for both orientation responses $F(3, 39) = 98.92$, $MSE = 33.13$, $p < .001$, and colour responses $F(3, 39) = 103.45$, $MSE = 42.59$, $p < .001$.

Post-Hoc Comparisons. For *no-feature masked trials* target accuracy for both features was close to ceiling (above 90%). For these trials accuracy for colour and orientation responses did not significantly differ. Accuracy for colour and orientation responses also did not differ significantly for *both-feature masked trials*. Accuracy for both colour and orientation responses was significantly lower in *both-feature masked trials* than in *no-feature masked trials*.

In *colour-only masked trials* accuracy for orientation responses was significantly better than for colour responses. Accuracy for colour and orientation also differed significantly for *orientation-only masked trials*. For these trials accuracy was significantly better for colour than for orientation. For both *colour-*

only masked trials and *orientation-only masked trials*, accuracy for the masked[11] feature was not significantly different than accuracy for the same feature in *both-feature masked trials*. Also occurring for both *colour-only masked trials* and *orientation-only masked trials*, accuracy for the non-masked feature was significantly better than accuracy for the same feature in *both-feature masked trials*, but significantly worse than accuracy for the same feature in *no-feature masked trials*. Accuracy for non-masked features did not significantly differ between *colour-only masked trials* and *orientation-only masked trials*. Between *colour-only masked trials* and *orientation-only masked trials*, accuracy for masked features also did not differ (See Figure 3 and Table 3).

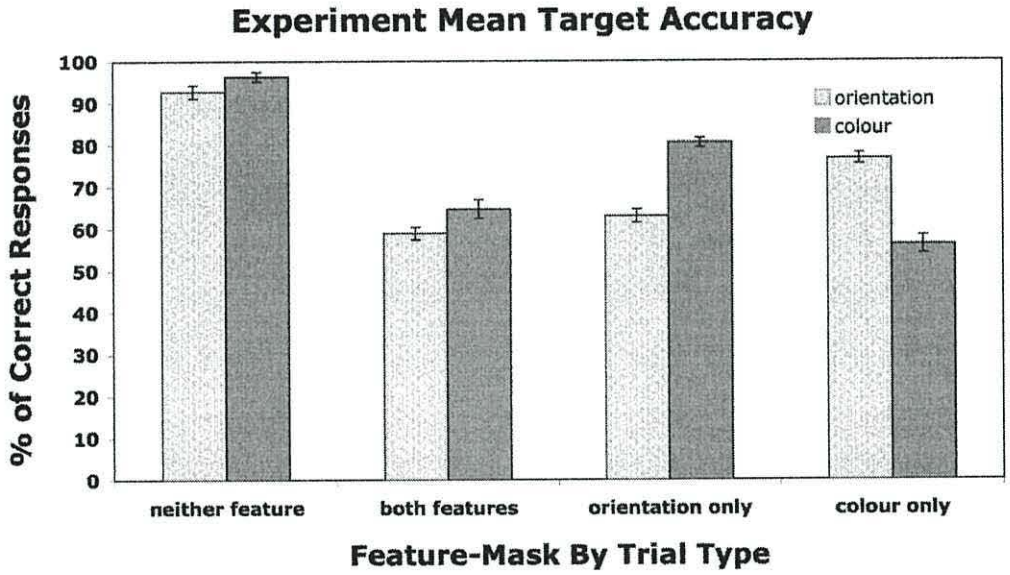

Figure 3. Mean Performance for Trial-Type (x) Response Types. Error bars represent standard error of the mea

[11] As indicated earlier in the introduction to Experiment 1, "masked features" are those that were held similar between target and mask. "Non-masked features" are those held dissimilar between target and mask.

Table 3

Mean Performance for Experiment 1

Trial-Type	Response-Type	
No Feature Masked Trials	Orientation	92.72 (*6.00*) a
	Colour	96.28 (*4.28*) a
Both Feature Masked Trials	Orientation	58.85 (*5.53*) b
	Colour	64.71 (*8.36*) b
Orientation-Only Masked Trials	Orientation	63.00 (*5.85*) b
	Colour	80.57 (*4.10*) c
Colour-Only Masked Trials	Orientation	76.71 (*5.06*) c
	Colour	56.14 (*7.81*) b

Note: Mean performances for Trial-Type (x) Response Types. Respective standard deviations are listed in parenthesis. Means sharing the designation "a", "b", or "c" did *NOT* significantly differ with Tukey's HSD post hoc test.

Discussion

As anticipated the target+1 item occurring in no-feature masked trials did not serve as an effective backward pattern interruption mask. This is apparent from the ceiling level performance for both colour and orientation responses in these trials. In accord with previous experiments examining the nature of multiple object judgements, *no-feature masked trials* indicated that participants were extremely accurate in making two simultaneous judgements about a single target object (Duncan, 1984, 1986). Alternatively, in *both-feature masked trials,* visual masking significantly influenced both colour and orientation responses. In these trials the influence of visual masking was equivalent for both task-relevant features. This is one of three outcomes that suggest Experiment 1 stimuli were successful in influencing colour and orientation judgements equally on the basis of task-relevant

similarity between target and mask. The second outcome to indicate a similar influence of task-relevant similarity for colour and orientation is the lack of significant differences in accuracy between masked features for *colour-only masked* and *orientation-only masked trials*. Further to this point, accuracy for masked features in *colour-only masked* and *orientation-only masked* trials also did not differ significantly from performance for the same feature in *both-feature masked* trials.

Critical to the driving hypotheses of Experiment 1, in *colour-only masked* and *orientation-only masked* trials significant differences in report accuracy emerged between colour and orientation responses. As previously explained, this pattern of results suggests that multiple target-object hypotheses are established under circumstances where multiple task-relevant features exist for a single target object. Had a single target-object hypothesis been established on behalf of both task-relevant features, then failure to confirm that hypothesis on the basis of either feature would have resulted in an absence of conscious awareness for the entire target. The end result would have been an inability to accurately report upon either feature, which would have manifested in the form of equally poor performance for colour and orientation responses in both *colour-only masked* and *orientation-only masked* trials. Rather, for a significant number of these trials the target-object hypothesis established for the non-masked feature appears to have been successfully confirmed, while the hypothesis established for the masked feature was not.

Importantly, in both *colour-only masked* and *orientation-only masked trials* accuracy for the non-masked feature was not at ceiling. Despite being held as dissimilar between target and mask, this outcome indicates that the target-object hypothesis established for this feature failed to be confirmed for several trials. This result is not surprising, and speaks to two very important general points. First,

despite dissimilarity between stimuli, target information relating to the non-masked feature still had to be unbound from the single target/mask representation produced by the process of object updating. While target/mask similarity for a task-relevant feature reduces the likelihood of successfully unbinding this information, the absence of similarity does not guarantee success. Second, although task-relevant target/mask similarity was the focus of Experiment 1, there were other masking issues that also contributed to performance such as image contrast and the SOA between target and mask. Critically, Experiment 1 data suggest no reason to think such factors confounded the influence of task-relevant similarity. Therefore, bear in mind throughout the remainder of this chapter that I do not deny the importance of such factors. Rather, my discussion only focuses on the implications for target/mask similarity for multiple task-relevant features.

In the general discussion section of this chapter implications for establishing multiple target-object hypotheses will be discussed. Looking forward to this discussion, establishing and testing multiple hypotheses is no doubt more costly in terms of information processing resources than a single hypothesis. So how does object processing benefit from the extra expenditure of resources? Establishing multiple target-object hypotheses in the presence of distinctly different forms of task-relevant information may have emerged over the course of cognitive evolution as a way to cope with partial losses of information relating to important stimuli. As will be discussed, the visual system contains a great deal of functional independence when processing various aspects of a single object (e.g., feature analyzers located along ventral vs. dorsal pathways). It is commonly believed that this functional independence makes the visual system prone to selective deficits in object processing (Humphreys & Riddoch, 2006).

Experiment 2

In Experiment 2 I inserted a masking manipulation similar to Experiment 1 as the second (T2) of two targets in an *Attentional Blink* (*AB*) task. The AB phenomenon demonstrates that for a brief 500 ms interval after a target stimulus has occurred attention is unavailable for processing other stimuli to a level sufficient for accurate report (e.g., Raymond, Shapiro, & Arnell, 1992). It has been suggested that the object representation of T2 – the second target – is degraded during the 500 ms interval and thus is not available for report. How T2 becomes degraded is however a debated issue, with proposed ideas ranging from T2 having to wait to enter a later stage of processing that is occupied by T1 – the first target (the *two-stage model*; Chun & Potter, 1995), to T2 receiving too few processing resources due to a low priority rating assigned during short-term memory (Shapiro, Raymond, & Arnell, 1994). Not debated by such models is that visual masking plays a key role in degrading T2. For example, in the two-stage model the mask following T2 has been suggested to over-write the encoded T2 representation while the second stage is occupied by T1.

Here I examined how Experiment 1 results relating to *colour-only masked* and *orientation-only masked trials* stand up under the temporary absence of attention that occurs during the AB. Leading into Experiment 2 I predicted these results might be influenced in two possible ways. First, less availability of attention may magnify differences in accuracy between masked and non-masked features for these trials. As indicated, unbinding information relating to target and mask from the process of object updating is cognitively demanding. Under the demands of divided attention operations relating to object processing are likely to be less equipped in terms of available resources to unbind target/mask information. Although less access to

resources is likely to influence performance for both the masked and non-masked feature, I proposed behavioural results would show a stronger influence for the masked feature. Unlike for the non-masked feature, during the AB interval, unbinding target and mask information relating to the masked feature is likely to be complicated by both a similarity between stimuli as well as a general reduction in access to processing resources.

The second possible outcome would require abandoning multiple target-object hypotheses for a single hypothesis. As mentioned in the discussion of Experiment 1, establishing two such hypotheses is no doubt more costly than a single hypothesis. I therefore proposed that the occurrence of attentionally demanding stimuli prior to T2 might trigger a recalibration of processes involved in formulating object hypotheses for future stimuli. A recalibration causing only one target-object hypothesis to be established for both colour and orientation may serve as a mechanism for maximising the efficiency of object processing under conditions of extremely limited cognitive resources. If under the influence of divided attention separate target-object hypotheses are no longer established for each task-relevant feature, then this should be clearly indicated by a lack of significant differences in accuracy for colour and orientation responses in *colour-only masked* and *orientation-only masked trials*.

The idea that information processes can be calibrated to most effectively handle task-relevant information in the presence of varying levels of attentionally competitive information is not unprecedented. One example involving the AB can be found in the investigation of magneto-electrical potentials carried out by Gross and colleagues (2004, 2006). As briefly indicated in Chapter One of the current document, these authors report differences in beta-band synchronisation between

target-and non-target stimuli across a tempo-parietal-frontal network. For No-AB trials beta-band synchronisation was much stronger for target-related activation than for non-target activation. Comparatively, synchronisation to non-target stimuli was increased significantly during a condition when the RSVP stream contained only non-target items. Gross and colleagues interpret this result as indicating that when participants expect the occurrence of task-relevant items, systems of attentional processing recalibrate their handling of task-irrelevant items in order to 'preserve' cognitive resources for the handling of task-relevant stimuli. Establishing a single target-object hypothesis on behalf of both task-relevant T2 features in Experiment 2 may represent another mechanism for preserving cognitive resources in order to most effectively handle task-relevant stimuli. As Experiment 2 results show, surprisingly neither of the two potential outcomes mentioned here actually occurred.

Methods

Participants

Twenty-Two undergraduate psychology students (mean age 22.7 years; 17 females, 5 males) from the University of Wales, Bangor volunteered to participate. All participants reported normal to corrected-to-normal visual acuity and had no knowledge of the Japanese language.

Visual Apparatuses

Stimuli were viewed on a twenty-inch CRT monitor – IIyama Vision Master Model 506. During the session participants were seated approximately 62 centimetres from the screen. Stimuli were projected with E-prime Version 1.1 experimental software (Psychology Software Tools, Inc., Pittsburgh, PA.).

Task Parameters

RSVP Stream – Non-Target Distracters. Each trial consisted of a rapid-serial-presentation (RSVP) stream of 24 items (i.e., 22 non-targets and 2 targets). All stream items were presented in the centre of black background. Across all trials, with the exception of the T1, T2, and T2+1 items, RSVP items consisted of a grey Japanese character. Twelve possible Japanese characters were presented as non-target distracter items in 26-point black font (see Figure 4).

First Target (T1). Across all trials T1 was presented as one of three possible letters of the English Alphabet – B, G, or S presented in 26-point New Times Roman white font. The temporal position of the T1 stimulus varied randomly between the 6th and 12th items of the RSVP stream. T1 always preceded T2 in the RSVP stream. The T1 task was to report the identity of the white English Alphabet letter. The chromatic and luminance values for T1 were 102.3 candelas per meter squared and R = 255, G = 255, B = 255.

Second Target (T2). Across all trials the T2 stimulus consisted of a solid geometric figure – a semi-circle. The T2 stimulus could appear in three possible colours (x) four possible spatial orientations. The size of the semi-circle was consistent across all trials – approximately the same size as the language characters presented in 26-point font. Participants were required to report the spatial orientation and the colour of T2. The four possible spatial orientations for T2 can be viewed in Figure 4 (See Response Prompt 2). Chromatic and luminance values for the three possible colours (Red, Green, and Blue) were identical to Experiment 1.

The T2 Mask. The experimental manipulation in Experiment 2 varied contents of the T2+1 item – i.e., T2 mask. There were four trial types. For *both-*

feature masked trials the T2 mask contained information relating to colour and orientation. In *colour-only masked trials* the T2 mask contained colour information but no orientation information. In *orientation-only masked trials* the T2 mask contained orientation information but no colour information. Critically, when both target and mask contained either colour or orientation, the mask always contained the specific colour or orientation contained in the target. For these trials target and mask both contained only one orientation. For colour however, the mask contained three colours – i.e., the colour contained in the target plus two more. The colours contained in the T2 mask were those that could potentially occur within T2 itself (Red, Green, and Blue). The use of multi-coloured T2 masks was based on the same pilot test results mentioned in Experiment 1 methods. Spatial orientations of the T2 mask were also those that could occur for T2. For the fourth trial type – *no-feature masked trials* - the T2 +1 stimulus contained neither colour nor orientation. These trials were meant to serve as a control measure reflecting participants' ability to report both T2 features in the absence of masking interference. As explained in the method for Experiment 1, it was anticipated that the spatially diffused nature of this stimulus would prevent it from serving as an effective mask. Also in accord with Experiment 1 methods, the multi-dot pattern masking T2 in *colour-only masked trials* was much more spatially compact than the dot pattern used in *no-feature masked trials*. For this reason the colour dot pattern was expected to serve as an effective backward pattern interruption mask. Colour and luminance information for target and mask stimuli was identical to that of Experiment 1 (See Table 2).

In order to insure a complete spatial overlap between stimuli, the T2 stimulus was 1.2 cm in width and 1.5 cm in length. Mask stimuli possessing one of the four spatial orientations were 2.5 cm in width and 3.2 cm in length. The multi-dot pattern

used in *colour-only masked trials* was approximately 3 cm in diameter. The T2+1 stimulus used in *no-feature masked trials* was approximately 5 cm in diameter.

RSVP Temporal Parameters. At the beginning of each trial a fixation cross appeared lasting for 2000 ms. During the last 500 ms of this interval the fixation cross changed to white as a warning that the trial was about to begin. After fixation offset a 500 ms blank interval occurred followed by RSVP onset. All RSVP items were presented for duration of 34 ms followed by a 68 ms blank interval ISI. Each subsequent RSVP item thus appeared at intervals of 102 ms SOA. For each of the four trial types T2 was presented with variable SOA relative to T1 (i.e., either 306 ms SOA (short lag) or 714 ms SOA (long lag)).

Randomized Trial-Type Design and Responses. A total of 100 trials was presented for each trial type - 50 per lag position. The experiment consisted of a grand total of 400 trials. The Experiment was completed as two identical trial-blocks. Each block consisted of 200 trials – 50 trials from each trial type randomly intermixed. All responses were given at the end of each trial by entering B, G, or S for T1 and either 1, 2, 3, or 4 for T2 colour and spatial orientation responses. For all three responses participants were reminded of response-options at the end of every trial. Across all trials participants were prompted for the T1 response first. The order of T2 responses was held constant across all trials (Orientation responses were given first; Colour responses were given second). Visual representations of response prompt screens can be viewed in Figure 4.

Japanese Characters

Visual information relating to colour and spatial orientation is processed with a great deal of functional independence across different neuronal pathways within

the ventral/dorsal division of visual processing (e.g., Goodale & Milner, 1992). The use of Japanese characters was intended to help balance processing demands placed on ventral and dorsal pathways post onset of the T2 stimulus. Due to the rapid temporal parameters of the RSVP stream it may be possible for the T2+2 item to exert some degree of masking interference (Breitmeyer & Ogman, 2006). With no knowledge of the Japanese language participants should perceive the characters as nonsense patterns. Had for example English alphabet letters been used as non-target distracters, participants would have more or less automatically processed their identity. Identity is strongly associated with ventral stream processing, specifically in the inferior temporal lobe region (e.g., Duncan, 2006). Thus, presenting the T2+2 item as an English letter would have added to demands placed on the ventral stream.

Importantly, the use of Japanese symbols did not perfectly equate the processing demands of ventral and dorsal pathways post T2. The ventral stream no doubt processed identity of T2 colour (e.g., Red) and also identity of the T2 shape (i.e., semi-circle). The dorsal stream processed not only orientation but global structure of the T2 shape as well. Furthermore, though unable to process the meaning of Japanese characters, participants were likely able to process an axis of orientation for these stimuli.

In sum, although the use of Japanese characters was intended to help equate processing across ventral and dorsal streams, this manipulation is unlikely to have been successful in this respect. It is unclear what effects equal vs. unequal processing demands on ventral/dorsal pathways have on empirical results arising from differences in task-relevant similarities between target and mask. At the time of designing Experiment 2 however, for the purpose of testing such effects for colour

and spatial orientation, attempting to maintain equal processing demands for ventral and dorsal pathways seemed a pertinent method of experimental control.

Procedure

Once participants arrived they were provided with a brief description of the task and asked to give their informed consent. A short 12 trial practice set was provided during which questions could be asked. Three repetitions of each trial type were included in the practice set. Between each experimental block of 200 trials a 2-minute break was offered. The entire experiment lasted between 60 and 90 minutes varying across participants.

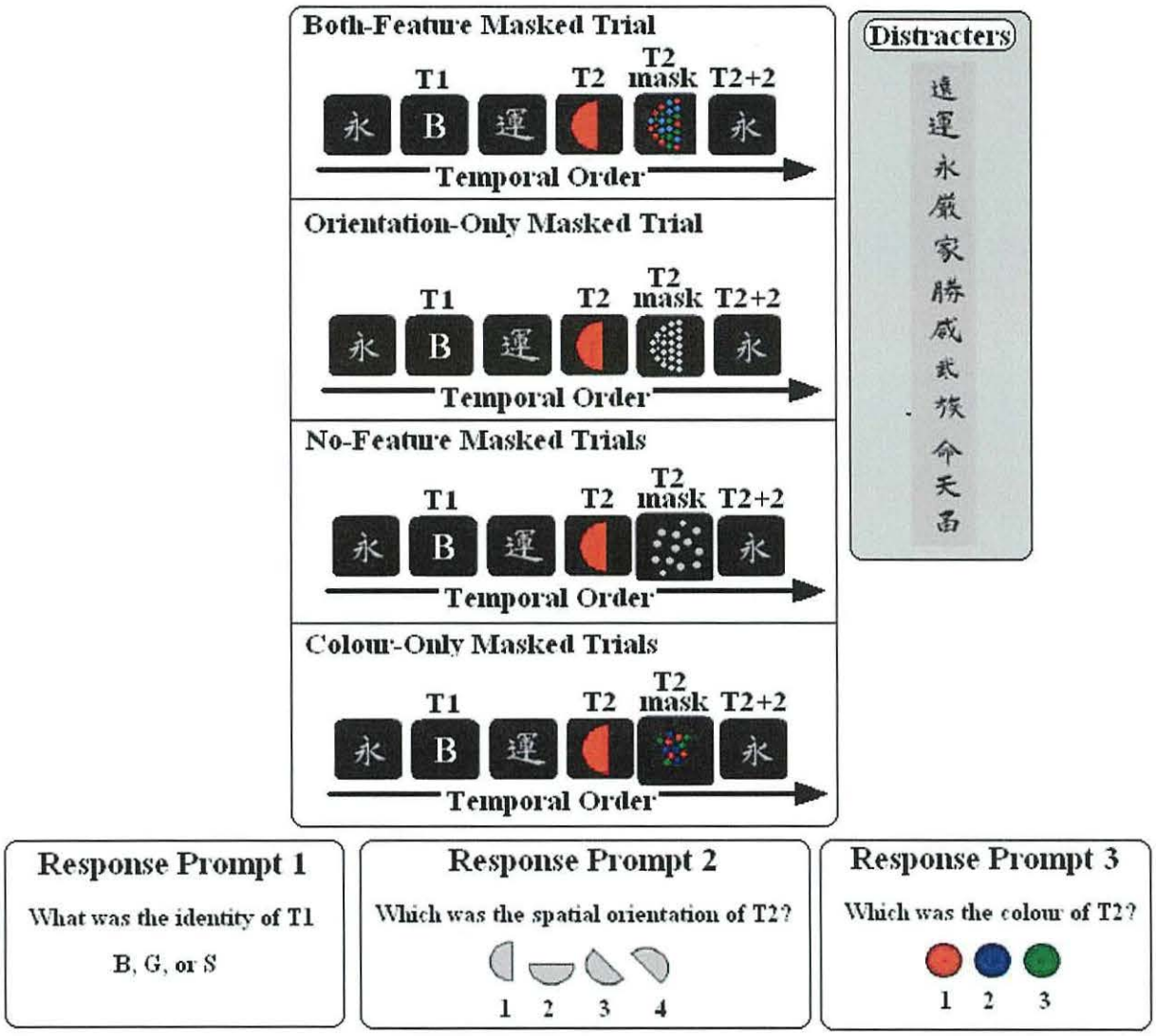

Figure 4. Visual representation of the four trial types from Experiment 2. Response Prompt 2 illustrates the four spatial orientations that could appears as T2 and the T2 mask. T2 masks containing orientation was comprised of 24 dots, 8 in each of the three colours (Red, Green, and Blue). The multi-dot patterns used for T2 mask without orientation were comprised of 21 dots, 7 in each of the three colours – the number of dots for these masks is not accurately represented in the above image due to the size of the figure image.

Results

T1 performance was analysed with a 2x4 within-subjects analysis of variance (ANOVA) with the factors of Trial-Type (version of mask) and Lag (short vs. long). Only trials for which T1 was correctly identified were used to calculate T2 performance. This restriction served the purpose of insuring statistical evaluations of T2 performance reflected that which occurs under the full dual-task demands provided by the Attentional Blink. Analysis of T2 performance was carried out in two stages. First, a within-subjects MANOVA was carried out to detect main effects of independent factors on the two dependent variables (colour and orientation responses). Second, follow-up 2x4 within-subjects univariate ANOVAs were then carried out for each dependent variable separately.

An additional analysis was carried out across Experiments 1 and 2 to assess changes in the magnitude of differences in accuracy between masked and non-masked features for *colour-only masked* and *orientation-only masked trials*. For these two trial types, difference scores were calculated for each participant. For example, in *colour-only masked trials* when participants on average responded more accurately to orientation than to colour, each participant's colour score was subtracted from their orientation score. From Experiment 2 data difference scores were calculated for short-lag trials only. Difference scores from Experiment 1 and Experiment 2 were analysed in a mixed 2x2 ANOVA for the between-subjects factor of Experiment (i.e., Experiment 1 vs. Experiment 2) and the within subjects factor of Trial-Type (i.e., colour-only masked vs. orientation-only masked trials). Long lag trials from Experiment 2 were not included in the cross-experiment analysis due to the pattern of results that emerged for these trials. The unequal sample size between Experiments (Exp. 1 n = 14; Exp. 2 n = 22) was not anticipated to yield significant

confounds for the mixed-factor ANOVA, as the number of participants was not influenced by any experimental factor[12]. All post-hoc comparisons were carried out using the Tukey's HSD test. All statistical tests were deemed significant at the .05 level.

Experiment 2 T1 Accuracy

Task-relevant similarity between T2 and its mask did not influence T1 performance as no main effect of Trial-Type was found $F(3, 63) = 1.83$, $MSE = 26.39$, $p = .150$. No effect of Lag $F(1, 21) = 5.73$, $MSE = 33.63$, $p > .05$ revealed T1 performance did not differ as a function of the inter-target interval. No interaction between Trial-Type and Lag was found either $F(3, 63) = .608$, $MSE = 38.23$, $p = .612$ (See Figure 5 and Table 4).

Experiment 2 T2 Accuracy (Multivariate Analysis)

Task-relevant similarity between T2 and its mask did significantly influence T2 accuracy. This was reflected in main effect of Trial-Type, *Wilk's Lamda* = .064, $F(6, 16) = 39.20$, $p < .001$. An effect of Lag, *Wilk's Lamda* = .066, $F(2, 20) = 141.60$, $p < .001$, indicated that T2 accuracy significantly differed as a function of the inter-target interval. An interaction was also present between factors, *Wilk's Lamda* = .104, $F(6, 16) = 22.87$, $p < .001$.

[12] When experimental factors relevant to hypothesis influence sample size significant confounds exist in the data. For example, a study examining treatment effects for patients with various levels of depression might find that unequal sample sizes emerge for different treatments. Such a difference could arise due to a relationship between the severity of depression and the likelihood of withdrawing early from the study.

Experiment 2 T2 Accuracy (Univariate Analysis)

Colour Attribute. A main effect of Trial-Type, $F(3, 63) = 15.36$, $MSE = 48.27$, $p < .001$, indicated that accuracy for colour responses significantly differed as a function of similarity between T2 and its mask. Accuracy for colour responses also differed as a function of the inter-target interval – as reflected by a main effect of Lag $F(1, 21) = 178.78$, $MSE = 46.51$, $p < .001$. An interaction was also present between factors $F(3, 63) = 25.30$, $MSE = 56.41$, $p < .001$ (See Figure 6 and Table 5).

Orientation Attribute. A main effect of Trial-Type, $F(3, 63) = 38.27$, $MSE = 44.35$, $p < .001$, indicated that accuracy for orientation responses significantly differed as a function of feature similarity between T2 and its mask. Accuracy for orientation responses also differed as a function of the inter-target interval – as reflected by a main effect of Lag $F(1, 21) = 203.18$, $MSE = 40.85$, $p < .001$. An interaction was also present between factors $F(3, 63) = 23.64$, $MSE = 41.61$, $p < .001$ (See Figure 7 and Table 5).

Experiment 2 Post Hoc Comparisons for Colour and Orientation Responses at Short Lag. In *no-feature masked trials* accuracy for both colour and orientation responses was at ceiling – at or above 90%. Accuracy for colour and orientation responses did not significantly differ within *no-feature masked trials*. Relative to *no-feature masked trials*, accuracy for both colour and orientation responses was significantly diminished for *both-feature masked trials*. Accuracy for colour and orientation responses did not significantly differ within *both-feature masked trials*. For *colour-only masked* and *orientation only masked trials*, accuracy for colour and orientation responses differed significantly. In *colour-only masked trials* accuracy for orientation responses was significantly better than for colour responses. The opposite was true for *orientation-only masked trials* for which accuracy for colour

responses was significantly better than for orientation responses. For both *colour-only masked trials* and *orientation-only masked trials*, accuracy for the masked[13] feature was not significantly different than accuracy for the same feature in *both-feature masked trials*. Also occurring for both *colour-only masked trials* and *orientation-only masked trials*, accuracy for the non-masked feature was significantly better than accuracy for the same feature in *both-feature masked trials*, but significantly worse than accuracy for the same feature in *no-feature masked trials*. Accuracy for non-masked features did not significantly differ between *colour-only masked trials* and *orientation-only masked trials*. Between *colour-only masked trials* and *orientation-only masked trials*, accuracy for masked features also did not differ (See Figures 6, 7 and Table 5).

Experiment 2 Post Hoc Comparisons for Colour and Orientation Responses at Long Lag. Colour and orientation responses did not differ significantly as a function of trial type during these trials (See Figures 6, 7, and Table 5). Accuracy for colour and orientation responses for long lag trials ranged between 89.63% and 95.03% across all four trial types.

Cross-Experiment Analysis (Experiments 1 and 2)

As indicated by the between-subjects effect of Experiment, $F(1, 34) = 15.74$, $MSE = 106.16$, $p < .001$, difference scores did differ significantly across Experiment 1 and 2. Significant differences were also present between *colour-only masked* and *orientation-only masked trials* indicated by a significantly effect of Trial-Type $F(1, 34) = 6.01$, $MSE = 74.30$, $p < .05$. No interaction was present between factors $F(1,$

[13] As indicated earlier in the introduction to Experiment 1, "masked features" are those that are held similar between target and mask. "Non-masked features" are those held dissimilar between target and mask.

34) = .546, *MSE* = 40.55, *p* = .465 (See Table 6). Post hoc comparisons revealed that difference scores for both *colour-only masked* and *orientation-only masked trials* were significantly larger in Experiment 1 than in Experiment 2.

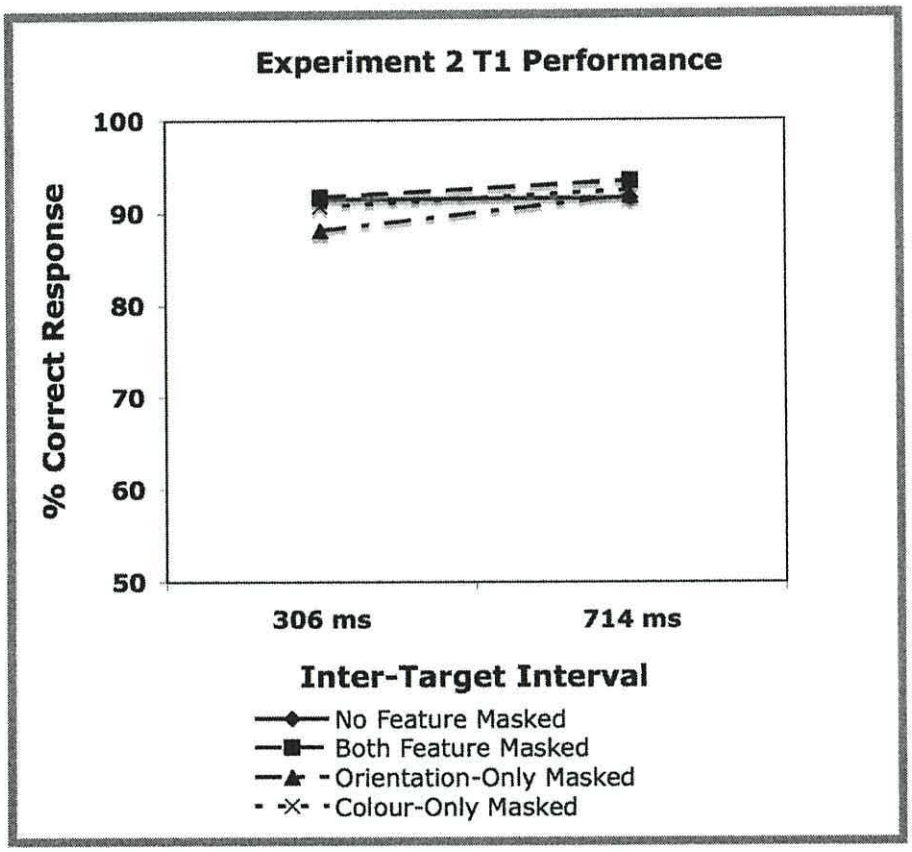

Figure 5. Mean T1 performance for Experiment 2. Error bars are not shown for T1 performance due to the low amount of variation in mean scores across trial types. Estimations of variance within each mean value can be viewed in the form of standard deviations in Table 3.

Table 4

Averaged T1 Performance for Experiment 2

Trial Type	Short Lag (306 ms)	Long Lag (714 ms)
No-Feature Masked Trials	91.45 (*5.28*) a Δ	91.63 (*5.84*) a Δ
Both-Feature Masked Trials	91.72 (*5.46*) a Δ	93.45 (*5.66*) a Δ
Orientation-Only Masked Trials	88.18 (*8.75*) a Δ	91.90 (*5.83*) a Δ
Colour-Only Masked Trials	90.72 (*6.09*) a Δ	92.45 (*5.75*) a Δ

Note. Mean T1 performance in Experiment 2. Respective standard deviations are included in parenthesis. Means in the same row that share the designation "a" did NOT differ with the Tukey's HSD test. Means in the same column that share the designation "Δ" also did not differ.

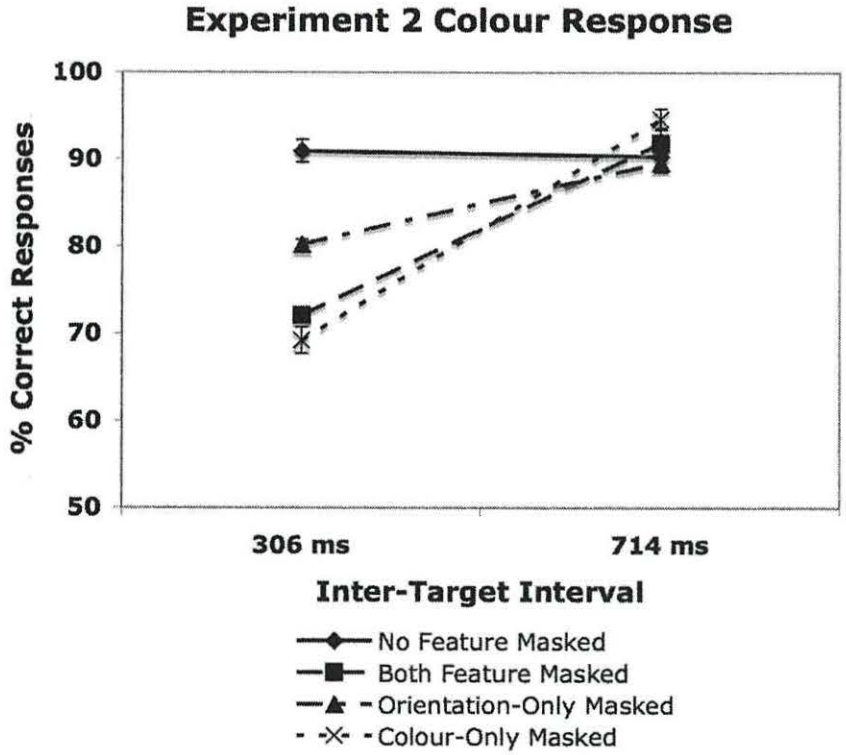

Figure 6. Mean T2 colour response performance. Error bars represent standard error of the mean.

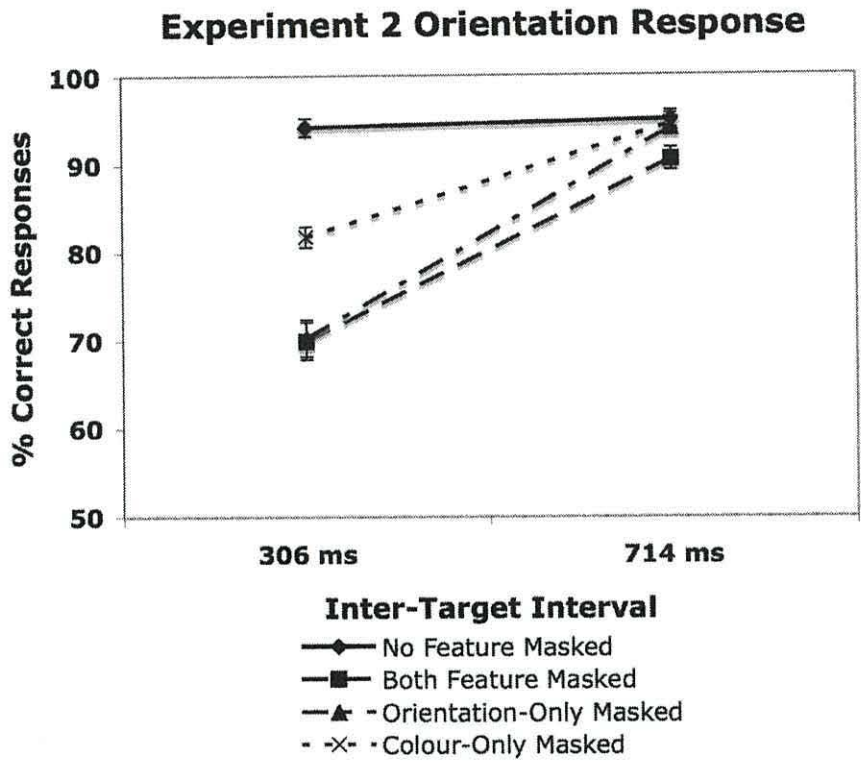

Figure 7. Mean T2 orientation response performance. Error bars represent standard error of the mean.

Table 5

Mean Performance for T2 Colour and Orientation in Experiment 2

Trial Type	Short Lag	Long Lag
No-Feature Masked Trials	Colour 90.95 (*6.04*) a Δ Orientation 94.22 (*4.84*) a Δ	Colour 90.34 (*8.43*) a Δ Orientation 95.03 (*4.58*) a Δ
Both-Feature Masked Trials	Colour 72.08 (*3.67*) a Ω Orientation 69.95 (*9.82*) a Ω	Colour 91.88 (*8.04*) b Δ Orientation 90.55 (*5.97*) b Δ
Orientation-Only Masked Trials	Colour 80.23 (*2.49*) a μ Orientation 70.25 (*9.82*) a Ω	Colour 89.63 (*4.85*) b Δ Orientation 94.07 (*4.02*) b Δ
Colour-Only Masked Trials	Colour 69.22 (*7.23*) a Ω Orientation 81.79 (*5.54*) a μ	Colour 94.61 (*5.64*) b Δ Orientation 94.50 (*5.43*) b Δ

Note. Means in the same row that share the same designation "a", or "b", did *NOT* differ with the Tukey's HSD test. Mean comparisons within the same column sharing the same designation Δ, Ω, or μ also did *NOT* differ..

Table 6

Differences Scores for Colour-Only Masked and Orientation-Only Masked Trials Across Experiments 1 and 2.

Trial-Type	Experiment 1	Experiment 2
Colour-Only Masked Trials	21.14 (*10.21*) a Δ	12.79 (*9.40*) b Δ
Orientation-Only Masked Trials	17.57 (*7.77*) a Δ	6.14 (*10.08*) b Δ

Note: Mean value of difference scores calculated between masked and non-masked features for *colour-only masked trials* and *orientation-only masked trials*. Standard deviations are also included in parenthesis. Means in the same row sharing the same designation "a" or "b" were not found to be significantly different. Means in the same column sharing the same designation "Δ", "Ω" also did not differ significantly.

Discussion

Experiment 2 Short Lag Trials

Reaffirming the conclusions drawn in Experiment 1 regarding *no-feature masked trials*, the T2+1 item induced a negligible level of masking influence in Experiment 2. This is evident from the ceiling level accuracy for colour and orientation responses. This outcome is expected despite ongoing demands of T1 processing, as the AB paradigm requires effective masking of both the T1 and T2 stimuli (Giesbrecht & Di Lollo, 1998).

As for the primary question raised by Experiment 2, the results suggest that despite the dual-task demands incurred by the AB, multiple target-object hypotheses were established for the T2 stimulus. This is indicated by the significant differences in accuracy between the masked and non-masked features in *colour-only masked* and *orientation-only masked trials*. As explained, had a single target-object hypothesis been established a similar influence of masking should have been seen for colour and orientation responses in each of these two trial types. This finding rules out the

possibility that establishing multiple object-hypotheses is abandoned as a way to conserve resources under demands of divided attention.

Experiment 2 Long Lag Trials

Traditionally, trials when T2 appears beyond 500 ms SOA are viewed as reflecting performance in the absence of dual-task deficits. When compared to trials with shorter SOA, long lag trials are thus used to illustrate magnitude of interference incurred by the AB – i.e., the difference in T2 performance between short and long SOA. According to this logic, it seems at first glance that long lag T2 performance in Experiment 2 should have matched target performance in Experiment 1[14]. I argue this is not what should be expected, and that long lag performance in Experiment 2 speaks to implications for target masking within an RSVP stream. Before preceding with this discussion, it is important to note that although temporal parameters for target/mask presentation differed slightly between Experiment 1 and 2[15], in both experiments these parameters were well within the temporal window during which backward interruption pattern masking is known to impact object processing – i.e., 0 – 150 ms SOA between target and mask (Breitmeyer, 1984; Enns & Di Lollo, 2000; Kahneman, 1968; Scheerer, 1973; Turvey, 1973).

As previously discussed, Gross and colleagues (2004, 2006) report less beta band synchronisation for non-target distracters when target stimuli are present in the RSVP stream. These authors interpret their results as indicating that when participants expect the occurrence of task-relevant items, systems of attentional processing recalibrate their handling of task-irrelevant items in order to 'preserve'

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[14] Similar to long lag trials in Experiment 2, target processing in Experiment 1 was carried out without ongoing dual-task demands of the AB.

[15] In Experiment 1 target and mask were present for 34 ms with an ISI of 51 ms and a SOA of 85 ms. In Experiment 2 these values were: target/mask duration – 34 ms, ISI – 68 ms, and SOA – 102 ms.

cognitive resources for the handling of task-relevant items. Here I propose that decreasing the devotion of attentional processes to non-target stimuli may also decrease interference from target masks.

If true, it is not surprising that the T2 mask was capable of influencing colour and orientation responses differently across trial types for short but not long lag trials. To explain, consider briefly the role of visual masking for T1. When simple and well-learned T1 stimuli are used, it has been suggested that the role of the T1+1 item is to increase T1 processing demands to a level sufficient for inducing the AB (e.g., Kunar & Shapiro, 2004). The level of T1 masking interference required to initiate the AB is likely less than occurs when full attention is directed toward the mask. This would explain how the T1 mask serves its role during the AB despite a reduced devotion of attentional processes to non-target stimuli.

A similar situation is possible for T2. The level of masking interference required to significantly affect T2 during short lag trials may also be less than occurs when full attention is directed toward the mask. To elaborate, despite reduced attentional devotion to non-target items, the T2 mask may still be able to influence object processing at short SOAs due to the time it takes for attentional processes to be released from T1. This idea is most congruent with a multi-stage model of target processing for which the mask has ample opportunity to interfere with an encoded representation of T2 while more advanced stages of processing are occupied by T1 (e.g., Chun & Potter, 1995). At long SOAs however, when the demands of processing T1 are no long ongoing, reduced attention to non-target items may render the T2 mask incapable of interfering with object processing at a measurable level. According to this explanation, the degree of masking interference placed on object processing for T1 and T2 – at long SOAs – is similar. Accuracy for T1 and T2 (long

lag) were indeed similar in Experiment 2 – post hoc comparisons revealed no significant differences between T1 accuracy and T2 accuracy at long lags[16].

An AB for both Masked and Non-Masked Features

For *colour-only masked* and *orientation-only masked trials* accuracy for both masked and non-masked features was significantly lower at short than long lag. This indicates that an AB effect occurred for both features. The presence of dual-task interference for non-masked features is not surprising. As indicated in the discussion of Experiment 1 results, non-masked features still undergo a degree of masking interference. The key result is that although dual-task deficits occurred for both task-relevant features, the magnitude of the deficit was significantly greater for the masked than non-masked feature. This indicates that on several trials the non-masked feature could be successfully reported while the masked feature could not. According to the logic presented thus far, in order for this to occur, two distinct object-hypotheses had to be established for T2.

Cross-Experiment Analysis

Although significant differences in accuracy were present between masked and non-masked features in colour-only and orientation-only masked trials in Experiment 2, these differences were not magnified relative to Experiment 1. Rather, differences between masked and non-masked features were significantly smaller in Experiment 2 than in Experiment 1. I propose that a reduction in these differences between experiments may be explained by the influences of RSVP streams on visual

[16] Post hoc comparisons between T1 performance and T2 for long lags are not included in either Table 4 or 5, but were carried out according to the same criteria as the means differences reflected in these tables.

masking. As explained, the influence of a single visual mask may be reduced when presented within a RSVP stream of other non-target distracters. An overall reduction in masking interference on behalf the T2 mask may have been responsible for reducing the degree that masked and non-masked features were influenced differently – perhaps by making it easier to unbind target/mask information relating to the masked feature.

In summary, Experiment 2 results indicated that even under the demands of divided attention multiple object-hypotheses were still established for the T2 stimulus. Due to the influences of RSVP streams on visual masking the T2 mask was only able to significantly influence second target processing during short lag trials. Even at short lag trials however, influence of the T2 mask was still not as strong as in Experiment 1, when target and mask were presented outside the RSVP stream.

General Discussion

Firstly, the results of Experiments 1 and 2 reaffirm Enns and Oriet's (2007) conclusion that masking interference is influenced by task-relevant similarities between target and mask. According to these authors' view the current findings reemphasise an important role for reentrant processing in visual masking, and suggest such task-relevant similarity complicates the unbinding of target/mask information after the process of object updating.

When interpreted within the context of the reentrant theories of perception and successful backward masking (e.g., Di Lollo, Enns, & Rensink, 2000; Enns, 2004; Enns & Di Lollo, 1997), the current experiments indicate the establishment of multiple target-object hypotheses when observers are instructed to report upon more than one task-relevant feature of a single target stimulus. As explained, had a single

target-object hypothesis been established on behalf of colour and orientation, failure to unbind target information relating to either feature from processes of object updating would have caused the entire hypotheses to fail to be confirmed, thus preventing the entire encoded representation of the target from breaching consciousness. Rather, as the results indicate, for many *colour-only masked* and *orientation-only masked trials*, observers failed to correctly report the masked feature but not the non-masked feature. This outcome is taken to indicate that upon successfully unbinding target/mask information relating to the non-masked feature, the object-hypothesis for that feature was confirmed. The hypothesis for the masked feature was not confirmed due to failure to unbind target/mask information relating to that feature. Critically, the idea that these results are an indication of multiple object-hypotheses is dependent upon the assertion that when an object-hypothesis fails to be confirmed, all the contents relating to that hypothesis fail to reach conscious awareness. As indicated, this is a key tenant of the reentrant theories of perception and successful backward masking.

While Experiment 1 served only the purpose of demonstrating that multiple target-object hypotheses could be established, Experiment 2 demonstrated that the establishment of multiple such hypotheses is not subverted during the temporary absence of attention characteristic of the AB. Experiment 2 also shed light on implications for visual masking within a RSVP paradigm. Less devotion of attentional processes to non-target distracters (Gross et al., 2004, 2006) likely reduces the degree of masking interference that occurs on behalf of these items. It is this reduction in masking interference that I propose was responsible for both the lack of differences in accuracy across trial types for long lag trials, and the

significant reduction in mean difference scores relative to Experiment 1 for short lag *colour-only masked* and *orientation-only masked trials* in Experiment 2.

Establishing multiple object-hypotheses for the same target stimulus is no doubt more costly in terms of cognitive resources than establishing a single hypothesis. Why then should the information processing system have evolved in such a way? I propose establishing independent object-hypotheses for different task-relevant features may have evolved as a strategy to maximise the efficiency of object processing under circumstances when partial information relating to an important object is lost during information processing. A great deal of previous research has demonstrated that the processes involved in object processing can fractionate. In other words, different aspects of object processing are carried out with a degree of functional independence. Such independence has been documented to allow for selective decrements in object processing.

For example, Heywood, Wilson, and Cower (1987) reported that discriminations of brightness could be spared in the presence of cerebral achromatopsia. These authors interpreted their results as suggesting that perception of colour and brightness are carried out along separate neural pathways. Humphreys and Riddoch (1987) reported relatively good perception of motion in achromatopsia patients, while Zihl, Von Cramer, and Mai (1983) reported the reverse – i.e., impaired motion perception in light of intact perception for colour. Other selective impairments in object processing have included impaired perception of texture in the presence preserved processing of object shape (Sartori, 1997). These examples are not exclusive of the literature documenting selective impairments in object processing. For a full review see Humphreys and Riddoch (2006). However, the few

examples mentioned here do demonstrate the potential for partial loss of information relating to important stimuli.

The potential for selective impairments to occur is often attributed to the functionally independent and spatially separate bodies of neurons in the visual cortex that processes various object characteristics. For example, colour processing is often attributed to area HV4 in the ventral pathway of the ventral/dorsal distinction in visual processing (Cowey, 1985). V5/MT on the other hand is heavily involved in processing motion and is located within the dorsal pathway (Zeki, 1993). Spatial orientation is also believed to heavily involve the dorsal stream, although the regions within this pathway responsible for orientation are likely diverse (e.g., Goodale & Milner, 1992).

Although the examples of selective impairments in object processing just mentioned, and indeed the vast majority of related publications, demonstrate their findings with either human patients or animals suffering from neurological insult, this is not to say that selective processing decrements in object processing only occur after cortical injury. As the results of the current chapter illustrate, in healthy humans visual masking can have a selective influence on object processing – colour and orientation of the same object were influenced to differing degrees by masking. While visual masking – as it occurs in the laboratory – does not constantly occur in everyday vision, often times we are bombarded with fast paced series of information that we must attend to – for example in busy automobile traffic. Under such circumstances some degree of visual masking is bound to take place. It therefore seems reasonable to presume that similarities between those stimuli relevant to ongoing task and other briefly occurring stimuli may occasionally cause selective impairments of object processing outside the laboratory setting.

Establishing multiple object-hypotheses might serve as a strategy for preserving partial object representations in the presence of selective failures in object processing. As the current results indicate, multiple object-hypotheses allow certain segments of an object representation to remain viable when other segments cannot be accessed. This of course raises the question: To what degree are selective impairments in object processing possible *because* we are capable of establishing multiple object-hypotheses? The arguments put forward in the current chapter suggest selective deficits relating to visual masking are closely tied to multiple object-hypotheses. However, other cases of selective impairment – specifically those relating to neurological insult – likely involve different systems and therefore may manifest by different means. Here it is not my goal to speculate on any such causal relationships. Rather, my intention is only to point out that establishing multiple object-hypotheses for a single stimulus might serve as a useful mechanism in a visual system that is prone to selective impairments in object processing.

As a final note, there is certainly a limit to the number of object-hypotheses that can be established for a single target stimulus. Because the processes of formulating and confirming object-hypotheses are not carried out consciously it is unclear what the limit might be[17]. Were these processes carried out consciously the limit would likely be related to working memory capacity. This is an interesting question for future study.

[17] The reentrant theories of perception and successful backward masking state that consciousness only occurs after the object hypothesis has been confirmed.

Chapter Six References

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Chapter Seven: Final Discussion – Temporal Attention Maintains Flexibility Across the RSVP Stream

Chapter Seven

Final Discussion: Temporal Attention Maintains Flexibility Across the RSVP Stream

Empirical results presented in Chapters 2-6 share the common theme of modulating the magnitude of dual-task deficits during the AB. In Chapter 2 the AB was attenuated by task-irrelevant activity presented in peripheral regions of the visual field. It was concluded that participants invested more attention in the motion condition in anticipation that the moving star field would make target detection more difficult. Motion being the strong attracter of attention that it is (Abrams & Christ, 2005; Bex, Dakin, & Simmers, 2003; James, 1890; Pashler, 2004; Rajimehr, Vaziri-Pashkan, Afraz, & Esteky, 2004; Rushton, Bradshaw, & Warren, 2007; Rushton, Morvan, & Wexler, 2005), continuous movement of the star field before RSVP onset may have prompted participants to anticipate difficulty in maintaining attentional focus on the RSVP stream. The attenuated AB effect suggests such difficulty was overestimated, and sufficient 'attention' was available to benefit target processing.

In Chapter 3 it was concluded that for AB trials – i.e., when T2 cannot be reported correctly – the ultimate fate of T2 processing varies depending upon the competitive nature of the T2 stimulus. More competitive T2 stimuli were processed further before succumbing to the AB than were less competitive T2 stimuli. Moreover, more competitive T2 stimuli were also less likely to succumb to the AB altogether – i.e., accuracy for T2 identity report was significantly better when T2 was a strong vs. a weak competitor for resources.

Chapter 4 manipulated the magnitude of dual-task interference for the lag-1 position – approx. 100ms post T1 onset. Presenting T2 at this temporal position within the RSVP stream commonly yields an absence of dual-task interference –

known as the lag-1 sparing phenomenon. While Chapter 4 does not rule out an important role for the temporal relationship between T1 onset and the lag-1 position, the results presented do suggest that a contributing factor to lag-1 sparing is the absence of T1 masking. In Experiments 1 and 2 inserting a T1 mask between T1 and the canonical lag-1 position significantly attenuated lag-1 sparing.

Chapter 5 demonstrated that discontinuity within the RSVP stream can have opposing effects on the AB. The alerting functions of attentional capture attenuated the AB in the presence of temporal discontinuity, but magnified the AB in the presence of spatial discontinuity. When the capturing event varies in a dimension task-relevant to the target (spatial size), the capturing event competes with target processing. For example, if the target identification task requires spatial analysis – as was the case in all three Chapter Four experiments – then capturing events that vary in their spatial characteristics (i.e., the *spatially* discontinuous distracters in Experiments 1 & 3) must be engaged and then disengaged before subsequent target items can be processed. Attentional disengagement takes time. If targets appear before attention disengages from previous stimuli, then target processing suffers. On the other hand, when a capturing event does not share properties with task-critical items, as was the case for *temporal* discontinuity in Experiments 2 & 3, then there is no competition, allowing the alerting function of attentional capture to exert its facilitating effects on target identification.

Finally, Chapter 6 demonstrated that when instructed to report upon two target features (i.e., two task-relevant features) observers establish and attempt to confirm multiple object-hypotheses – one for each feature. The concept of object-hypotheses, and justification for the claim of multiple such hypotheses, was based on the reentrant theories of perception and successful backward masking (e.g., Enns &

Oriet, 2007). It was suggested that the strategy of establishing multiple object-hypotheses for a single stimulus might have evolved as an adaptive mechanism to cope with selective impairments in object processing. Regarding the AB, it was concluded that because it is possible to establish and confirm multiple object-hypotheses for a single-target object, the magnitude of the AB for two target features (colour and orientation) can differ significantly depending on whether a given feature is held as similar or dissimilar with the T2 mask.

Cognitive processes contributing to dual-task interference in the AB are not static but flexible and dynamic. The empirical findings of Chapters 2-6 are not the first to demonstrate this fact (e.g., Bleckley, Hollingsworth & Maki, 2005; Colzato et al., 2008; Cornwell, Echiverri, & Grillon, 2006; Jefferies et al., 2008; Kihhara & Osaka, 2008; Koelewijn, Burg, Bronkhorst, & Theeuwes, 2008; Martens & Johnston, 2005; Marti, Paradis, Thibeault, & Richer, 2006; Olivers & Nieuwenhuis, 2005, 2006; Visser, 2007). The goal of the following discussion is not to provide an exhaustive review of previous publications, but rather to illustrate how Chapters 2-6 combined with selected examples of previous work, indicate that the magnitude of dual-task interference can be modulated from multiple points within the time course of RSVP presentation. For the purposes of discussion this time-course is divided between three stages of RSVP presentation. Stage One: *Before RSVP Onset.* Stage Two: *Before, During, and After Presentation of T1 and its Mask.* Stage Three: *During Presentation of T2 and its Mask.* When relevant it will be discussed how the potential to modulate dual-task interference at various points during the RSVP stream corresponds to popular accounts of the attentional blink.

Before RSVP Onset

In Chapter 2, as well as in Arend, Johnston, and Shapiro (2006), task-irrelevant visual motion beginning before RSVP onset and continuing throughout the RSVP stream attenuated the AB. It was suggested by Olivers and Nieuwenhuis (2006) and confirmed in Chapter 2 that task-irrelevant activity influences the commitment of attentional investment to the AB task. However, Chapter 2 results and the overinvestment hypothesis (Olivers & Nieuwenhuis, 2006) present conflicting ideas as to precisely how attentional investment is influenced by task-irrelevant activity. The overinvestment hypothesis proposes the AB is attenuated by means of a reduction in attentional investment triggered by task-irrelevant activity, while Chapter 2 proposes the AB is attenuated by an increase in attentional investment. Importantly, although proposing an important role for attentional investment, Arend, Johnston, and Shapiro (2006) and Olivers and Nieuwenhuis (2005, 2006) did not show that task-irrelevant activity alters processes relating to attentional investment at a point before RSVP onset. This is a unique contribution of the CNV data presented in Chapter 2.

It is currently unclear whether CNV related changes in attentional investment influence the commitment of attention to task-irrelevant and task-relevant RSVP items alike (Olivers & Nieuwenhuis, 2006), or if such influences are more focused – perhaps for T1 specifically (Arend, Johnston, & Shapiro, 2006). As discussed in Chapter 2 these two possibilities have distinctly different implications for how changes in attentional investment modulate interactions between T1 and T2. These implications will not be discussed again here. However, it is worth mentioning one potential method by which these possibilities might be evaluated.

As mentioned in earlier chapters, Gross and colleagues (2004, 2006) reported differences in beta-band synchronisation between target-and non-target stimuli across a tempo-parietal-frontal network. For No-AB trials beta-band synchronisation was much stronger for target-related activation than for non-target activation. Comparatively, synchronisation to non-target stimuli was increased significantly during a condition when the RSVP stream contained only non-target items. Gross and colleagues interpret this result as indicating that when participants expect the occurrence of task-relevant items, systems of attentional processing recalibrate their handling of task-irrelevant items in order to 'preserve' cognitive resources for the handling of task-relevant stimuli. If task-irrelevant activity modulates attentional investment toward targets and distracters alike, then beta-band synchronisation to distracter stimuli might be expected to differ between conditions when task-irrelevant activity is present vs. absent. Chapter 2 results predict synchronisation to distracters would be increased in the presence of task-irrelevant activity as attentional investment toward these items is increased. If investment is modulated for T1 specifically, Chapter 2 results suggest synchronisation to distracters may either not differ between conditions, or decrease in the presence of task-irrelevant activity due to the extra attention devoted to T1. Furthermore, if attentional investment is modulated (i.e., increased) for T1 specifically, increases in synchronicity and/or P300 amplitude to this stimulus might be expected when task-irrelevant activity is present.

While it was suggested in Chapter 2 that task-irrelevant motion caused participants to over invest attention in anticipation that maintaining attentional focus on the RSVP stream would be difficult, an alternative explanation may be found in the effects of temporal discontinuity reported in Chapter 5 – i.e., to reflect capture

and alerting to a non-task relevant event. By this account peripheral task-irrelevant activity simply could be capturing attention and alerting the system, in turn creating a heightened state of processing. Because visual motion of the star-field in Chapter 2 was present during the interval between fixation and RSVP onset, alerting functions of attention during this period of time may have influenced the CNV component. This alternative explanation would be expected to yield greater CNV amplitude for No-AB than AB trials (The Chapter 2 result), thus indicating that dual-task deficits were less likely to occur on trials when alerting functions were most successful in increasing attentional investment. To test this hypothesis, it would be interesting to see if peripheral task-*relevant* information produced an outcome similar to that produced by spatial discontinuity in the present set of experiments.

Before, During, and After the Presentation of T1 and its Mask

The level of attentional investment set prior to RSVP onset – as reflected by the CNV – does not ultimately determine the level of dual-task interference that will occur between T1 and T2. After observers begin monitoring the RSVP stream much opportunity still exist to modulate dual-task interference. In Experiment 3 of Chapter 5 it was demonstrated dual-task interference can be modulated by events leading to attentional capture that occur either before T1 onset or between offset of the T1 mask and onset of T2. When considered in conjunction with previous publications that modulate dual-task interference by manipulating T1 difficulty, it becomes clear that the AB bottleneck can be influenced before, during, and even after the appearance of T1 and its mask[1]. This is important because it is T1 and its mask that AB models claim set in motion the processes ultimately responsible for preventing

[1] T1 and its mask are discussed in conjunction here primarily because several experiments manipulating T1 difficulty have done so by altering stimulus properties of the T1 mask.

overt report of T2. The two-stage model (Chun & Potter, 1995) and competition hypothesis (Shapiro, Raymond, & Arnell, 1994) suggest T1 and its mask either delay T2 in gaining access to a later capacity-limited stage of processing, or result in a level of competition that leaves too few resources available for T2. The temporary loss of control model (Di Lollo et al., 2005) and reactive suppression account (Olivers, 2007) suggests the combination of T1 and its mask sets in motion either a loss in top-down control over monitoring processes or suppression of future stimulus processing.

Events or factors relating to stimulus parameters that modulate dual-task interference indicate something different about the AB bottleneck depending upon their temporal position relative to T1 and its mask. When appearing before offset of the T1 mask, such influences indicate that the AB bottleneck is sensitive to the demands of T1 processing and/or the availability of resources at the time T1 processing begins. In other words, dual-task interference is related to the 'strain' T1 and its mask place on the information processing system. Such findings are considered to be most compatible with limited capacity/resource accounts of the AB (e.g., competition hypothesis, and two-stage model).

Previous publications manipulating T1 difficulty claim to influence how well processes outlined by limited capacity/resource models are capable of hindering T2 (Chun & Potter, 1995; Brehaut et al., 1999; Grandison et al., 1997; Seiffert & Di Lollo, 1997)[2]. These publications claim to influence either the speed of T1 processing, or the level of competition on behalf of T1 and its mask. Influencing the

[2] As indicated in Chapter 2, previous publications are split as to whether T1 difficulty actually modulates AB magnitude (i.e., T2 accuracy). Studies suggesting T1 difficulty does not have an influence on AB magnitude are Shapiro et al. (1994), Raymond et al. (1995) and Ward et al. (1996, 1997). Visser (2007) addresses questions as to why some publications point to a relationship between T1 difficulty and AB magnitude and some do not. Visser's findings confirm that under certain circumstances T1 difficulty does have the ability to modulate AB magnitude.

speed of T1 processing alters the amount of time before T2 can enter a later capacity-limited stage of processing (two-stage model), while influencing competition on behalf of T1 and its mask alters the level of resources that remain for T2 during visual short-term memory (competition hypothesis).

Notably, the finding that attentional capture pre-T1 onset influences AB magnitude may also be interpreted within a similar framework – i.e., *task-irrelevant* attentional capture (see temporal discontinuity Chapter 5) may speed up T1 processing or increase the availability of resources. *Task-relevant* forms of attentional capture pre-T1 (see spatial discontinuity Chapter 5) require attentional engagement, which delays processing of, and perhaps further reduce resource availability for future targets.

I propose that the temporary loss of control model (Di Lollo et al., 2005) and the reactive suppression account (Olivers, 2007), which claim T1 and its mask trigger the AB not because of capacity/resources requirements, but rather because these stimuli initiate top-down alterations in information processing systems, may be revised so that they to can account for the influence of T1 difficulty and capturing events occurring before T1. Such revision only requires that the 'amount' of top-down influence triggered by T1 and its mask – i.e., the amount of control that is lost over monitoring processes or the degree to which future stimulus processing is suppressed – be influenced by T1 difficulty and/or the level of resource availability at the time T1 is presented.

For example, the reactive suppression account (Olivers, 2007) states T1 triggers a temporary enhancement of attention due to its being task-relevant. This enhancement reaches its maximum only after the T1+1 item has appeared. Upon determining that task-irrelevant information (i.e., the T1+1 item) is being enhanced,

systems of attention respond by strongly suppressing processing of subsequent RSVP items, which includes T2. Perhaps this account could be revised to suggest that the 'strength' of the response triggered by the T1+1 item depends on the processing requirements of T1 and its mask, or perhaps the current capacity of the information processing system to handle those requirements.

Events or factors relating to stimulus parameters that modulate dual-task interference after offset of the T1 mask but before onset of T2 (See Chapter 5 and Wee & Chua, 2004[3]), say something important about the extent to which stimulus processing is hindered during the critical 500 ms AB interval. Limited capacity/resource accounts of the AB suggest attention is unavailable during this time period because insufficient capacity/resources are available to processes additional stimuli. However, these models propose such limitations involve high-level stages of stimulus processing involving stimulus consolidation and/or short-term memory. It is within the framework of these models to propose that attention processes are not limited at lower level stages that are responsible for detecting target-defining features or salient aspects of a capturing stimulus. Thus, the idea that attentional capture can be triggered by non-target items appearing between offset of the T1-mask and onset of T2, and that the consequences of capture can in turn affect T2, is consistent with these models. Attentional capture during this period of RSVP presentation is also consistent with the reactive suppression account, which proposes suppression of stimulus processing post offset of the T1-mask, but does not specifically identify a particular point when processing of subsequent stimuli is terminated. The suppression of stimulus processing triggered by the T1-mask may

[3] In Experiment 3 of Chapter 5 and in Wee & Chua 2004, attentional capture occurred during the temporal interval after offset of the T1-mask but before onset of T2. In Chapter 5 capture was initiated in response to either temporal or spatial discontinuity. In Wee & Chua's experiment capture was initiated by a yellow square surrounding one of the non-target RSVP distracters.

target mechanisms at higher-level stages than those required to initiate attentional capture.

Notably, attentional capture occurring post offset of the T1-mask but before onset of T2 is more difficult to incorporate into the temporary loss of control model (Di Lollo et al., 2005). If observers are unable to effectively monitor the RSVP stream, then how are capture inducing aspects of non-target stimuli detected? Perhaps the most likely answer involves the salient nature of capturing stimuli. Salient stimuli 'grab' attention, which perhaps increases the likelihood of detection even when monitoring processes are disrupted.

During Presentation of T2 and its Mask

The fact that AB magnitude can be modulated by stimulus properties of T2 indicates that some stimuli are more resilient to dual-task interference than others. What properties of a T2 stimulus increase its likelihood of surviving the AB? In Chapter 3 it was suggested that the answer to this question is properties that increase the strength of T2 as a competitor for resources. Here I provide some examples of previous publications that also modulate dual-task interference by manipulating properties of T2, and suggest that these results might also be interpreted within a similar framework as Chapter 3 results.

Chua 2005 attenuated the AB by increasing the contrast of T2 – a manipulation very similar to that in Chapter 3. While Chua explained his results by suggesting an increased contrast-ratio for T2 prolonged attentional engagement, it is also possible that increased contrast-ratio allowed more biased-competition to be established on behalf of T2. As explained in Chapter 3, by increasing the contrast of T2 Chua made T2 more distinguishable from surrounding non-target distracters. As

Duncan (1987) demonstrates, the level of biased-competition established on behalf of task-relevant stimuli is increased as these stimuli become more distinguishable from task-irrelevant stimuli. This of course does not mean Chua's explanation of prolonged attentional engagement is wrong. Perhaps prolonged attentional engagement and increased biased-competition are linked in some way. In light of the fast temporal pace of RSVP presentations, a prolonged period of attentional engagement might have increased the quality of the encoded representation of T2 in Chua's experiment. In turn, a higher quality representation of T2 may have produced stronger signals along neural pathways responsible for encoding the stimulus as task-relevant. Stronger signals along such pathways may therefore have aided in boosting the level of biased-competition established on behalf of T2.

Shapiro, Caldwell, and Sorensen (1997) demonstrated a visual version of the classic auditory cocktail party effect (Cherry, 1953). Dual-task deficits were attenuated when T2 was the participant's own name as opposed to an unfamiliar name. Much like Cherry (1953), these authors suggest highly relevant information can give attention a 'boost', despite the demands of other ongoing processes. This "boost" of attention might very well have manifested in the form of increased biased-competition on behalf of T2. As described in Chapters 1, the 'strength' of biased-competition established on behalf of a stimulus increases as a function of relevance to ongoing cognitive goals. In Shapiro and colleagues experiment the participant's own name carried with it not only task-relevance[4] but also a level of personal relevance.

The idea that manipulating the strength of T2 as a competitor for resources can modulate dual-task interference in the AB is consistent with all current models

[4] Task instructions in Shapiro, Caldwell, and Sorenson (1994) experiment were to report the name presented as T2.

of the AB. It is important to note that the AB itself does not need to be triggered by the processing capacity/resources requirements of T1 and its mask for this statement to be true. Regarding the temporary loss of control model (Di Lollo et al., 2005), a strongly competitive T2 stimulus likely increases the probability that T2 will be detected under conditions when processes responsible for monitoring the RSVP stream are disrupted. For the reactive suppression account (Olivers, 2007), the adaptive mechanisms of attention initiated by the T1+1 item are likely to suppress processing of encoded representations of T2 that are weak competitors for resources more than representations of T2 that are strong competitors.

Like the T1 mask, the item following immediately after T2 has been shown to influence second target processing, and as such modulate dual-task interference during the AB. Early examinations of this issue Giesbrecht and Di Lollo (1998) demonstrated not only will failure to mask T2 result in no AB, but T2 performance is sensitive to the type of mask presented. The effects of both integration and interruption masking on T2 were considered. Only when interruption masking was applied were the signature temporal constraints on T2 processing observed (i.e., processing deficits for 200-500 ms post T1 onset).

Giesbrecht, Bischof, and King (2003) and Marti, Paradis, Thibeault, and Richer (2006) followed up these results by examining whether the temporal relationship between T2 and its mask was still important when these stimuli appeared in different spatial locations. Both publications confirmed the finding that when T2 and its mask share a common temporal onset either no AB at all, or a very attenuated AB occurs. When considered in conjunction with the findings of Giesbreacht and Di Lollo (1998), Giesbracht and colleagues (2003) and Mari and colleagues (2006) concluded that the crucial processes that occur between T2 and its

mask in the AB are absent in common-temporal-onset masking. Two possible explanations as to differences in processing that occur between common and delayed temporal onset masking were suggested. First, early visual processes critical for the AB that are recruited by delayed-onset masks may not be recruited by common-onset masks (Giesbrecht et al., 2003). The attenuation of the AB in scotopic vision is compatible with this early processing explanation (Giesbrecht et al., 2004). A second hypothesis is that the sudden onset of a new object (i.e., delayed-onset mask) immediately after T2 may pull attention away from the target more than a common-onset mask.

Chapter 6 of the current document also demonstrated a relationship between the magnitude of the AB and the T2 mask. However, these results are distinctly different from, and thus not easily compared with, previous publications that examine the role of T2 masking. The critical difference is that the T2 mask used in Chapter 6 modulated AB magnitude between two task-relevant features of the same target object. Unlike previous AB studies, Chapter 6 results demonstrate that T2 masking has the potential to cause processing of the T2 object to fractionate. Importantly, current AB models are not inconsistent with the notion that T2 masking can cause the magnitude of dual-task interference to differ between two features of the same target stimulus. Such models, as well as the AB literature in general, have not yet explored dual-task interference when participants are instructed to report on multiple dimensions of T2. At the current time this aspect of Chapter 6 results appears to be unique.

Chapter Seven References

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