OBJECT-BASED ATTENTION AND VISUAL TEMPORAL RESOLUTION

INFLUENCES OF OBJECT-BASED SELECTION

ON THE RELATION BETWEEN

ATTENTION AND VISUAL TEMPORAL RESOLUTION

By

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Abstract

Attended objects are perceived differently than unattended objects. Spatial attention is consistently associated with an enhancement in spatial resolution. However, the relation between spatial attention and temporal resolution is not as straightforward. Some studies have shown that attention enhances temporal resolution, and others have shown that attention degrades temporal resolution. The motivation of the present work was to investigate the source of this discrepancy. In particular, the research herein examines the hypothesis that attention degrades temporal resolution when the target stimuli are easily integrated (i.e., according to the Gestalt principles of grouping), and that attention enhances temporal resolution when the targets are easy to perceptually segregate. Temporal resolution was assessed by the mean just noticeable difference (the minimum temporal interval in milliseconds required by observers to perform the task at 75% accuracy) in a visual temporal order judgment (TOJ) task. Trials involved the presentation of two targets, at randomly varying stimulus onset asynchronies, and observers reported which one they perceived first. The primary research questions concerned the effect of perceptual grouping on temporal resolution, and the influence of attention on that relation. Grouping processes were manipulated using a variety of Gestalt principles and attention was investigated under conditions of automatically- and voluntarily-driven orienting. Three main findings emerged: temporal resolution is worse for grouped than ungrouped targets; attention modulates the effect of grouping on temporal resolution on a continuum – strong grouping effects produce large impairments on temporal resolution, and weaker grouping effects produce smaller impairments; and automatic and voluntary spatial orienting affect the relation between grouping and

temporal resolution differently – automatic orienting augments the relation, while voluntary orienting does not. I conclude that the discrepant findings in the previous research are due to object-based factors pertaining to the target stimuli and propose an object-based theory of temporal perception.

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Preface

During the completion of my Ph.D. at McMaster University, I had the pleasure of collaborating with a number of other researchers in my department. I worked closely with my supervisor Dr. David Shore on all my research projects. Many of the experiments that I conducted where borne out of ideas that were developed during casual discussions about my program of research and other published studies that we found interesting. His critical role in the development of my research program is reflected by the fact that he is a co-author on all three manuscripts that comprise the data chapters of my thesis. In both of our published manuscripts, *Perceptual grouping impairs temporal resolution* (Chapter 1) and *Object-based attention mediates the effect of attention on temporal resolution* (Chapter 2), he conceived of the stimuli, while I wrote the program, ran the participants, and analyzed the data. I also wrote the manuscripts, which he in turn edited with valuable constructive criticism. The latter manuscript met with many challenging reviewers, and other obstacles over the several years that it was developed, and while I re-wrote drafts of the article several times, he graciously offered to do the polishing that was required to get it accepted for publication. In our recent submission entitled *Temporal order judgments reveal different effects of exogenous and endogenous spatial attention on perceptual grouping* (Chapter 3), I was solely responsible for all aspects of the experiment and manuscript and Dr. Shore served as an invaluable consultant.

In the manuscript, *Object-based attention mediates the effect of attention on temporal resolution* (Chapter 2), Kellie Gray was responsible for conducting an experiment that served mainly as a replication of two other experiments that I had previously conducted for that manuscript, and Dr. Scott Watter provided invaluable assistance with the programming.

Introduction

The idea that there are factors that can affect the subjective perception of the temporal occurrence of events has a long history in experimental psychology. William James (1890), the founding father of psychology in North America, recognized that the perception of the relative order of temporally contiguous events does not always correspond to their actual order of occurrence (Carver & Brown, 1997). In fact the very origin of research in experimental psychology was concerned with the consequences of attention on the subjective experience of temporal events (Mollon & Perkins, 1996). In spite of its seminal influence on experimental psychology, however, a great deal still remains to be learned about the relation between visual attention and temporal perception. This is evidenced by the contradictory findings that beset the extant research—some studies suggest that attention enhances temporal resolution, while others indicate that attention degrades temporal resolution.

In the present review, I propose an object-based attentional selection theory of temporal resolution that can account for the variety of findings concerning the effect of attention on temporal perception. The paper begins with an introduction to the concept of selective attention, including a description of two putative modes of attentional orienting—exogenous and endogenous attention. Then I contrast models of selective attention that currently polarize the research: space-based theories and object-based theories. Following that, I review the empirical research investigating the effect of spatial attention on temporal resolution. Finally, I present our object-based attentional selection theory of temporal resolution and describe how it can account for the seemingly inconsistent findings that have emerged in the extant research.

I. Selective Attention and Attentional Orienting

Over a century ago, William James (1907) wrote, "Everyone knows what attention is. It is the taking possession by the mind in clear and vivid form out of what seem several simultaneous objects or trains of thought" (cited in Posner, 1994). Indeed, attention is an intuitive term with many meanings commonly used in everyday life. Here I define attention as the perceptual mechanism that determines what information, or stimuli, from our surroundings we are consciously aware of. Due to the inherently limited capacity of conscious processing, far more information constantly falls upon the retinas than we are capable of attending to; accordingly visual processing is characterized by selectivity. Selective processing ensures that our limited resources are directed to stimuli that are the most relevant to survival or to our present goals (e.g., Klein, 2004). Selective attention is the mechanism that accomplishes this by affording a privileged status to specific objects or locations, by determining which stimuli receive enhanced perceptual and cognitive processing, and which are processed less efficiently.

Exogenous and Endogenous Orienting

The allocation of attentional resources can be controlled by sensory and cognitive factors. These factors reflect two distinct modes of controlling visual attention, often referred to as exogenous (referring to a source from outside the organism) and endogenous (referring to a source from inside the organism) attention, respectively. On the one hand, exogenous shifts of attention are deployed rapidly and automatically in response to salient stimuli that appear abruptly in the periphery of the visual field (e.g., motion detection, or strike of lightning). On the other hand, endogenous shifts of attention occur voluntarily, take relatively longer to deploy, and take place in response to the presentation of informative stimuli that usually appears centrally in the visual field (e.g., an arrow, or a pointed finger).

There is growing evidence that there may be a greater distinction between exogenous and endogenous attentional control than simply the process by which they attract attention to a particular object or region of space. Jonides (1981) demonstrated that relative to endogenous orienting, exogenous orienting is: less affected by memory load, less resistant to suppression, and less sensitive to changes in expectancy. Briand and Klein (1987) showed similar effects of attention on both feature and conjunction search in response to an endogenous cue, but greater effects of attention on conjunction than on feature search, in response to an exogenous cue. Apparently the exogenous orienting system, but not the endogenous orienting system performs the function of feature integration putatively ascribed to attention (Briand & Klein, 1987). Also, Posner and Cohen (1984) showed suppressed responses for stimuli appearing at recently attended locations —the inhibition of return (IOR) effect—are observed under conditions of exogenous, but not endogenous, orienting (but see Lupianez, Decaix, Sieroff, Chokron, Milliken & Bartolomeo, 2004). Evidence for dissociation between these two orienting mechanisms has also been found using the spatial Stroop task. Funes, Lupianez and Milliken (2007) showed that exogenous cues reduce the spatial Stroop effect while endogenous cues increase the size of the effect. Moreover, they showed that cue – target

SOA modulated the magnitude of the exogenous cueing effect (i.e., a pronounced reduction at short SOAs that diminished at longer SOAs), but not the endogenous cueing effect (i.e., performance was similar across all SOAs). This demonstrated double dissociation, led Funes et al. (2007) to conclude that exogenous and endogenous cues rely on different spatial representations mechanisms. Furthermore, neuro-imaging studies have revealed that the brain areas involved in these two modes of orienting are partially segregated. Functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) have shown that endogenous attention is associated with a network of bilateral activation in the intraparietal cortex and superior frontal cortex, while exogenous attention is associated with a network of activation in the temporoparietal cortex and inferior frontal cortex, primarily the right hemisphere (see Corbetta & Shulman, 2002 for a review). Thus, exogenous and endogenous attentional control may actually engage fundamentally different attentional processes and orienting mechanisms altogether, rather than simply reflecting two distinct modes of transporting information within a unitary mechanism (e.g., Briand & Klein, 1987; Klein & Shore, 2000; Funes et al., 2007). Later, we will review in greater detail the results of two recent studies (Hein, Rolke, & Ulrich, 2007; Chapter 3: Nicol & Shore, submitted) that further support this notion by showing hat exogenous and endogenous attention also differentially affect temporal resolution.

II. The Units of Attentional Selection

The attentional system has two putative ways of extracting, or selecting, visual ›rmation from the environment. Although many researchers agree that the visual ›m is not limited to one or the other, two main theories of attentional selection distinguish the research: one theory posits that the units of attentional selection are space-based, and the other theory posits that selection is object-based. Space-based models contend that the spatial location of a stimulus determines whether or not it will be selectively attended. These models liken attention to a spotlight (Posner & Cohen, 1984; Posner, Snyder & Davidson, 1980), zoom lens (LaBerge, 1983), or gradient (Downing & Pinker, 1985). Object-based models assert that attentional selection is determined by the number of objects that are present in the visual field and emphasize the influence of Gestalt grouping factors on the distribution of attention (Duncan, 1984; Neisser, 1967).

Space-based Theory of Attentional Selection

According to the spotlight model, attentional processing is like a search beam that is moved about the visual field. Stimuli that fall under the illuminated area of the beam are selected for further processing and stimuli outside of the boundary of the spotlight are inhibited from processing. In support of the spotlight model, research has shown that performance is negatively affected when a target stimulus is flanked by spatially contiguous distractors (i.e., within 1° of visual angle), but not when distractors that are more spatially disparate from the target (Eriksen & Eriksen, 1974; Eriksen & Hoffman, 1972).

Results from spatial cueing tasks originally designed and employed by Posner and colleagues (Posner, 1980; Posner, Snyder & Davidson, 1980) also support the spotlight model. In a typical cueing task observers attend to a central fixation point and are presented with a spatial precue that directs their attention to one side or the other of fixation (or a neutral cue that appears at fixation). Observers are fastest to detect the onset of a stimulus appearing at the cued, or expected location and slowest to detect the onset of a stimulus appearing at the uncued, or unexpected spatial location. This pattern of behavior is believed to reflect the benefit of directed attention and cost of misdirected attention, respectively. Proponents of the spotlight model contend that the benefit occurs because attention is already positioned at the cued location, and the cost occurs because attention must be moved from the spatially cued to the uncued location (Posner, 1978).

Other space-based models of selection, such as the zoom lens and gradient models posit that the efficiency of attentional processing varies across the visual field. The zoom lens model proposes that the size of the attentional spotlight varies depending on the situation. Support for this model comes from research showing that attentional resources can be allocated across a relatively narrow, or wide, spatial area depending on the strategy of the observer. La Berge (1983) showed that when attention is focused on the middle letter of a five-letter word, or non-word, stimulus reaction times (RTs) to the onset of a probe stimulus are fast when it appears at the location of the middle letter, slower when it appears at the position of the second or fourth letter, and slowest when it appears at the position of the first or fifth letter (i.e., a V-shaped RT function). In contrast, when attention is broadly focused across all five letters of a word, RTs are constant regardless of what letter position the probe stimulus appears at.

Gradient models of space-based selection are similar, except that rather than emphasizing solely the breadth of attentional focus, they posit that processing efficiency falls off in depth and lateral distance for stimuli that are further from the focus of attention (Downing & Pinker, 1985; Hughes & Zimba, 1985; Mangun & Hillyard, 1987).

Evidence for an attentional gradient comes from a study by Downing and Pinker (1985). Observers were presented with two parallel rows of four lights (i.e., one row of lights was close to, and the other row was further away from the observer) at various eccentricities from retinal fixation and were informed which light was likely to onset with a spatial precue. The task was to respond when the onset of a light was detected. The costs associated with the misdirection of spatial attention increased as the lateral distance between the cued location and the location of the onset increased. Moreover, the cost increased more severely when the onset was at different depth than the cued location. Together, the results suggest that attention falls away from the fovea on a 3-D spatial gradient (Downing & Pinker, 1985). While the evidence in support of space-based attentional selection is compelling, there are also a number of studies that have provided data for which such space-based theories cannot account for.

Object-based Theory of Attentional Selection

In contrast to space-based models, object-based models such as the one proposed by Neisser (1967), posit that attentional selection is a two-stage process. In the first stage, the visual field is pre-attentively parsed into perceptual units (i.e., into objects) determined by the Gestalt principles of grouping (e.g., similarity, proximity, closure). Then, in the second stage, the object is analyzed in detail by focal attention. Proponents of object-based theories of selection argue that once attention is directed to an object, all parts or features of that object are automatically selected regardless of spatial location (e.g., Duncan, 1984; Egly, Rafal, & Driver, 1994; Kahneman & Henik, 1977, 1981; Kahneman & Treisman, 1984). As such, all parts of the same object are processed in a parallel fashion while different objects are processed serially (Treisman, Kahneman & Burkell, 1983).

The notion that attention automatically spreads across selected objects is supported by a number of empirical studies. In an experiment by Egly et al. (1994), two rectangular placeholders were presented lengthwise on either side of fixation. A brief bolding at one end served to cue observers' attention exogenously to the top or bottom of one of the two placeholders. The task required observers to respond when they detected the onset of a target, which could appear at any one of the four rectangle ends. Targets could appear at the cued or uncued end of the cued rectangle, or at the end of the uncued rectangle that was adjacent to the cued location on the cued rectangle. Critically, the uncued end of the cued rectangle and the uncued end of the uncued rectangle were equidistant from the cued location (i.e., targets appearing at the uncued location were equidistant from the cued location whether they appeared on the cued rectangle or not). Despite equal spacing between these conditions, observers were faster to respond to targets that appeared at the uncued end of the cued object than the uncued end of the uncued object; suggesting that attention had automatically spread across the cued object (Egly et al., 1994).

Object-based theories of attentional selection are also supported by the results of experiments by Treisman et al. (1983) that measured the latency of word reading. On some trials only a word was presented on one side or the other of fixation. Other trials included a coloured rectangular frame in addition to the word. Critically, the rectangular frame either surrounded the word or appeared on the opposite side of fixation. Not surprisingly, reading latency was fastest on trials when only the word was presented. Interestingly however, reading latency was slower when the word and the frame appeared on opposite sides of fixation, than when they were superimposed on the same side of fixation. These data suggest that a "filtering cost" is incurred when attentional resources are divided between objects, and that this cost is attenuated when these objects can be integrated into a single perceptual unit (Treisman et al., 1983).

The cost involved in attentional filtering, or switching, between objects was also demonstrated in a study by Duncan (1984). The task required observers to make two feature-based discriminations concerning two spatially overlapping objects. One object was a line; its two attributes were tilt direction (left or right), and surface pattern (dotted or dashed). The other object was a box; its two attributes were size (large or small), and gap location (left or right). Before each trial, observers were instructed as to which two attributes they would need to report, which could concern either same-object or different-objects. The results revealed that discriminations were less accurate when observers reported two attributes of different objects (e.g., the tilt of the line and the size of the box) than two attributes of the same object (e.g., the size of the box and the side of the gap). Because the objects appeared in the same location, a space-based account would not predict that performance would differ across the same- and different-object conditions. Thus, this result clearly supports an object-based theory of attentional selection.

III. Effect of Attention on Temporal and Spatial Resolution

Attended stimuli are perceived differently than unattended stimuli. Indeed, research has shown that attention actually alters the appearance of stimuli (Carrasco, Ling

& Read, 2004; Gobell & Carrasco, 2005). For centuries theorists have argued that attention exerts its effects on perception by increasing the perceptual clarity of a stimulus (Helmholtz, 1886/1924; James, 1890/1981; Wundt, 1912 from Downing, 1988). Perceptual clarity can be considered in terms of spatial and temporal resolution. Temporal resolution refers to the ability of the visual system to distinguish the relative temporal occurrence (i.e.. onset or offset) of events, or the ability to detect rapid changes in light intensity across time (Yeshurun & Levy, 2003). Spatial resolution refers to ability to perceive and resolve the fine spatial details of stimuli in the environment (Yeshurun, 2004). Psychophysical research examining the temporal and spatial resolution is important because it informs and constrains theories of visual processing by revealing the performance limits of the visual system (Poggel et al., 2006).

Effect of Attention on Spatial Resolution

An extensive amount of research has demonstrated that attention improves spatial resolution (e.g., Balz & Hock, 1997; Tsal & Shalev, 1996; Yeshurun & Carrasco, 1998; 2000). It is believed that attention enhances discriminability of a stimulus by accelerating the rate of information processing (Carrasco & McElree, 2001) and enhancing signal strength (Carrasco, Williams & Yeshurun, 2002). Selectively attending to a specific spatial location or object has been shown to enhance performance on a wide variety of tasks that require spatial processing (Eriksen & Hoffman, 1972; Yantis & Jonides, 1984); contrast sensitivity (Pestilli & Carrasco, 2005); letter identification (Prinzmetal, Presti & Posner, 1986); and gap and vernier detection (Yeshurun & Carrasco, 1999).

However, it has been shown that spatial attention actually degrades performance in a texture segregation task, when performed within the fovea (Yeshurun & Carrasco, 1998). The accelerated processing and signal enhancement that resulted from attention made spatial resolution too high for optimal performance when this task was performed within the fovea (Yeshurun & Carrasco, 1998). Interestingly, this interpretation of the effect may also be germane to the relation between attention and temporal resolution.

Effect of Attention on Temporal Resolution

Since perceptual events occur across space, as well as time, our ability to process the temporal characteristics (e.g., duration, order) of a stimulus is also critical for effective interaction in our environment (Poggel, Treutwein, Calmanti & Strasburger, 2006). In contrast to the amount of research based on the relation between attention and spatial resolution, a relative paucity exists regarding the effect of spatial attention on temporal resolution. Moreover, the results from the few studies that have been conducted indicate that the effect of attention on temporal resolution is not nearly as straightforward as it is on spatial resolution. Indeed, some findings indicate that spatial attention enhances temporal resolution, while others suggest that it degrades temporal resolution.

Several models have been proposed in an attempt to account for the effect of attention on temporal resolution. Thomas and Weaver (1975) suggest that temporal intervals are judged by an internal timing mechanism that generates pulses corresponding to the passage of time. According to this model, when attention is paid to a stimulus we are more aware of the accumulation of these pulses and consequently the duration of its interval is perceived to be longer. Similarly, the model posits that the duration of an unattended stimulus is perceived to be shorter because attention is detracted from the internal timer and the accumulation of pulses that correspond to it. Although Thomas and Weaver's (1975) model implies that temporal perception is not veridical at attended or unattended locations, it clearly postulates that attention does not enhance temporal resolution. Rather since the model attributes prolonged perception to attended stimuli, it suggests that attention degrades visual temporal resolution. A longer neural response function (e.g., Ikeda, 1986; Watson, 1986) decreases temporal resolution because it increases the likelihood that the response associated with the perception of one stimulus will be integrated over time with another stimulus that briefly follows (Yeshurun, 2004).

In contrast to Thomas and Weaver's (1975) position, Tsal, Meiran and Lamy's (1995) resolution theory and Stelmach and Herdman's (1991; Stelmach, Herdman & McNeil, 1994) temporal-profile model both postulate that spatial attention enhances temporal resolution. The temporal-profile model proposes that the neural temporal response function associated with the visual processing of a stimulus (e.g., Ikeda, 1986; Watson, 1986) is sharpened by attention (Stelmach & Herdman, 1991; Stelmach et al., 1994). Specifically, it posits that attention produces both a faster rising and faster falling temporal profile, and as a consequence the visual response for stimuli at an attended location is more efficient than one associated with processing of stimuli at an unattended location (Stelmach & Herdman, 1991).

Resolution theory posits that the visual system is comprised of a series of overlapping dimensional (i.e., orientation) detectors that provide a rough representation of the environment. According to resolution theory, attention enhances temporal sensitivity by integrating the outputs of adjacent detectors and comparing their relative levels of activation (Tsal et al., 1995). Moreover, the theory posits that temporal sensitivity is not enhanced for unattended stimuli since this integrative and comparative process requires attentional resources (Tsal et al., 1995).

Research on the effect of attention on temporal resolution

According to Titchener (1908): "the object of attention comes to consciousness more quickly than the objects that we are not attending to (p.251)". He called this the law of prior entry, one of his seven fundamental laws of attention. Stelmach and Herdman (1991) revealed a prior entry effect using the visual temporal order judgment (TOJ) task and a combined endogenous – exogenous cue to direct spatial attention. They presented observers with three placeholder squares, one at fixation and one to the left and right of fixation. Observers fixated on the centre square while covertly attending to the square with marker (i.e., the endogenous cue). Before the onset of the first target, a flash (i.e., the exogenous cue) appeared around the marked placeholder. A target dot was then presented asynchronously in the left and right placeholder and the observer reported which target they perceived first. They found that the dot in the unattended placeholder needed to precede the onset of the dot in the attended placeholder by approximately 40 ms in order for the two to be perceived simultaneously. Thus, they found evidence of prior entry and concluded that attended stimuli reach the brain's "temporal comparator" before unattended stimuli (Stelmach & Herdman, 1991). A weakness of that study, however, was that Stelmach and Herdman did not sample across the range of SOAs equally. Rather, in the "attend right" condition observers were presented with mainly left-first target SOAs and in the "attend left" condition they were presented with mainly right-first target SOAs.

An additional shortcoming of the above study (and most studies that have investigated the prior entry effect) is that they may have confounded prior entry with a response bias (Shore, Spence, & Klein, 2001). Observers may have simply been biased to report that they perceived the target at the attended location first, particularly on trials when observers are uncertain about the correct temporal order of the targets (Shore et al., 2001). To address this issue Shore et al. (2001; Spence et al., 2001) devised a methodology in which attentional-cuing and response dimensions are orthogonal. Attention was oriented to the left or right by an exogenous or endogenous spatial cue and observers performed a TOJ in which they reported whether a vertical or horizontal line segment was perceived first. Thus, attention was manipulated in the spatial dimension, which was orthogonal to orientation, the response dimension. Shore and Spence (2005; Shore et al., 2001; Spence et al., 2001) argued that the orthogonal technique would alleviate response bias since there is no reason to assume that a cue to the left or right would bias observers toward making either a vertical- or horizontal-first response. To be sure that observers were not simply reporting that line segment at the attended location, Shore et al. asked some observers to report what line segment they perceived second. They expected that this second task would have the opposite effect on response bias, while leaving the perceptual influence of prior entry unaffected. Their results revealed a larger prior entry effect in response to exogenous than endogenous cues for both the "which first" and the "which second" task (74 ms vs. 48 ms and 30 ms vs. 3 ms;

respectively). These effects were then averaged together to yield a prior entry effect of 61 ms and 17 ms for exogenous and endogenous cuing respectively. By averaging together the difference between the "which first" and "which second" tasks they estimated the contribution of the response bias to be 13 ms. These results confirm that attention does speed up the processing of stimulus onsets and suggest that some of the discrepancy concerning the effect of attention on temporal resolution is likely due to the varying amounts of response bias inherent across experimental designs.

Attention has a similar effect on the perception of stimulus offsets. In a study by Downing and Treisman (1997) subjects were exogenously cued to one side or the other of fixation by the transient brightening of one of two target placeholders (there was also an endogenous component to the cue since it validly predicted the location of the target event on 67% of trials). Following the cue one of two target dots offset at either the cued or uncued location and observers responded as soon as they detected a target offset. When the target offset occurred at the cued location observers were 33ms faster to respond relative to when the offset occurred at the uncued location. That effect of cue validity shows that "attention facilitates the detection of offsets at least as much as detection of onsets" (Downing & Treisman, 1997; p. 770). Thus, findings above showing that attention speeds the perception of stimulus onsets and offsets suggest that the neural response function of an attended stimulus is sharpened, and support Stelmach & Herdman's (1991) temporal-profile hypothesis.

At the same time, support for Thomas and Weaver's (1975) temporal comparator model of temporal processing, comes from research indicating that attention prolongs perceived duration. Mattes and Ulrich (1998) investigated the effect of attention on perceived duration by assuming that more attention is paid to precues as they become more valid. In a blocked design, observers were given spatial precues of various validities (0.9, 0.7, 0.5). The precue validity indicated the probability that the target stimulus would be presented at that spatial location (i.e., to the left or right of fixation). Observers were aware of the precue validity in each block and their task was to judge whether the presentation of the target stimulus was a short, medium, or long duration (although there were only short and long stimulus durations). As expected, the results indicated that as cue validity increased, so did mean ratings of perceived. Accordingly, in support of Thomas and Weaver (1975), Mattes and Ulrich concluded that attention prolongs perceived duration.

Since attended stimuli are perceived sooner than unattended stimuli (Hikosaka et al., 1993; Shore et al., 2001; Spence et al., 2001; Stelmach & Herdman, 1991), Enns, Brehaut and Shore (1999) suggested that the influence of attention on the duration effect could be an artifact of the influence of attention on the onset effect. In other words, it may be that they are perceived to last longer because they seem to onset sooner. To examine the relation between these two illusions they performed a between-subjects experiment that included a duration and TOJ version of the same task. Following the presentation of an endogenous cue, a flash appeared at the attended or unattended location, followed by another flash at the opposite location. One flash was always presented for a standard 50 ms and the other flash was a test flash that was presented for 10-90 ms at an SOA of 0-100 ms. Either flash could be presented first, and either one could appear at the attended or unattended location. In the duration version of the task observers reported which flash appeared to last longer and in the TOJ version observers reported which one appeared to onset first. On the one hand, the TOJ task revealed a prior entry effect—flashes at the attended location appeared to onset sooner. But, the size of the onset effect was not related to the duration of the test flash. On the other hand, the duration task showed that flashes at the attended location seemed to last longer, and the size of that illusion was not related to the SOA between the two flashes. Thus, Enns et al. (1999) replicated Mattes and Ulrich's (1998) finding that attention prolongs perceived duration, and extended upon it by demonstrating that the influence of attention on perceived duration is independent from its influence on perceived onset.

Enns et al. (1999) performed an additional experiment to ensure that their findings were not due to visible persistence—a continued neural response associated with a brief flash after it has been terminated (c.f. Colheart, 1980; Di Lollo, 1980). To examine the potential influence of visible persistence on the duration illusion, they used a temporal gap detection task. They reasoned that if attention had enhanced visible persistence, and in turn prolonged the perceived duration of the flash, then the effect would be reversed when observers judged the length of a temporal gap, and the temporal gap would be perceived as shorter at the attended than the unattended location. Observers were endogenously cued to a dot on the left or right of fixation. Following the cue, briefly offsetting the dots and then presenting them again after a short duration produced temporal gaps. The first temporal gap occurred in the dot at the attended or unattended location, and the second temporal gap occurred in the other dot. Similar to their previous experiment, one dot was offset for a standard gap length of 50 ms and the other was offset for a test gap length that ranged between 10-90 ms. The results showed that even though observers were now judging the duration of a gap rather than a flash, that longer durations were still reported at the attended than unattended location. That finding clearly ruled out a visible persistence account of the attention-related perceived duration illusion (Enns et al., 1999).

The studies reviewed above indicate that attention affects the three periods of a temporal event differently. Attended stimuli are perceived sooner (Shore et al., 2001), seem to last longer (Mattes & Ulrich, 1998), and appear to offset (Downing & Treisman, 1998) before unattended stimuli. Because the magnitude and direction of the effect of attention is not the same across these periods, it is possible some discrepancies in the research may be a result of considering the effect of attention on a particular stage of an event, rather than on the entire event itself.

Rather than examining temporal resolution for a particular stage of an event, Yeshurun and Levy (2003) considered the effect of attention on temporal gap detection. Observers were presented with a brief target flash at either a valid or neutral cued location and were asked to report whether the flash was a single continuous pulse or contained a brief temporal gap (i.e., two successive flashes). It was shown that observers were less able to detect the temporal gap when the flash appeared at the validly cued location than at the neutral cued location. The results therefore showed that exogenous spatial attention degrades temporal resolution (Yeshurun & Levy, 2003). To explain this rather counterintuitive finding, Yeshurun and Levy put forward the parvocellular –

magnocellular inhibition hypothesis. According to the hypothesis, covert spatial attention (i.e., attending to location without making an eye movement) facilitates processing in the parvocellular retinal pathways while inhibiting processing in the magnocellular retinal pathways (Breitmeyer & Williams, 1990; Tassinari, Marzi, Lee, Di Lollo, & Campara, 1999). This pattern of neural activation would purportedly impair temporal resolution for two reasons. First, the receptive fields of parvocellular neurons are smaller than those of magnocellular neurons and are associated with increased spatial resolution. However, temporal processing relies on a process of spatial summation (i.e., the aggregation of information from spatially contiguous areas)(Makela, Rovamo, & Whitaker, 1994; Raninen & Rovamo, 1987), which is more effective with larger receptive fields. Second, relative to magnocellular neurons, parvocellular neurons have more prolonged and more variable onset latencies (e.g., Derrington & Lennie, 1984; Merigan & Maunsell, 1993). As mentioned earlier, if two stimuli, separated by a short temporal interval, have prolonged neural latencies it is more likely that they will be integrated over time (Yeshurun, 2004). Clearly these temporal characteristics would result in poorer temporal resolution.

Yeshurun (2004) put the parvocellular – magnocellular inhibition hypothesis to the test by isolating the functions of the parvocellular and magnocellular systems by employing Yeshurun and Levy's (2003) temporal gap detection task under isoluminant and red background conditions. It was assumed that the parvocellular system would be dominant under these conditions because the magnocellular system is relatively colorblind (e.g., Schiller & Logothetis, 1990) and is inhibited by diffuse red light (e.g., Livingstone & Hubel, 1984). It was predicted that since the magnocellular system would have little effect on task performance under these conditions that any parvocellular – magnocellular inhibition due to attentional processes would be abolished or attenuated (Yeshurun, 2004). As expected, when magnocellular inhibition was eliminated by isoluminance and red background the attentional decrement on temporal resolution was attenuated.

While Yeshurun's (2004) results appear to provide support for the parvocellular – magnocellular inhibition hypothesis, findings from single-cell recording research conducted by Logothetis, Schiller, Charles & Hurlbert (1990) indicate otherwise. They examined the responses of cells in parvocellular and magnocellular portions of lateral geniculate nucleus in monkeys and concluded "isoluminant stimuli are inappropriate for the psychophysical isolation of these pathways" (p. 247). Indeed, not only did they show that isoluminant stimuli activate the magnocellular pathway; they showed that magnocellular responses are actually greater than parvocellular responses at isoluminance (Logothetis et al., 1990). Although Yeshurun (2004) was able to replicate the iso-luminance findings when she used a red background to suppress magnocellular activity, it appears that the parvocellular – magnocellular inhibition hypothesis does not offer a tenable account of the relation between attention and temporal resolution.

Yeshurun and Levy's (2003; Yeshurun, 2004) finding that attention reduces our ability to detect a temporal gap is at odds with Enns et al.'s (1999) finding that attention prolongs the perceived duration of a temporal gap (but see Visser & Enns, 2001). However, these studies used different types of attentional cueing techniques (e.g., a spatially informative peripheral cue versus a centrally presented arrow), suggesting that cue type, and the associated attentional mechanisms, may be a determining factor on the relation between attention and temporal resolution. The effects of exogenous and endogenous attention on visual temporal resolution were examined independently in a TOJ study conducted by Hein et al. (2006). In the exogenous cueing condition, they directed observers' attention to one side of fixation by briefly emboldening a target placeholder (i.e., there was one placeholder on either side of fixation). Two horizontally arranged target dots then appeared in either the cued or uncued location and observers reported which one they perceived first. In the endogenous cueing condition the task was the same but the placeholders were not used and attention was directed to the left or right of fixation by a centrally presented double arrow stimulus. Interestingly, their results showed that exogenous and endogenous attention have opposite effects on temporal resolution. Observers were more accurate at the uncued location in response to the exogenous cue and more accurate at cued location in response to the endogenous cue (Hein et al., 2006). This pattern of data may explain the discrepant results between the studies by Enns et al. (1999) and Yeshurun and Levy (2003; Yeshurun, 2004). Enns et al. (1999) found that attention prolonged the perception of a temporal gap because they used an endogenous cue, which improves temporal resolution, and Yeshurun and Levy (2003) showed that attention reduced temporal gap detection because they employed an exogenous cue, which impairs temporal resolution.

To account for the differential effects of exogenous and endogenous spatial cues on temporal resolution, Hein et al. (2006) referred to Briand and Klein's (1987) proposal that automatically controlled attention is involved in early stages of visual processing, but voluntarily controlled attention is not. Accordingly, they suggested that the differential effects of exogenous and endogenous spatial cues reflect the influence of attention at lower and higher levels of the visual system; attention impairs temporal resolution when it is involved at an early stage of visual processing, but enhances temporal resolution when it is involved at higher levels of processing in the visual system (Hein et al., 2006).

Thus, it appears that the differential effects of exogenous and endogenous cues can also explain some of the inconsistencies in the literature regarding the relation between attention and temporal resolution. However, the results of a study by Baek, Kham & Kim (2005) illustrate that even different cueing procedures cannot fully account for the complex nature of the relation between attention and temporal resolution. They tested the generality of Yeshurun and Levy's (2003; Yeshurun, 2004) results using a luminance-based TOJ task. Observers were presented with two target disks at the same location, which were either the same luminance polarity or different luminance polarities. When the targets were different luminance polarities (i.e., one target was brighter and the other was darker than the background) temporal resolution was better at the exogenously cued than uncued location. However, when the targets were the same luminance polarity (i.e., both targets were brighter or dimmer than the background) temporal resolution was better at the exogenously uncued than cued location. Thus cueing techniques (i.e., exogenous and endogenous spatial cues) also do not fully account for the inconsistent effects of attention on temporal resolution found in the literature. Indeed, Baek et al. used the same exogenous cueing technique employed by Yeshurun and Levy and got different results. The temporal gap detection task revealed impaired temporal resolution at the attended location (Yeshurun & Levy, 2003), while the luminance-based TOJ task revealed an enhancement in temporal resolution at the attended location. This pattern of data suggests that properties of the target stimuli used in the experimental task may critically affect the relation between attention and temporal resolution. In the section that follows we present a theory that ascribes a mediating role of object-based target selection on the relation between attention and temporal resolution.

IV. A Proposed Theory of the Effect of Attention on Temporal Processing

The research reviewed above indicates that the effect of attention on temporal processing differs depending on what period (i.e., onset, duration, offset) of the temporal event is examined (e.g., Downing & Treisman, 1997; Enns et al., 1999; Shore et al., 2001) and depending on what type of cue (i.e., exogenous or endogenous) is used to orient attention (Hein et al., 2006). Different effects have also emerged when temporal resolution of the entire event is examined rather than just a specific period of an event (e.g., Mattes & Ulrich, 1998; Yeshurun & Levy, 2003), and even when the same type of attentional cue is used (e.g., Baek et al., 2005; Hein et al., 2006). However, these factors do not fully account for the inconsistent results that exist in the literature since different attentional effects have emerged even when these differences are accounted for (Bæk et al., 2005; Yeshurun & Levy, 2003).

I propose that another critical factor determining the effect of attention and temporal resolution is object-based selection (i.e., an effect of perceptual grouping at the attended location). I suggest that due to factors such as spatial proximity, similarity, onset asynchrony, and enclosure, the target stimuli exist on a "gradient of object-ness". That is, in some conditions targets are easily distinguished as two objects, but in other conditions they are perceived as a single object. It is more likely that two targets will be misperceived as one at the attended, relative to an unattended location, because spatial attention enhances feature integration (e.g., Briand & Klein, 1987; Paul & Schyns, 2003). This theory posits that in contrast to spatial discriminations, which are benefited by the ubiquitous "same-object advantage" (e.g., Duncan, 1984), temporal discriminations are impaired when the targets are perceptually integrated into a single object.

The first empirical test of our object-based theory was based on the Gestalt grouping principle of good continuity (see Chapter 1). Before explicitly investigating the effect of attention, we wanted to be sure that perceptual grouping of target stimuli would, in fact, impair temporal resolution. Observers were presented with two targets that appeared adjacent to one another on either the left or right side of fixation, at randomly varying SOAs, and they were asked to report the one that appeared first. The targets were outlines of three-sided squares. In one condition, the *one-object* condition, the open sides of the targets faced toward each other, which provided good continuity between stimuli and encouraged them to be perceptually integrated into one object. In the other condition, the *two-object* condition, the open sides faced away from each other, which did not promote good continuity and the targets were easily perceptually segregated as two distinct objects. Temporal sensitivity was indexed by the average just noticeable difference (JND)—the smallest temporal interval (in milliseconds) required to correctly report what target appeared first on 75% of trials. As expected, temporal sensitivity was worse (i.e., the JND was higher) in the one-object than the two-object condition (Nicol & Shore, 2007). Since observers need more time to between the onsets of the targets in the one-object condition, than in the two-object condition, we concluded that perceptual grouping impairs temporal resolution (Chapter 1: Nicol & Shore, 2007).

Having demonstrated an effect of grouping on temporal resolution, next I sought to extend our results by examining the influence of other grouping factors on temporal resolution—namely, that of spatial separation between targets (same vs. different locations), target enclosure (by placeholder), and target distinctiveness (distinct vs. identical) (see Chapter 2). In our examination of the effect of spatial separation, observers were presented with two distinct targets (× and +) at varying SOAs, at an exogenously cued or uncued location. One group of observers performed the TOJ task with targets appearing at different locations (vertically aligned) and reported the location of the first target, and another group of observers performed the task with targets appearing at the same location (superimposed) and reported the identity of the first target. The results showed that when the targets were spatially separated observers' temporal sensitivity was better (a lower JND) at the cued location, but when the targets were not spatially separated observers' temporal sensitivity was worse (a higher JND) at the cued location (Chapter 2: Nicol, Watter, Gray, & Shore, 2008). The same results were observed in a mixed-design experiment when targets were randomly presented at same or different locations. This pattern of data provides additional support for our object-based theory of temporal perception. On one hand, performance at the cued location is enhanced when distinct targets are presented at different locations because attentional processes have no difficulty distinguishing them as two separate objects. On the other hand, performance at the cued location is impaired when the targets are presented at the same location because attentional processes facilitate integration of the features of the two targets into a single percept (e.g., Briand & Klein, 1987; Paul & Schyns, 2003).

In contrast to these exogenous cueing results, Hein et al. (2006) reported that TOJs for spatially separated targets are more accurate at the unattended location. However, there are at least two important differences between the studies that may have produced this discrepancy. First, our experiments did not employ target placeholders, while in Hein et al.'s study two placeholders were positioned on either side of fixation for the duration of each trial. Second, the targets used in our study were clearly distinguishable from each other, while in Hein et al.'s study they were identical. In the next set of experiments (see Chapter 3), I hypothesized that placeholders and non-distinct targets represented grouping factors that contributed to the impairment in temporal resolution at the cued relative to the uncued location reported by Hein et al. (2006). These experiments revealed that when placeholders were added to our TOJ task, performance did not differ at the attended and unattended locations (Chapter 2: Nicol et al., 2008). However when non-distinct targets were used with placeholders, temporal sensitivity was worse at the attended than unattended location (Chapter 2: Nicol et al., 2008). Therefore, thinking in terms of the our object-based selection theory: spatially separated distinct targets are easily perceived as two objects, so temporal resolution is enhanced by spatial attention because the targets are not perceptually integrated; spatially separated distinct targets framed by a placeholder are somewhat harder to perceive as two objects, so temporal resolution is somewhat impaired by spatial attention (i.e., not different than temporal resolution at the unattended location) because the targets can be perceived as a single object; and finally spatially separated non-distinct targets framed by a placeholder are difficult to perceive as two objects, so temporal resolution is degraded by spatial attention because the targets are integrated into a single percept. Indeed, it has been shown that placeholders produce consistent object-based effects even when they have no functional value (Goldsmith & Yeari, 2003).

In my first study (see Chapter 1), it was shown that perceptual grouping impairs temporal resolution, but my co-author and I did not manipulate spatial attention. While in the second study (see Chapter 2), it was shown that temporal resolution is degraded when grouping factors facilitate target integration, however my co-authors and I did not explicitly manipulate grouping. Thus, in the final test of our object-based selection theory, target grouping was explicitly manipulated at the attended and unattended location (see Chapter 3). This methodology permitted me to *directly* determine if grouping effects mediate the relation between attention and temporal resolution, and also to determine whether attention is required for perceptual grouping. I examined the effect of exogenous and endogenous attention on the relation independently since Hein et al. (2006) showed these two types of spatial cues have different effects on temporal resolution (i.e., exogenous attention degrades temporal resolution and endogenous attention enhances temporal resolution). Since it has been shown that exogenous spatial attention impairs temporal resolution (when conditions facilitate target grouping), it was expected that exogenous attention would augment the negative effect of grouping on temporal resolution (Chapter 1: Nicol & Shore, 2007). I also predicted that endogenous spatial attention and grouping would have additive effects on temporal resolution; however, since endogenous spatial attention enhances temporal resolution (Hein et al., 2006), I expected it to counteract the grouping effect (i.e., endogenous attention and grouping should have opposing effects on temporal resolution). This final hypothesis addressed the debate concerning the role of attention on perceptual grouping processes. Some researchers argue that attention is required for perceptual grouping (Mack, Tang, Tuma, Kahn, & Rock, 1992; Rock, Linnet, Grant, & Mack, 1992), while others contend that grouping can occur in the absence of attention (Lamy, Segal, & Ruderman, 2006; Moore & Egeth, 1997). I posited perceptual grouping does indeed require attentional resources, and predicted that temporal resolution would be negatively affected by the grouping manipulation at the attended, but not at the unattended location.

Observers were presented with pairs of vertically aligned diamond-shaped stimuli to the left and right of a central fixation point (i.e., flanker or distractor stimuli). Following cue presentation, a pair of horizontally aligned target diamonds appeared asynchronously at the cued or uncued location and observers reported which target appeared first. On half of the trials the targets grouped with the flankers (by colour or surface pattern) to form one large uniform diamond. On the other half of the trials the targets did not group with the flankers, so that the resulting stimulus looked like a large diamond comprised of two smaller pairs — the target pair that matched horizontally and the flanker pair that matched vertically. As expected, under exogenous and endogenous cueing conditions temporal sensitivity was worse when the targets and flankers grouped than when they did not group—perceptual grouping impaired temporal resolution (see Chapter 1: Nicol & Shore, 2007; Chapter 2: Nicol et al., 2008). It was also revealed that neither form of spatial cueing produced a difference in temporal sensitivity across grouping conditions at the unattended location. Thus, it seems that perceptual grouping does require attention (e.g., Mack et al., 1992; Rock et al., 1992). Most importantly, the results showed that attention and grouping have additive effects on temporal sensitivity. These effects worked together in response to exogenous cues, which augmented the grouping effect at the attended location (Chapter 3: Nicol & Shore, submitted). In contrast, endogenous cues—which enhance temporal resolution (Hein et al., 2006)—likely worked in opposition to the grouping effect, resulting in equivocal performance across grouping conditions at the attended location (Chapter 3: Nicol & Shore, submitted). Based on the results revealed by these experiments, which included a direct manipulation of target grouping at the attended and unattended locations, we conclude that perceptual grouping factors that promote object-based attentional selection mediate the relation between attention and temporal resolution.

These results offer some support for Hein et al.'s (2006) finding that exogenous and endogenous spatial cues have differential effects on temporal resolution. As discussed above, Hein et al. suggested that this difference reflects the fact that exogenous attention influences lower levels of visual processing, whereas endogenous attention affects higher levels of the visual system, and that at earlier stages attention interferes with temporal resolution, while at later stages it facilitates temporal resolution (Hein et al., 2006). However, it is also possible to interpret this pattern of data in terms of an object-based, or perceptual grouping, effect. It has been suggested that object-based attention is the default attentional mode when a diffused attentional setting is adopted (Goldsmith & Yeari, 2003). Since exogenous cueing conditions encourage the adoption of a diffuse attentional setting (i.e., since the cue could appear on either side of fixation), but endogenous conditions require a narrowly focused attentional setting (i.e., on fixation where the directional cue appears), it follows that exogenous orienting is associated with object-based selection, whereas endogenous orienting is not (Macquistan, 1997). Thus, as the object-based selection theory of temporal perception would predict: exogenous spatial cues degrade temporal resolution because they induce object-based attention, and endogenous spatial cues enhance temporal resolution because they promote non-object-based attention (presumably space-based attention).

V. Summary and Conclusions

Spatial attention has a number of effects on temporal perception. For example, attention affects the temporal stages of an event—the onset, duration, and offset. Indeed, attended stimuli are perceived sooner (Shore et al., 2001), seem to have longer durations (Mattes & Ulrich, 1998), and appear to offset sooner (Downing & Treisman, 1998) than unattended stimuli. Given these effects, it is perhaps not surprising that the relation between spatial attention and temporal processing is not a straightforward one.

Early investigations of this relation indicated that transient spatial attention impairs temporal resolution (Hein et al., 2006; Yeshurun & Levy, 2003; Yeshurun, 2004) but more recent studies suggest that it actually enhances temporal resolution (Baek et al., 2005; Nicol et al., 2008). Complicating the issue further is that the nature of the relation depends on how attentional resources are deployed. Automatic shifts of attention—elicited by exogenous spatial cues—tend to degrade temporal resolution (Hein et al., 2006; Yeshurun & Levy, 2003; Yeshurun, 2004, but see Baek et al., 2005; Chapter 2: Nicol et al., 2008), while voluntary shifts of attention—elicited by endogenous spatial cues—enhance temporal resolution (Hein et al., 2006).

In the present paper, I have put forth a theory that reconciles these discrepancies. I posited that object-based selection plays a mediating role in the relation between spatial attention and temporal resolution. According to the object-based selection theory, stimulus factors that promote target integration, or perceptual integration, have a negative influence on temporal resolution. In support of that hypothesis, I reviewed the results of a number of studies showing that when the experimental conditions promote perceptual grouping (i.e., due to a lack of spatial disparity between targets, enclosure from placeholders, lack of target distinctiveness, and endogenous spatial cues) temporal resolution is degraded. Thus, we assert that object-based attentional selection (i.e., perceptual grouping), which benefits spatial perception (Duncan, 1984; Egly et al., 1997) by facilitating an automatic spread of processing across all relevant and irrelevant features of a selected stimulus (e.g., Kahneman & Henik, 1981; Treisman et al., 1983), impairs temporal resolution because the perceptual integration of spatially and temporally contiguous stimuli causes them to be perceived as a single object and renders them difficult to temporally discriminate from each other (Chapter 1: Nicol & Shore, 2007; Chapter 3: Nicol & Shore, submitted; Chapter 2: Nicol et al., 2008).

In sum, my theory proposes that object-based attentional selection affects temporal resolution in ways that promote the binding of stimuli over time that belong to the same event, just as it affects spatial resolution in ways that promote uniting stimuli that belong to the same object. This attentional effect on temporal resolution makes sense from an ecological perspective, as we must constantly figure out how changes over time relate to discrete events, and how changes over space relate to discrete objects.

Chapter 1

Nicol, J.R., & Shore, D.I. (2007). Perceptual grouping impairs temporal resolution. *Experimental Brain Research, 183,* 141-148.

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Abstract

Performance on multisensory temporal order judgment (TOJ) tasks is enhanced when the sensory stimuli are presented at different locations rather than the same location. In our first experiment, we replicate this result for spatially separated stimuli within the visual modality. In Experiment 2, we investigated the effect of perceptual grouping on this spatial effect. Observers performed a visual TOJ task in which two stimuli were presented in a configuration that encouraged perceptual grouping or not (i.e., one- and two-object conditions respectively). Despite a constant spatial disparity between targets across the two conditions, a smaller just noticeable difference (i.e., better temporal resolution) was found when the two targets formed two objects than when they formed one. This effect of perceptual grouping persisted in Experiment 3 when we controlled for apparent motion by systematically varying the spatial distance between the targets. Thus, in contrast to the putative same-object advantage observed in spatial discrimination tasks, these findings indicate that perceptual grouping impairs visual temporal resolution.

Introduction

Perceptual grouping can occur automatically at an early level of visual processing (Baylis & Driver, 1992; Julesz, 1984; Neisser, 1967; Treisman, 1982; but see Mack & Rock, 1982). We exploited this phenomenon in order to investigate the relative influences of object-based and space-based factors of perception on visual temporal resolution. The effect of spatial factors on temporal resolution has been demonstrated robustly in multisensory temporal order judgment (TOJ) studies with improved performance when stimuli are presented at different spatial locations, relative to the same location (e.g., Keetels & Vroomen, 2005; Kitagawa, Zampini & Spence, 2005; Spence, Baddeley, Zampini, James, & Shore, 2003; Spence, Shore & Klein, 2001; Zampini, Shore, & Spence, 2003a; 2003b; for exceptions see Zampini, Brown, Shore, Maravita, Roder & Spence, 2004 and Zampini, Shore & Spence, 2003b; Experiments 1-3 & 5). This space-based effect on temporal resolution has also been recently been demonstrated within the visual modality (Nicol, Watter, & Shore, 2005; Nicol, Watter, Gray, & Shore, submitted).

While several cogent explanations for the spatial effect have been put forward in the multisensory literature (Keetels & Vroomen, 2005; Spence et al., 2003; Zampini et al., 2003b), the perceptual mechanisms related to spatial modulations of temporal resolution within a sensory modality may differ from those pertaining to temporal perception across sensory modalities (e.g., Kubovy & Van Valkenburg, 2001). Also, to our knowledge, the impact of perceptual grouping on temporal resolution has not been evaluated with unimodal visual stimuli. Here we use a visual TOJ task to investigate if automatic integrative perceptual processes (i.e., object-based factors) contribute to the increase in temporal resolution observed when targets are presented at different spatial locations.

The TOJ task is commonly used to investigate temporal resolution. In a typical trial, two targets are presented at a randomly varying stimulus onset asynchrony (SOA) and observers are asked to judge what location (or sensory modality) was stimulated first. Temporal resolution is derived from this task using the just noticeable difference (JND)—the smallest temporal interval required to correctly judge the location of the first stimulus on 75% of the trials. Accordingly, enhanced temporal resolution corresponds to a smaller JND.

Experiment 1

Although some research has examined how the distance between targets affects temporal resolution in the visual domain (e.g., Allik & Kreegipuu, 1998; Westheimer & McKee, 1977), to our knowledge no published studies have compared temporal resolution for visual targets presented at the same location versus different locations (although see Nicol et al., 2005; Nicol et al. submitted). Thus, before examining the impact of perceptual grouping on TOJ performance, we felt it prudent to demonstrate a spatial effect on visual temporal resolution in a TOJ task. In the present experiment we presented observers with one red and one blue target at the same or different spatial locations and asked them to judge what target colour appeared first. In line with the spatial effect reported by Nicol et al. (2005; submitted) we predicted that visual temporal resolution would be better (i.e., a lower JND) when the two targets appear at different spatial locations than when they appear at the same spatial location.

Method

Participants

Seven undergraduates enrolled in a third year perception laboratory class at McMaster University. No participants were excluded from the analysis.

Stimuli & Materials

Stimuli consisted of a black fixation cross (1x1 degree of visual angle), two square black placeholders (4x4 degrees of visual angle), and one red and one blue colour target (3x3 degrees of visual angle), presented against a white background. The fixation cross was presented at the centre of the screen and the placeholders were presented on the horizontal meridian, 4 degrees of visual angle to the left and right of fixation. The fixation cross and the two placeholders were present throughout the trial. Targets appeared in the centre of the placeholder. Each one was made up of concentric circles with alternating sections of colour and empty-space within each circle (i.e., like a dartboard or pinwheel).

Stimuli were presented on an Apple G3 iMac computer, and were programmed using PsyScope Version 1.2.5 with the OS 8.6 operating system. Responses were made by key press on the number pad of an Apple iMac keyboard, using the first two fingers of the right hand. The "2" and "8" keys were used; these keys were above and below each other on the number pad aligned with the centre of the screen.

Procedure

Participants sat in a dimly lit room, approximately 75 cm from the computer screen and were instructed to place the first 2 fingers of their right hand over the "2" and

"8" keys of the number pad. The participant was instructed to fixate on the fixation cross, which was on the screen for 1150 ms at the start of each trial. The stimuli were then presented asynchronously with SOAs ranging from 15 to 240 ms (specifically, -240, -120, -60, -30, -15, 15, 30, 60, 120, 240; with negative values indicating SOAs at which the blue stimulus is first). Target side (left or right) and target color (red or blue) of the first stimulus were varied randomly. Targets were also equally likely to appear at the same location or different locations (i.e., same or different placeholder). Both stimuli remained on the screen until a response was given. The participant was asked to report the color of the first stimulus (red or blue). Six hundred trials were presented in this task; that is, the 40 (2 first-target side X 2 first-target colour X 2 location X 5 SOA) conditions were presented randomly 20 times in one blocked session.

Results & Discussion

The threshold of each participant was determined by the JND—the minimum temporal interval required between the onset of the first and second target to perform the TOJ task at 75% accuracy. To derive this index, the proportion of red first responses was converted to the equivalent z-scores under the assumption of a cumulative normal distribution (cf. Finney, 1964). The best-fitting straight line for each individual was then averaged together to produce the mean JND for each position. A paired comparisons test of the JND (in ms) revealed that observers' temporal resolution was better when the targets appeared at different positions (M=33 ms, SE=4 ms) than the same position (M=64 ms, SE=10 ms, respectively) [$t(6) = 3.9, p < .01$].

These results provide a straightforward replication of the findings observed in previous visual (Nicol et al., 2005, submitted) and multisensory TOJ experiments (Keetels & Vroomen, 2005; Spence et al., 2003; Spence et al., 2001; Zampini et al., 2003a; 2003b). Temporal resolution was better when the targets were presented at different locations than at the same location. In fact, the JND was twice as large in the latter condition, indicating that in order to reliably judge the correct temporal order of the two targets, observers needed twice as much time between the onset of the two targets when they were presented at the same location than when they were presented at different locations. While the magnitude of the difference in temporal resolution between the same location and different locations conditions was quite large, the respective JNDs are not inconsistent with other TOJ studies that have investigated the effect of exogenous cueing on visual temporal resolution (e.g., Nicol, et al., 2005; submitted; Spence, Shore & Klein, 2001).

Several different factors could be causing this effect including both space-based and object-based effects. Visual masking of the first target by the second target could cause poorer resolution for the same-location trials. Indeed, a stimulus that is highly visible when presented briefly in isolation can be rendered invisible by a spatially and temporally contiguous subsequent stimulus (Enns & Di Lollo, 2000). Since this would affect performance on trials when targets were presented at the same location, but not different locations, masking could be responsible for the present result. However, previous studies have demonstrated that metacontrast and backward masking effects are actually reduced when stimuli are presented at attended locations (Enns & Di Lollo, 2000; Ramachandran & Cobb, 1995). This seems to undermine a masking account of the data since, in the present Experiment, the targets never appeared at an unattended location. Even so, a masking account is not incompatible with the spatial effect that we propose. Indeed, we suggest that part of the reason why temporal resolution improves when the targets are spatially separated is because masking effects do not apply.

Experiment 2

Experiment 1 clearly demonstrated the effect of spatial disparity on temporal resolution. When the TOJ targets were presented to different locations temporal precision improved dramatically. While spatial factors are clearly contributing to the observed effect on temporal resolution, other factors may also be involved. Nicol et al. (2005; submitted) suggested that temporal resolution improves when targets were spatially separated because they are perceived as distinct objects. In support of that idea, Zampini et al. (2003b) showed that spatial separation alone is not sufficient to improve temporal resolution, and Keetels and Vroomen (2005) reported that temporal resolution only improves when target stimuli are actually perceived as though they emanated from different spatial locations. Thus, the present experiment was designed to test Nicol et al.'s (submitted) hypothesis that in addition to spatial factors, object-based factors also contribute to the enhanced temporal resolution when targets are spatially separated. To do so, we designed a visual TOJ task in which two identical target stimuli were presented at different spatial locations. Critically, by presenting these targets in one of two orientations they appeared as two distinct objects, or grouped into one perceptual object. Given our hypothesis that object-based factors contributed to the effects seen in

Experiment 1, we predicted that performance would be better (i.e., a smaller JND) in the two-object than the one-object condition.

Method

Participants

Fourteen undergraduates attending McMaster University participated in the study for partial course credit. Six participated in the side (i.e., left or right first) TOJ task and eight participated in the elevation (i.e., top or bottom first) TOJ task. No one participated in both experiments and no participants were excluded from the analysis.

Stimuli & Materials

Stimuli consisted of three black line segments arranged into a left and right facing C-shape, or an upright and inverted facing U-shape (4 degrees of visual angle) presented on the horizontal or vertical meridian, six degrees of visual angle to the right or left, and above or below, respectively, a black central fixation dot (0.5 degrees of visual angle), against a dark grey background.

Stimuli were presented on a 20" ViewSonic CRT color monitor (1024 x 900 resolution) at a refresh rate of 75 Hz, powered by a Dell PWS 360 (1.5 Mhz) personal computer. Presentation software (Version 9.9) was used to run the experiment and record responses. Participants responded using the up and down or left and right arrow keys of the keyboard.

Procedure

Participants sat in a dimly lit room, approximately 75 cm away from the computer screen and were asked to fixate on the dot at the centre of the screen. There were two versions of the experiment, in which two stimuli were presented in each trial. In the side version, completed by the first six participants, one stimulus was presented on the left and one on the right of the vertical meridian (0.75 degrees of visual angle), and participants used the left or right arrow key to report the stimulus side (left or right) they perceived first. In the second version, completed by the next eight participants, one stimulus was presented above and one below the horizontal meridian (0.75 degrees of visual angle), and participants used the up or down arrow key to report the stimulus elevation (top or bottom) they perceived first. Two versions were run in order to be comprehensive, and to see to be sure that the results applied to elevation- and side-based TOJs. Each version of the experiment included a one-object condition in which the open ends of the two stimuli faced each other and a two-object condition in which the open ends faced away from each other (see Fig. 2). The first stimulus was presented 700 ms after the onset of the trial in one of the four possible positions depending on the version of the experiment (i.e., left or right of the vertical meridian and above or below fixation, or above or below horizontal meridian and to the left or right of fixation). The second stimulus was presented after a randomly selected stimulus onset asynchrony (SOA) of 15, 30 or 45 ms on the opposing position on the same side of fixation of the first stimulus. Targets remained on the screen until response. An experimental session comprised 672 trials divided equally into 7 blocks. Each block included 8 presentations of the 12 conditions (2 target location X 2 target orientation X 3 SOA), yielding 96 trials.

Results & Discussion

The JND was calculated in the same way as Experiment 1. Separate paired comparisons of the JND for the side and elevation TOJ tasks revealed that participants' temporal resolution was better in the two-object (M=14 ms, SE=2 ms; M=12 ms, SE=1 ms, respectively) than the one-object condition (M=20 ms, SE=2 ms; M=16 ms, SE=2 ms, respectively) ($t(5) = 5.4, p < .01$; $t(6) = 2.59, p < .05$, respectively) in both versions of the experiment.

This result reveals an influence of object-based perception on visual temporal resolution. It is harder to temporally discriminate two spatially separated targets when they perceptually integrate into one-object, than when they perceptually segregate into two-objects. Because the targets were mirror images of each other, and the spatial disparity between them was held constant across both conditions, we contend that the observed effect on temporal resolution was caused by perceptual grouping mechanisms. This interpretation of the data depends in part on how an object is defined. Indeed, one might question whether the line segments that comprise our two targets should be considered an object or not. According to Logan (1996), there is no accepted definition of an object, but "most agree that objects are hierarchical; can be decomposed into parts and each part can be treated as a single object (p.604)." Logan (1996) also asserts that objects are conjunctions of properties that occur at a common location. Based on those descriptions, we suggest that our target stimuli can be considered as one object when they are integrated together, and two objects when they are segregated.

To be sure, we asked an additional ten participants to rate the extent to which our two conditions resembled an object on a 5-point Likert scale (1= definitely not an object, to 5= definitely is an object). The one-object condition received an average rating of 3.8, which was significantly higher than the 1.9 average rating that the two-object condition received. These data confirm our belief that participants generally perceived the two conditions as we intended (i.e., as either one-object or two-objects) and are consistent with research by Marino and Scholl (2005) showing that fully-fledged objects are not necessary to induce object-based effects on visual perception.

In addition to the influence of perceptual grouping, however, it is possible that the present result emerged as a consequence of apparent motion. It has been established that motion cues enhance temporal resolution (e.g., Westheimer & McKee, 1977), and that the strength of the apparent motion illusion increases as the space between two temporally contiguous target stimuli decreases (e.g., Burt & Sperling, 1981; Kolers & Pomerantz, 1971). Although the space between targets was held constant across conditions in the present experiment, the line segments opposite to the open side of each target were closer in the two-object than one-object condition.[1] Since this would give rise to differing amounts of apparent motion, it is important to establish that the present result did not occur simply because observers perceived more apparent motion in the two-object than the one-object condition. Experiment 3 was specifically designed to reveal the relative contributions of perceptual grouping and apparent motion to the effect on temporal resolution in our TOJ task.

Experiment 3

The potentially confounding effect of spatial distance in Experiment 2 requires an additional test of the strong claim being made that object-related processes degrade temporal resolution. The present experiment examines the impact of object grouping on the spatial gradient previously observed in temporal resolution (cf. Allik & Kreegipuu, 1998; Westheimer & McKee, 1977). Targets were presented at three spatial disparities (3, 4.5, and 6 degrees of visual angle). For one group of observers, there was a fixation display that grouped with the target at the middle disparity, whereas for the other group there was no fixation display. To the extent that perceptual grouping affects temporal resolution, a spatial gradient effect should be evident for the targets without the grouping stimulus present, but not for the targets that perceptually integrate with grouping stimulus (see Fig. 4). In other words, when the grouping stimulus is present, it should group with the target in the middle disparity and the relation between target spatial disparity and temporal resolution should be non-linear; on the other hand, in the control task, when the grouping stimulus is absent temporal resolution should decrease linearly as spatial disparity between the targets increases. Thus, for the present Experiments, we expect to see a task (grouping and control) X target spatial disparity (inside, middle and outside) interaction.

Method

Participants

Twenty undergraduates attending McMaster University participated in the study for partial course credit. Ten participants contributed data in each of the two versions of this experiment. No one participated in both experiments and no participants were excluded from the analysis.

Stimuli & Materials

In the grouping version of the experiment, a black square that subtended 4.5 degrees of visual angle in height and width served as the fixation stimulus, which was presented in the centre of the screen, against a dark grey background. There was a gap in the centre of the left and right sides of the square, which was 2.25 degrees of visual angle in length. The targets were black vertical line segments that were the same size of the gap in the fixation square (i.e., 2.25 degrees in length) and the same width of all other line segments used as stimuli (i.e., 0.20 degrees of visual angle). Targets were presented such that they were either: 1) inside: misaligned with the gaps and inside the square (3 degrees apart from each other), 2) middle: aligned with the gaps by of the fixation square (4.5 degrees apart), or 3) outside: misaligned with the gaps and outside the square (6 degrees apart from each other). The size and spacing of all stimuli in the control version of the experiment remained unchanged. The exception being that the fixation square was not used.

Stimuli were presented on a 20" ViewSonic CRT color monitor (1024 x 900 resolution) at a refresh rate of 75 Hz, powered by a Dell PWS 360 (1.5 Mhz) personal computer. Presentation software (Version 9.9) was used to run the experiment and record responses. Participants responded using the up and down or left and right arrow keys of the keyboard.

Procedure

Participants sat in a dimly lit room, approximately 75 cm away from the computer screen and were asked to fixate at the centre of the screen. In the grouping and control versions of the experiment (i.e., with or without the fixation square), each trial comprised the presentation of a target on either side of fixation (i.e., the vertical meridian) at one of three randomly varying SOAs (15, 30, or 45 ms), and at one of three spatial disparities (inside, middle, outside) and observers judged which one appeared first. Responses were made using the left or right arrow key to report the stimulus side they perceived first. In both versions, the initial trial began 2000 ms after the participant initiated the block, and in subsequent trials, the first target appeared 2000 ms after the response to the previous trial. Targets remained on the screen until response. An experimental session comprised 672 trials divided equally into 7 blocks. Each block included 4 presentations of our 24 conditions, yielding 96 trials.

Results & Discussion

To test our hypothesis concerning the interaction between the presence or absence of grouping cues and target spatial disparity, we performed a two-way mixed model ANOVA on the JNDs with target spatial disparity (inside, middle, outside) as the within-subjects factor and TOJ task (grouping or control) as the between-subjects factor. Critically, the interaction between these factors was significant ($F(2,54) = 3.13$, $p < .05$); indicating that when grouping cues were present temporal resolution was worse in aligned than the misaligned-inside condition, but when grouping cues were absent, temporal resolution across these two target spatial disparities did not differ.

To reveal the nature of the above interaction we performed two one-way ANOVAs on the data for the grouping and control experiments separately. For the control data, pair wise comparisons revealed that that the JND of the inside condition (M=14 ms, SE=0.2 ms) was smaller than the outside condition (M=17 ms, SE=3 ms) (t

(9)= -3.0, $p < .005$), while the JND of middle condition (M=16 ms, SE=3 ms) did not differ from either the inside or outside conditions ($t(9) = -1.9$, $p > .05$ and $t(9) = 1.0$, $p > .20$) (see Fig. 5). Thus, when the grouping stimulus was absent, there was a trend indicating a linear negative relation between temporal resolution and target spatial disparity. For the grouping data, however, pair wise comparisons showed that the JND of the inside condition (M=19.3 ms, SE=3.8 ms) was smaller than the middle (M=34 ms, SE=6 ms) and outside conditions (M=33 ms, SE=5 ms) ($t(9) = -14.9$, $p < .005$ and $t(9) = -17.1$, $p < .001$, respectively), while the middle condition did not differ from the was outside condition ($t(9) = 2.1$, $p > .6$). Thus, the presence of the grouping stimulus disrupted the spatial gradient on temporal resolution by impairing the JND in the middle (grouping) condition.

When perceptual grouping cues were absent, temporal resolution was better for the two target line segments spatially separated by 3 degrees than for two target line segments separated by 6 degrees of visual angle—a result that can either be attributed to an effect of spatial disparity or eccentricity (Allik & Kreegipuu, 1998; Westheimer & McKee, 1977) or apparent motion (Burt & Sperling, 1981; Kolers & Pomerantz, 1971). Since in Experiment 2, the corresponding line segments of the one-object and two-object target orientations were separated by 1.5 degrees and 9 degrees, respectively, we concede that the difference in spatial distance between these critical target elements must have contributed to the difference in temporal resolution across those conditions. Critically however, the non-linear relation that we found between temporal resolution and target spatial disparity in the Grouping condition supports the perceptual grouping account of the data reported in Experiment 2. Indeed, the expected task X target spatial disparity interaction indicates that perceptual grouping does impair visual temporal resolution.

One problem for this interpretation is that in the grouping data, the JNDs for the outside and middle conditions did not differ. Apparently the fixation display interfered with performance on trials in the outside condition. However, the fixation display also interfered with performance in the inside condition. Indeed relative to the control data observers' sensitivity dropped by approximately 20% and 50% in the inside and outside conditions respectively. The fixation display may have interfered with performance in the outside condition in particular because on those trials observers' attention would initially be drawn to the outer area of one side of the display by the onset of the first target, then it would be drawn back through the display to the outer area of the other side by the onset of the second target. This process of traversing attention across the boundaries imposed by the fixation stimulus may have been detrimental to performance and could explain why the JND for the outside condition was so high.

General Discussion

The goal of the present study was to investigate the influence of perceptual grouping on visual temporal resolution. In Experiment 1 we confirmed that visual temporal resolution is enhanced when targets are spatially separated (Nicol et al., 2005; submitted). In Experiment 2 we showed that visual temporal resolution is worse for two targets that perceptually group (i.e., perceived as one object) than it is when the same two targets do not group (i.e., perceived as two objects). Finally, in Experiment 3 we showed that although apparent motion effects contributed to the observed differences in temporal resolution across the one-object and two-object conditions of Experiment 2, that a complete account of our data includes the influence of perceptual grouping on visual temporal resolution. From these results we conclude that object-based perceptual factors contribute to the enhancement in temporal resolution that is observed when TOJ targets are presented with spatial disparity.

To our knowledge these results provide the first demonstration that perceptual grouping impairs temporal resolution within the visual modality. A similar effect of perceptual grouping was however, recently demonstrated cross-modally. Vatakis & Spence (in press) showed that observers were worse at reporting the sensory modality that was presented first when an auditory (i.e., spoken syllable or word) and a visual (i.e., face) stimulus were gender matched (i.e., female voice and female face) than gender mismatched (i.e., male voice and female face). Thus, both multisensory and unisensory TOJ experiments demonstrate an inverse relation between perceptual integration and temporal resolution.

Our findings may have implications for the theoretical accounts put forward in the multisensory TOJ literature to account for the fact temporal resolution improves when the targets are spatially separated—the spatial redundancy hypothesis and the integration hypothesis. While our data cannot refute the spatial redundancy hypothesis (Spence et al., 2003), since it is primarily a multisensory account of the phenomenon (which states that temporal precision improves due to redundant sensory and spatial information concerning the onset of the targets), they do lend support for the integration hypothesis (e.g., Radeau, 1994). That hypothesis states that temporal resolution is negatively related to spatial disparity because stimuli that are spatially and temporally contiguous are more likely to be integrated into a single percept, thereby making it harder to distinguish between them. In fact, in regard to the integration hypothesis, Keetels and Vroomen (2005) suggested that presentations that promote the pairing of target stimuli could result in the loss of the relative temporal onsets of the components. Our results support that hypothesis, since conditions that facilitated perceptual integration in the present research, degraded temporal resolution. This pattern of data suggests that at least some of the effect to temporal resolution that occurs when TOJ stimuli are spatially separated can be attributed to the fact that they are perceived as distinct objects.

As discussed earlier, the one potential problem for our conclusion is that the JNDs of the middle and outside conditions of the grouping data in Experiment 3 did not differ. Indeed, a perceptual grouping account would predict poor temporal resolution in the middle condition, but not in the outside condition. We contend that the impairment to temporal resolution in the outside condition was caused by attentional shifts across the boundaries imposed by the fixation display. Critically, the JNDs of the middle and inside conditions did differ in the grouping data, while in the control data they did not, and this pattern of data can only be considered as a perceptual grouping effect.

With regard to the same-object advantage often seen in spatial discriminations (e.g., Behrmann, Zemel, Mozer, 1998; Duncan, 1984; Egly et al., 1984; Macquistan, 1997), these results show that it does not extend to a temporal discrimination task. The same object-advantage is a ubiquitous finding is spatial vision research—we are better at making two feature discriminations about one object than we are at making one feature discrimination on each of two objects. In a classical demonstration of the effect, Duncan (1984) briefly presented observers with two spatially superimposed objects that each varied in two dimensions. Participants made two spatial discriminations: both regarding the same object or one for each object. Observers were significantly less accurate when the two spatial discriminations concerned different objects than when the discriminations concerned the same object. Thus, object-based attentional selection enhances our ability to make accurate spatial/feature-based discriminations. In contrast, the temporal discrimination task used in the present research produced a same-object *disadvantage:* whenever both targets could be perceptually grouped into one object, temporal discriminations were less accurate.

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Footnotes

1. We would like to thank an anonymous reviewer for bringing this important point to our attention.

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Figure Captions

Figure 1. Mean JNDs for Experiment 1. The smaller JND indicates that temporal resolution was worse when the targets were presented at the same than different locations. The inset shows the target stimulus (which was blue or red). Error bars reflect within-subject variability for each condition separately.

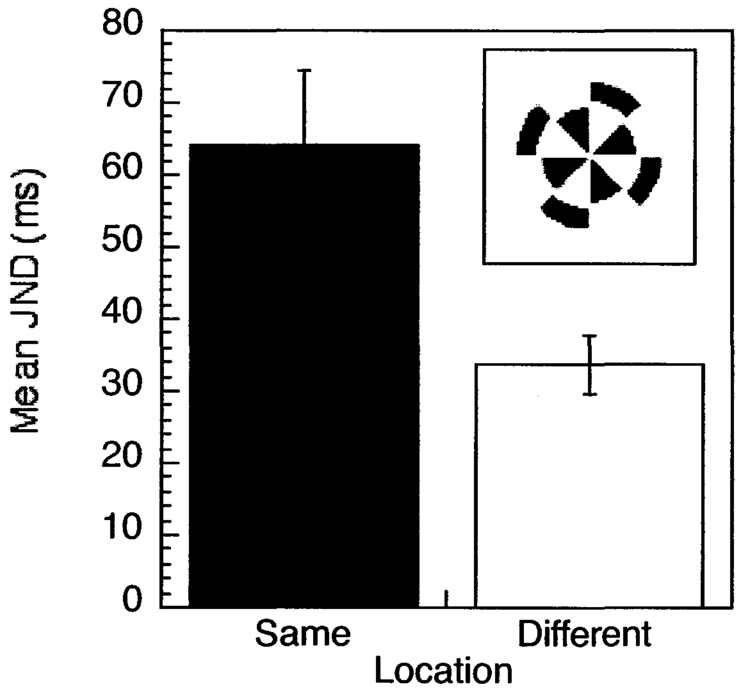
Figure 2. Schematic of the stimuli used in Experiment 2. The upper target pair shows the two-objects condition from the side version of task, and the right target pair shows the one-object condition from the elevation version of the task. Stimuli are not drawn to scale.

Figure 3. Mean JNDs for side and elevation temporal order judgment (TOJ) tasks used in Experiment 2. The smaller JND for the two-object condition relative to the one-object condition indicates better temporal resolution in the side ($p < .01$) and elevation ($p < .05$) versions of the task. Error bars reflect within-subject variability for each condition separately.

Figure 4. Schematic of the stimuli used in the grouping and control temporal order judgment (TOJ) tasks of Experiment 4. In the grouping task trials began with the presentation of the grouping stimulus followed by the presentation of the two target line segments at varying SOAs. The control task was identical, except the grouping stimulus was absent.

Figure 5. Mean JNDs for grouping and control temporal order judgment (TOJ) tasks used in Experiment 3. In the grouping task (left) temporal resolution was worse in the aligned than the misaligned-inside condition. In the control task (right), the corresponding

conditions (inside and middle) did not differ. Error bars reflect within-subject variability for each condition separately.



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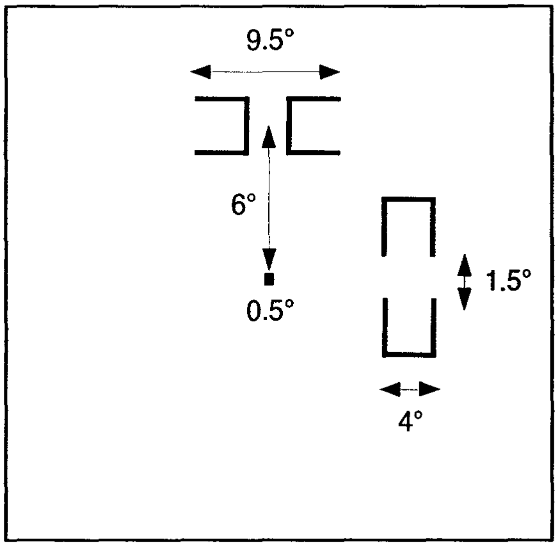

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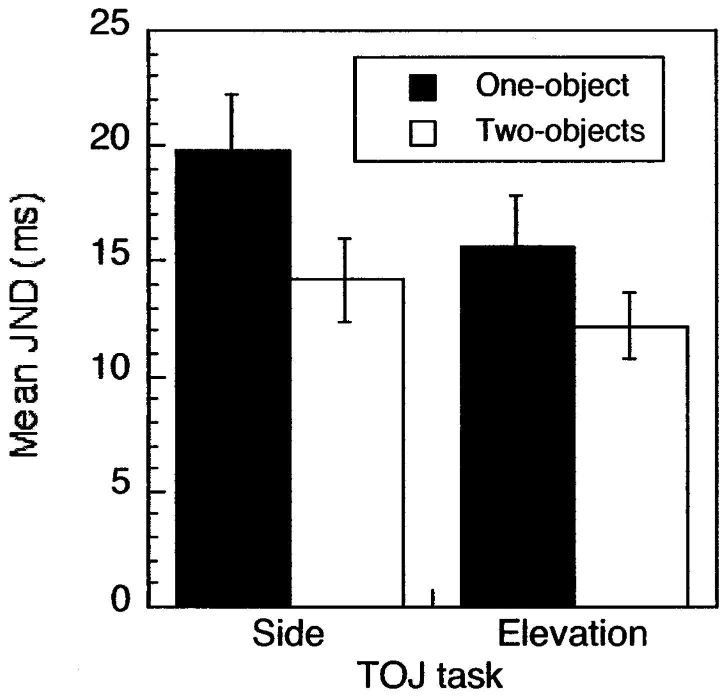

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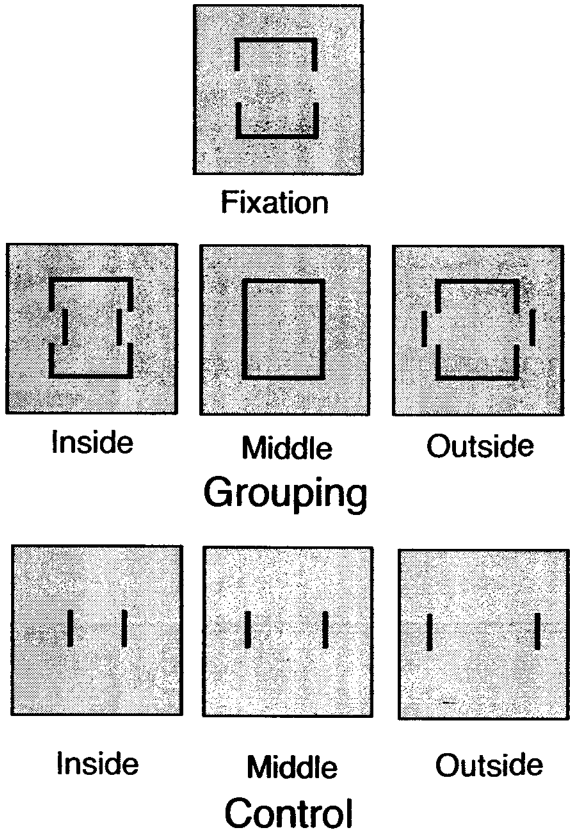

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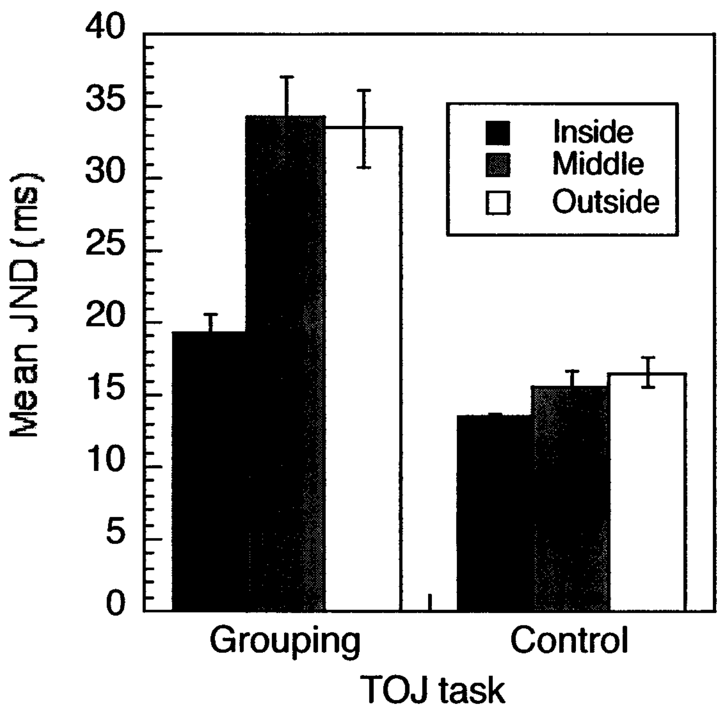

Nicol & Shore (2007). Figure 5.

Chapter 2

Nicol, J.R. Watter, S., Gray, K., & Shore, D.I. (2008). Object-based perception mediates the effect of exogenous attention on temporal resolution. *Visual Cognition,* XX, XX-XX.

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Dear Dr. Watter:

I am completing a Ph.D. thesis at McMaster University entitled *Influences of object-based selection on the relation between attention and visual temporal resolution.* I would like your permission to reprint the following journal in my thesis.

Nicol, J.R., Watter, S., Gray, K. & Shore, D.I. (2007). Object-based perception mediates the effect of exogenous attention on temporal resolution. *Visual Cognition.*

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Sincerely,

Jeffrey R. Nicol

Permission Granted for the Requested Above

Authorized by: Scott Watter

Title: Assistant Professor

Date: Nov. 21, 2008

Signature: Scott Watter

Jeff Nicol
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August 25, 2008

Dear Kellie:

I am completing a Ph.D. thesis at McMaster University entitled *Influences of object-based selection on the relation between attention and visual temporal resolution.* I would like your permission to reprint the following journal in my thesis.

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Sincerely,

Jeffrey R. Nicol

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Authorized by: Kellie Gray.

Title: J.D. Candidate, 2011

Date: August 27, 2008

Signature: [signature]

Abstract

The effects of target distinctiveness, target placeholders, and target spatial separation on the relation between exogenous attention and temporal resolution were examined in a visual temporal order judgment (TOJ) task. When identical targets were presented at different locations within a cued or uncued placeholder, attention degraded temporal resolution (Experiment 1), but when distinct targets were presented at different locations that cueing effect disappeared (Experiment 2), and when the target placeholders were not used, attention enhanced temporal resolution for distinct targets presented at different locations (Experiment 3). Attention also degraded temporal resolution when distinct targets were presented at the same location (Experiment 4). The latter two results were then replicated in a task in which distinct targets appeared randomly at the same or different locations (Experiment 5). Clearly, the nature of the relation between exogenous attention and temporal resolution is not a straightforward one—the relative location of targets, the similarity of targets, and the presence of placeholders all qualitatively affect the cuing relation. We hypothesize a mediating role for object-related processes. Specifically, exogenous attention enhances feature binding and related object representations, which subsequently degrade temporal resolution.

Introduction

In order to deal with the overwhelming amount of stimulation that constantly inundates our sensory systems we selectively process only some of the available information from our surroundings. This selection results in modulation of both spatial and temporal aspects of information processing. While we know a great deal about the consequences of selective attention on spatial resolution (see Carrasco, Ling & Read, 2004; Carrasco & McElree, 2001; Gobell & Carrasco, 2005; Yeshurun & Carrasco, 1998, 1999), the research on temporal effects is less extensive and coherent. Indeed, while a growing body of evidence indicates that attention degrades temporal resolution (e.g., Hein, Rolke, & Ulrich, 2006; Yeshurun, 2004; Yeshurun & Levy, 2003), there is also evidence that attention improves temporal resolution (Baek, Kham & Kim, 2005; Tsal, Meiran & Lamy, 1995). The present research sought to investigate the source of these equivocal results. Specifically we examined the extent to which grouping properties of the stimuli used in a temporal order judgment (TOJ) task mediate the relation between exogenous attention and visual temporal resolution.

Early work examining the effect of attention on temporal perception focused on the perception of onsets (Stelmach & Herdman, 1991; Shore, Spence & Klein, 2001; Titchener, 1908) and durations (Enns, Brehaut & Shore, 1999; Macar, Grondin & Casini, 1994; Mattes & Ulrich, 1998). The ubiquitous finding, regardless of the type of attention (i.e., endogenous or exogenous) was sooner perceived onset—*prior entry*—and longer perceived duration. These two results appear to be independent of each other (Enns et al., 1999) and may depend on distinct neural machinery. While these findings clearly concern the relation between attention and temporal perception, they do not address the question of temporal resolution per se. One could argue that longer perceived duration results in poorer temporal resolution and better spatial resolution; however, resolution is typically measured by determining the smallest temporal interval that can be reliably reported. More recent work has directly addressed the question of temporal resolution using gap detection and temporal order judgment tasks.

Yeshurun and Levy (2003) examined the effect of attention on temporal resolution using a temporal gap detection task. Attention was either focused with a 100% valid spatial cue or a spatially uninformative cue, which presumably resulted in diffuse attention. Observers attempted to detect a brief temporal gap between two disks of light that were presented 94 ms following the onset of the cue. Performance was degraded (i.e., a longer gap was needed for accurate gap detection) when the target appeared at the cued location (i.e., focused attention) compared to the neutrally cued location (i.e., diffuse attention). Accordingly, Yeshurun and Levy concluded that exogenous attention degrades temporal resolution.

A more recent study by Hein et al. (2006) using a TOJ task supported Yeshurun and Levy's (2003) result by also showing that exogenous attention degrades temporal resolution. In their study, observers performed a laterality-based TOJ (i.e., left or right first) for two adjacent target dots that appeared within the cued or uncued placeholder. TOJs were less accurate at the cued than at the uncued location. Hein et al. also concluded that exogenous attention degrades temporal resolution.

The generality of this claim was brought into question when the gap detection task used by Yeshurun and Levy (2003) was converted into a luminance-based TOJ task (Baek, Kham & Kim, 2005). Observers were presented with two target disks at the same location, which were either the same luminance polarity or different luminance polarities. When the targets were different luminance polarities (i.e., one target was brighter and the other was darker than the background) temporal resolution was better at the cued than uncued location. However, when the targets were the same luminance polarity (i.e., both targets were brighter or dimmer than the background) temporal resolution was better at uncued than cued location. Thus it appears that exogenous attention does not always degrade temporal resolution.

When considered together, the above research reveals that the relation between exogenous spatial attention and visual temporal resolution is not straightforward. We hypothesized that the nature of the relation may depend on properties of the stimuli being used to measure it. Specifically, the extent to which the stimuli are susceptible to perceptual grouping may be critical for understanding this relation. The present research investigated this hypothesis by examining the effect of exogenous attention on temporal resolution using a variety of different experimental stimuli in the context of a visual TOJ task. Temporal resolution was indexed by the magnitude of the just noticeable difference (JND), which is the minimum average temporal interval that observers require to report the correct temporal order of the two targets 75% of the time. We examined three factors that putatively modulate object-related processes: the effect of target distinctiveness

(Experiments 1 & 2), the effect of using placeholders (Experiments 2 & 3), and the effect of target spatial separation (Experiments 3, 4 & 5).

Experiment 1

The purpose of the present experiment was to determine if we could replicate the finding of reduced temporal resolution at cued locations (e.g., Hein et al., 2006). We asked observers to report the temporal order of two identical target dots presented at different locations within either the cued or uncued placeholder. Consistent with Hein et al. (2006), we expected worse performance (i.e., a larger JND) at the exogenously attended location. In other words, temporal resolution should be better when the targets appear in the uncued placeholder than when they appear in the cued placeholder.

Methods

Participants

Eleven (8 female, all right-handed) undergraduates from McMaster University, between the ages of 17 and 20 years, participated in partial fulfillment of course credit.

Stimuli & Apparatus

All stimuli were black presented against a light grey background (see Figure 1). A fixation dot was presented in the centre of the screen (0.4° x 0.4°) flanked by two rectangular placeholders (3° x 6°) presented 5° to the left or right of fixation throughout each trial. The two target dots (1° x 1°) were presented 5° to the left or right of fixation, separated by a vertical gap of 3° (i.e., 1.5° above and below the horizontal midline). The placeholders also served as cues by briefly increasing the thickness of the lines from 4 point to 8 point width.

A Dell PWS 360 personal computer running Presentation (Version 9.1) software and connected to a ViewSonic P220f monitor driven at a resolution of 1280 x 720 @ 65 Hz was used to generate the stimuli and collect responses. Participants sat in an adjustable chair and rested their chins in a support that was placed 75 cm in front of the computer monitor. Responses were made using the arrow up and arrow down keys of the keyboard.

Procedure

Figure 1 shows a schematic of the trial sequence. Participants were instructed to fixate on the dot in the centre of the screen, and were told that the cue provided no predictive value concerning the location of the targets. Each trial began with the presentation of the fixation dot and a placeholder on either side, all of which remained visible for the entire block. After 500 ms, observers were cued to the one side of fixation by the brief emboldening of one of the placeholders for 100 ms. The first target stimulus appeared 100 ms after cue offset in either the cued or uncued placeholder. After one of three SOAs (15, 30, or 45 ms), the second target appeared above or below the first target in the same target placeholder. Participants indicated the location of the target stimulus that appeared first by pressing either the arrow up (a top-first response) or arrow down (a bottom-first response) keyboard button. The next trial began 500 ms after a response was made. Participants were encouraged to take self-terminating rests between blocks. They pressed the space bar when they were ready to continue. The experiment consisted of 480 trials divided equally into 4 blocks of 120 trials. Each of the 24 conditions (2 cue locations X 2 first target locations X 6 SOA) was presented 20 times.

Results & Discussion

The threshold of each participant was determined by the JND—the minimum temporal interval required between the onset of the first and second target to perform the TOJ task at 75% accuracy. To derive this index, the proportion of top-first responses was converted to the equivalent z-scores under the assumption of a cumulative normal distribution (cf. Finney, 1964). The best-fitting straight line for each individual was then averaged together to produce the mean JND for each position. The JND was calculated in this way in all of the present experiments. We also examined the Point of Subjective Simultaneity (PSS), which is the SOA at which the observer is maximally uncertain about the relative order of the targets. In previous work (e.g., Shore et al., 2001), there were robust effects of attention on the PSS; however, in those cases, only one of the targets was attended and the PSS was shifted such that the other target had to be presented sooner to achieve the PSS. Here we focus on the JND since both targets are either attended or not and so we expect no shift in the PSS. Indeed, we did not find any PSS differences in the experiments reported here.

A paired comparisons test showed that the JND was smaller at the uncued (M= 13 ms, SE = 1 ms) than the cued location (M = 16 ms, SE = 1 ms; $t(10) = 3.30$ $p < 0.01$). Thus, as expected, we replicated the result reported by Hein et al. (2006) and found better temporal resolution at the unattended than attended spatial location (see Figure 2).

Experiment 2

While the finding of degraded temporal resolution at exogenously cued locations appears to be a general finding being observed with a temporal order judgment task (Hein et al., 2006; Experiment 1) and a temporal gap detection task (Yeshurun & Levy, 2003), there is some indication of opposing results (Baek et al., 2005). The critical difference between these studies could be the extent to which the parts of the stimulus array can be grouped together into one perceptual object. Specifically, Baek et al. (2005) found qualitative differences with same-polarity targets and different-polarity targets. We sought to replicate this result using stimuli similar to those used in Experiment 1. As such, we replaced the identical dots used previously with distinctive shapes (i.e., an 'X' and a '+') that would not as easily support grouping.

Methods

Participants

Eleven (7 female, 10 right-handed) undergraduates from McMaster University, between the ages of 17 and 20 years participated in partial fulfillment of course credit.

Stimuli, Apparatus & Procedure

The apparatus and procedure was the same as in Experiment 1. Stimuli, other than the targets, were the same as in Experiment 1. The targets consisted of an × and + (2° x 2°) presented at the same location as the dots used in Experiment 1. Each experimental session consisted of 4 blocks of 120 trials; each of the 48 conditions (2 cue location X 2 first target location X 2 first target identity X 6 SOAs) were presented 10 times. Since the identity of the first target was irrelevant to the task, we collapsed across this factor in the data analysis, thus providing 20 trials per condition.

Results & Discussion

A paired comparisons test showed the JND did not differ at the cued and uncued location (M= 15 ms, SE = 1 ms and M = 16 ms, SE = 1 ms, respectively; t (10) = 0.21, *p* = 0.84; see Figure 2). Changing the TOJ targets from identical dots used in Experiment 1 to distinct stimuli mediated the relation between attention and temporal resolution. However, we did not replicate the results of Baek et al. (2005) of improved temporal resolution. We hypothesized that the presence of the placeholder, acting as an object frame could enhance the perceptual grouping of the object components. As such, we replicated Experiment 2 without placeholders.

Experiment 3

Placeholders can have very strong effects on the nature of the cuing effect (cf. Driver & Baylis, 1998), driving attention to segmented objects, rather than unparsed regions of space (see also Bennett & Pratt, 2001). In support of that assertion, several studies have shown that exogenous attention cues can induce object-based processing (e.g., Egly, Rafal & Driver, 1994; Macquistan, 1997). It is possible, therefore, that the exogenous cueing technique used by Hein et al. (2006)—briefly emboldening a placeholder—may have invoked object-based attention. Intuitively, one may expect that the consequence of object-based processing would be reduced temporal resolution (see also Nicol & Shore, 2007). To investigate that hypothesis, we replicated Experiment 2 without the placeholders.

Methods

Participants

Seven (5 female, 6 right-handed) undergraduates from McMaster University participated in partial fulfillment of course credit. Participants were between the ages of 17 and 25 years.

Stimuli, Apparatus & Procedure

With the exception of the removal of the placeholders throughout the trial, the stimuli used were identical to the previous Experiment. We cued attention by briefly presenting a rectangle (i.e., the placeholder used in the previous Experiments) to one side of fixation. The apparatus was identical to Experiment 1 and 2. The procedure was the same as in the previous Experiments. The experiment consisted of 480 trials divided equally into 4 blocks of 120 trials. Each of the 48 conditions (2 cue location X 2 first target location X 2 first target identity X 6 SOAs) was presented 10 times. Since the identity of the first target was irrelevant to the task, we collapsed across this factor in the data analysis, thus providing 20 trials per condition.

Results & Discussion

A paired comparisons test of the JND for each condition revealed that the JND was smaller at the cued (M=15 ms, SE = 1 ms) than uncued location (M = 21 ms, SE = 1 ms) (t (6) = -3.79, $p < .01$). Thus temporal resolution was better at the cued than uncued location when distinct targets were used without placeholders. This result is qualitatively different from our observations from Experiment 1. It appears that both target distinctiveness and the presence of placeholders can affect the relation between exogenous attention and temporal resolution. While we hypothesized that object-related processes may be mediating the relation between attention and temporal resolution, we sought another factor that would putatively mediate this process.

Space is a very powerful factor that can change the extent to which stimuli are treated as one or two objects.

Experiment 4

Given the large number of studies showing the importance of space as a mediating factor in TOJ performance (e.g., Keetels & Vroomen, 2005; Nicol & Shore, 2007; Spence et al., 2001; Spence et al., 2003), the present experiment was designed to examine the effect of exogenous attention on temporal resolution when the target stimuli were presented at the same spatial location. To do so, we modified the different-stimuli TOJ task used in Experiment 3, by presenting the targets at the same spatial location (i.e., overlapping) and asked observers to report the identity of the target that appeared first (i.e., × first or + first). Based on the results of previous TOJ studies, we expected that spatially overlapping the targets would produce an overall decrease in temporal resolution (cf. Nicol & Shore, 2007, Experiment 1); however, the critical question concerns the difference between the cued and the uncued location. If moving the stimuli together promotes the perception of a unified object, and if this factor is important for the effect of an exogenous cue, then we expect to observe poorer temporal resolution at the cued location relative to the uncued location.

Methods

Participants

Ten (8 female; 9 right-handed) undergraduates from McMaster University participated in partial fulfillment of course credit. Participants were between the ages of 17 and 24 years.

Stimuli, Apparatus & Procedure

The same stimuli used in Experiment 3 were used in the present Experiment. The only difference concerned the location of the target stimuli. These were presented on the horizontal meridian at the same eccentricity as used in all of the previous experiments. When both targets were presented, at the end of the trial, the resulting percept was a 2° x 2° asterix (✳). The same apparatus used in the previous Experiments was used in the present Experiment. The procedure was the same, with the exception that observers could not report where the stimuli appeared, since they appeared at the same location. Thus, they reported which stimulus (X or +) appeared first by using the left or right arrow key. There were 480 trials divided equally into 4 blocks of 120 trials. Each of the 24 conditions (2 cue location X 2 first target identity X 6 SOA) was presented 20 times.

Results & Discussion

A paired comparisons test of the JND for each condition revealed that the JND was smaller at the uncued (M= 49 ms, SE= 4 ms) than cued location (M= 76 ms, SE= 8 ms) (t (9) = 2.91, $p < .01$; See Figure 2). Two important results emerged from the present experiment. First, temporal resolution was, on the whole, worse when the targets were presented at the same spatial location compared to the different locations used in Experiment 3 (average JNDs of 18 ms versus 62 ms, respectively). This result is consistent with previous research showing that performance on TOJ tasks improves when targets are presented at different locations (e.g., Keetels & Vroomen, 2005; Nicol & Shore, 2007; Spence et al., 2003). The more important result to emerge from the present experiment was that when the targets were presented at the same spatial location, attention degraded temporal resolution. One additional difference between Experiments 3 and 4 was the task used. In Experiment 3, observers reported *where* the first target appeared whereas in Experiment 4 they reported *what* target appeared first. Thus, we replicated the comparison of same- and different-location targets with the same task.

Experiment 5

In order to strengthen the comparison of results from Experiments 3 and 4, we conducted another experiment in which we mixed same-location trials with different-location trials within the same block of trials. Observers reported the identity of the target that appeared first regardless of whether it was presented at the same location as the second target (on the horizontal midline) or at a different location (above or below the midline). We also changed the identity of our target stimuli from × and + to a ◊ and □. Given that the result of Experiment 2 suggests that the psychophysical properties (e.g., distinctiveness) of the targets can strongly influence the observed relation between exogenous attention and temporal resolution, we wanted to be sure that the results of Experiments 3 and 4 were not specific to the particular target stimuli that we employed. Mixing the same and different location trials within each block of trials also obviates the concern that strategic allocation of attention (broad versus focused distribution), put in place before the trial started, could account for the differences observed between Experiments 3 and 4 (cf. Shore, McLaughlin & Klein, 2001).

Methods

Participants

Thirteen (10 female, 12 right-handed) undergraduates from McMaster University participated in partial fulfillment of course credit. Participants were between the ages of 17 and 23 years.

Stimuli & Apparatus

The target stimuli used were changed to a ◊ and □, but subtended a similar degree of visual angle as the previous target stimuli. The targets were presented 1.5° above and below the horizontal meridian 5° from the fixation point (i.e., if the first TOJ stimulus appeared in the bottom right quadrant of the screen then the second TOJ stimulus appeared in the top right quadrant of the screen) or both on the horizontal meridian 5° horizontally from fixation. The apparatus was the same as used in the previous experiments.

Procedure

The procedure was similar to Experiment 4 with two exceptions: the SOA values were changed to 15, 30, 45 and 90 ms, and the participants reported the identity of the stimulus that appeared first by pressing the left arrow key (a "◊" first response) or right arrow key (a "□" first response). The two trial types—targets at the same or different locations—were mixed within blocks. The experiment consisted of 5 blocks of 125 trials, yielding a total of 625 trials.

Results & Discussion

Two paired comparisons tests were performed on the JNDs of the four experimental conditions. When target stimuli were presented at the same location observers were more sensitive at the uncued location (M= 39 ms, SE = 6 ms) than the cued location (M = 82 ms, SE = 11 ms; t (9) = -4.63, $p < .005$), and when target stimuli were presented at different locations observers were more sensitive at the cued location (M = 29 ms, SE = 6 ms) than the uncued location (M = 41 ms, SE = 5 ms; t (10) = 2.31, $p < .05$; see Figure 2). Three observers were removed from the analysis for producing a threshold that was greater than 2 standard deviations above the mean. The remaining observers all showed the interaction pattern shown by the group. The results of the present experiment replicate Experiments 3 and 4: temporal resolution was degraded at the attended location when targets were presented at the same location, and was enhanced at the target location when targets were presented at different locations.

General Discussion

The present experiments investigated the general claim that exogenous spatial attention degrades visual temporal resolution (Hein et al., 2006; Yeshurun & Levy, 2003; but see Baek et al., 2005). We examined the effects of target distinctiveness, location placeholders, and spatial separation on the relation between attention and temporal resolution. In Experiment 1, we replicated previous results (e.g., Hein et al., 2006) by showing that temporal resolution was better at uncued locations for identical targets that appeared at different spatial locations within a placeholder. That cueing effect disappeared in Experiment 2, when distinct targets were presented at different locations within placeholders. In Experiment 3, when there were no placeholders and distinct targets were presented at different locations, we observed better resolution at the cued location (i.e., a qualitatively different pattern of data from that seen in Experiment 1). When distinct targets were presented at the same location (without placeholders) in Experiment 4, the cueing effect reversed again and temporal resolution was better at the uncued location. Finally, in Experiment 5, we replicated the results of Experiments 3 and 4 (i.e., better and worse temporal resolution at the cued location, respectively) in a mixed experimental design in which a new set of distinct targets randomly appeared at either the same or different spatial locations.

The mixed pattern of data that emerged from the present research mirrors what has been reported in the literature. Some studies report that exogenous spatial attention degrades temporal resolution (Hein et al., 2006; Yeshurun & Levy, 2003) while others have shown that it can also enhance temporal resolution (Baek et al., 2005). Therefore, when considered together, the extant data indicate that the general claim that exogenous attention degrades temporal resolution is not tenable. Rather, we propose that the relation depends on the characteristics of the stimuli and the task. Indeed, the present research shows that the effect of exogenous attention on temporal resolution depends on spatial relations between the targets (i.e., presented at the same or different locations), the distinctiveness of the targets, and the presence or absence of placeholders.

Baek et al. (2005) also found similar results when they investigated the influence of exogenous attention on temporal resolution. To account for their findings they proposed a temporal summation hypothesis. According to that hypothesis, targets presented in the same luminance polarity were temporally integrated by attention, resulting in degraded temporal resolution; but targets presented in different luminance polarities were temporally segregated by attention, resulting in enhanced temporal resolution at attended locations. Our results concerning the effect of target spatial disparity on the relation between exogenous attention and temporal resolution support Baek et al.'s hypothesis if one proposes that space and luminance have similar effects on the relation between attention and temporal summation. That is, when targets were presented at the same location, attention would operate to integrate the targets, similar to the effect proposed by Baek et al. for the same luminance polarities. On the other hand, with targets presented at different locations, such integration would not be applicable, similar to the different luminance polarities in the Baek et al. study. The same hypothesis could account for the effects of target distinctiveness and the presence of placeholders, if one assumes that these factors affect the object status of the targets.

We propose that target presentations that encourage perceptual integration decrease temporal resolution at the attended location. The present experiments provide a number of examples. When targets are not spatially separated temporal resolution is worse than when they presented at different locations (compare Experiment 3 and 4, and see Experiment 5). It could also be argued that the use of placeholders produced grouping by closure and common region, which also resulted in diminished temporal resolution at the attended location (compare Experiment 2 and 3). Finally, it is possible that grouping by similarity was responsible for the further reduction in temporal resolution observed when we used identical rather than different targets (compare Experiment 1 and 2). [1] Support for the idea that Gestalt grouping processes negatively affect temporal resolution can also be found in a recent TOJ study in which we showed that perceptual groping impairs temporal resolution (Nicol & Shore, 2007). The targets in that experiment were three-sided squares, presented closely together at different spatial locations. On half of the trials the open sides of the targets were presently adjacent to each other which encouraged them to be perceptually grouped into a single object, and on the other half of the trials the open sides faced away from each other which encouraged to be perceived separately. Temporal resolution was worse on trials when the targets grouped than when they did not group. To be clear, we are proposing that object-related processes mediated the relation between exogenous attention and temporal resolution. Specifically, attention operates to enhance object representations, when possible, and these enhanced representations lead to degraded temporal resolution.

Masking and motion as mediating factors

Motion and masking represent potentially mediating factors on the effect of target spatial disparity on temporal resolution. Although forward masking of the first target by the cue cannot account for the present pattern of data since the same cueing technique facilitated performance in Experiments 3 and 5 but impaired performance in Experiments 1 and 4. On the other hand, visual backward masking in Experiments 4 and 5 (same location conditions) could account for some of the findings. Indeed, a stimulus that is highly visible when presented briefly in isolation can be rendered invisible by a spatially and temporally contiguous subsequent stimulus (Enns & Di Lollo, 2000). Furthermore, backward masking effects are most robust when a small temporal interval is inserted between the two stimuli—a scenario that aptly describes that same-location TOJ task. The main problem with this account concerns the finding that, in general, attention reduces the effect of masking (Di Lollo, Enns, & Rensink, 2000; Ramachandran & Cobb, 1995). Thus, if the main difference between Experiments 3 and 4 (or the two trial types in Experiment 5) was the presence of masking when the targets appeared at the same location, but not when they appeared at different locations, then performance should actually have been better at the cued location in Experiment 4 or the same-location trials of Experiment 5. We found the opposite pattern—attention degraded temporal resolution (i.e., increased the potential contribution of masking) when the targets appeared at the same location.

Apparent motion represents another potential candidate account concerning the spatial effect observed across Experiments 3 and 4 (and replicated in Experiment 5). Indeed, any benefits arising from the effects of apparent motion would only be evident when stimuli were presented at different spatial locations. This would explain why temporal resolution was so much better when targets were presented at different locations, relative to the same location. Intuitively, the appearance of motion or directionality would improve temporal resolution at attended, relative to unattended locations, but to our knowledge this hypothesis has not been examined empirically. An apparent motion account does not, however, explain the discrepancy between the results of Hein et al. (2006) (and our replication of their result in Experiment 1) and Experiments 2 and 3, since in all cases the targets were spatially separated. In fact while our targets were separated by 3°, their targets were only separated by 1.1°, which would actually give rise to a greater effect of apparent motion (Allik & Kreegipuu, 1998). Regardless of the causal mechanism, the present research clearly demonstrates the critical role of space on the relation between exogenous attention and temporal resolution: when targets are presented at the same location attention degrades temporal resolution and when the targets are presented at different locations attention can enhances temporal resolution.

Attention as a unitary concept?

The argument that attention enhances temporal resolution is clearly disputable. Indeed, it may be that "attention" has a multitude of concurrent effects that can only be revealed by manipulating both stimuli and task. Consider the phenomenon of Inhibition of Return (Klein, 2000), which was originally attributed to the perceptual system's reaction to the allocation of attention. That is, there was one process—the allocation of attention—that produced a subsequent compensatory response—the inhibition of reallocation of attention (cf. Posner & Cohen, 1984). While this would attribute only one attentional response directly to the presentation of the cue, it appears that the cue actually produces two concurrent responses—an enhanced perceptual-motor connection and a concurrent decreased response potential—that add together to reveal the bimodal response over time. The present results are also consistent with two distinct effects of the cue that can be revealed by manipulating the object nature of the targets—when two distinct objects are used in the TOJ task, attention enhances performance, whereas if the two stimuli are perceived as parts of a single object, attention degrades performance. The results of Experiment 5 seem to support the concurrent implementation of these two processes. Thus, one implication of the present results concerns the multifaceted nature of exogenous attention (i.e., the processing modulation resulting from the presentation of an abrupt onset cue). We must consider the distinct effects that "attention" can have depending on how those effects are measured (i.e., the task and stimuli used). A unitary concept with one set of effects on the perceptual system seems overly simplistic.

This proposal is inconsistent with the account proposed by Yeshurun and colleagues (Yeshurun & Levy, 2003; Yeshurun, 2004; Yeshurun & Marom, in press) in which transient attention acts on the parvocellular pathway to enhance spatial resolution and this, in turn, has an inhibitory effect on the magnocellular pathway. That is, in their proposal, the cue has a single effect on the neural processing system (i.e., increased sensitivity in the parvocellular pathway), which has collateral effects in the other pathway. Rather, we would propose several distinct consequences of transient attention on different neural pathways. One consequence of the cue results in enhanced spatial perception and other consequences result in the temporal resolution changes we see here. Consider that processing in the visual cortex is highly parallel with the same stimulus affecting different parts of cortex in distinct ways. It may indeed be that the cue affects the subcortical pathways corresponding to parvocellular and magnocellular structures in distinct ways and still have other effects in cortex.

Perhaps the other temporal effects of attention discussed in the Introduction may shed some light on the locus of the current effects. Specifically, attention prolongs the perceived duration of a brief event (Enns et al., 1999; Mattes and Ulrich, 1998; Yeshurun & Marom, in press) and also produces a *prior entry* effect such that the onset is perceived sooner (Enns et al., 1999; Shore, et al., 2001; Scharlau & Neuman, 2003; Scharlau, 2004, Titchener, 1904). These two effects appear to be independent of each other (Enns et al., 1999), which again argues for at least two independent effects of the cue. One conceptual way to think about all of these effects concerns the various tasks and stimuli presented to the observer. In a duration judgment task the goal is to attend to every sample available and provide an estimate of the amount of information (e.g., Grondin, 2001). On the other hand, with a typical TOJ task, only the onset is important. If the exogenous cue results in a sharper impulse response function in one visual pathway for the subsequent stimulus, the findings of sooner onset and faster responses would ensue. At the same time, the same cue may stretch the impulse response function out over time in a different pathway, thus enhancing the spatial resolution through increased samples, and concurrently result in the longer perceived duration results (e.g., Yeshurun & Marom, in press). In this context, the present pattern of data may be understood if one assumes that different stimulus arrays preferentially tap these two pathways. Specifically, the object-based nature of the stimuli may promote use of one or the other pathway.

An important implication of our proposal concerns the ubiquitous finding that observers are better at judging multiple attributes of a single object than single attributes from multiple objects (Duncan, 1984; Behrmann, Zemel, Mozer & 1998). In all cases, the attributes being judged have been spatial in nature. If the task involves judging temporal parameters, exactly the opposite pattern is observed—better temporal resolution with two objects than with two attributes of a single object (Nicol & Shore, 2007; see also Spence, Shore & Klein, 2001; Spence, Baddeley, Zampini, James & Shore, 2003 for examples with multisensory stimulation). The critical point, for the present results, concerns the strong effect that object-related processes can have on both spatial and temporal processing. Further, the interaction between these object-related processes, temporal resolution, and exogenous attention appears quite complex. One way to understand the present data would be to propose that exogenous attention enhances the integration of features into objects and through this process degrades temporal resolution for these features. Thus, object-related processing mediates the relation between exogenous attention and temporal resolution.

Cued versus uncued locations.

In examining the data from the first three experiments (see Figure 2), it appears that the major change across them occurs at the uncued location. That is, the JND at the cued location is identical across our manipulation of stimulus similarity and placeholder presence, while the JND at the uncued location shows modulation. While it is difficult to make strong claims about this pattern because of the between-observer nature of the experiments, we nonetheless wish to highlight this pattern in order to make the point that the effects in the present experiment may be occurring not as a result of attention, but as result of misdirected attention. In this regard, some of the previous work examining the relation between attention and temporal resolution may have missed something because they compared focused attention versus diffuse attention (cf. Yeshurun & Levy, 2003). That is, in those experiments, attention was either cued to the target location with 100% validity, or else spread across many target locations with equal probability. In contrast, the present experiments directed attention to one or the other location with equal probability and when the target appeared at the uncued location, attention was presumably equally focused, just in the wrong location. The results of Experiments 1-3 seem to indicate that this difference—diffuse versus misdirected focused attention—may be significant and should be examined more carefully in future work. Note that this comment is also related to the difficulty in coming up with an appropriate neutral cue in Posner-type paradigms (cf. Jonides & Mack, 1984).

Conclusions

The relation between exogenous attention and temporal resolution is not a simple one. The present data demonstrate an effect of target separation, target distinctiveness, and the presence of placeholders. We believe that these factors can affect the object-status of the targets used in the task, and thus the relation between exogenous attention and temporal resolution. When the two targets are considered part of the same object, attention acts to degrade temporal resolution. When they are perceived as distinct objects, attention enhances temporal resolution. These effects may be manifestations from unique cortical consequences of the presentation of an abrupt onset.

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Endnotes

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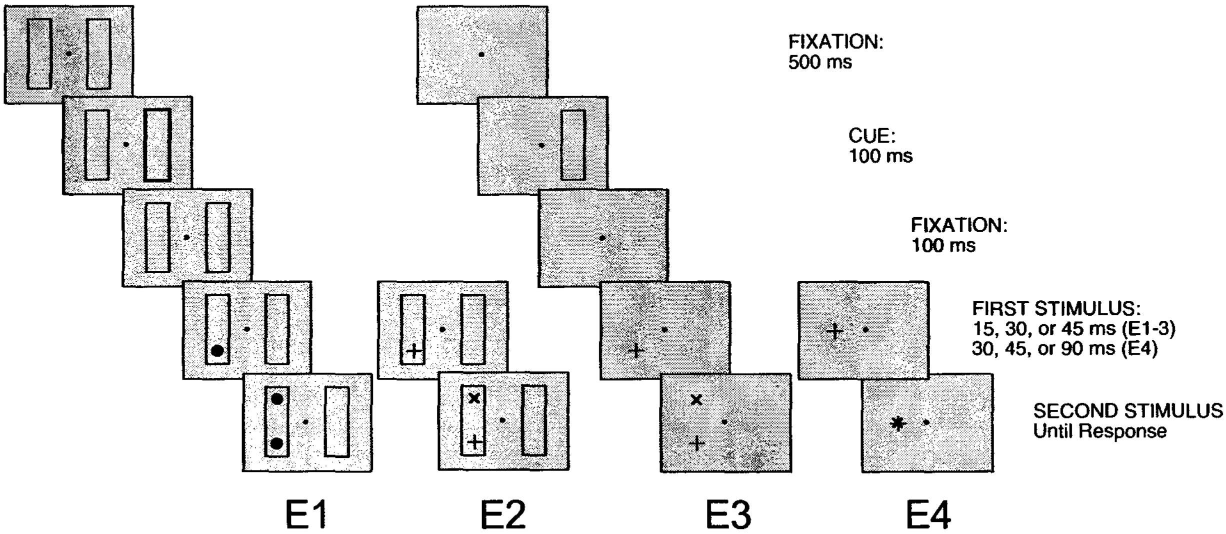
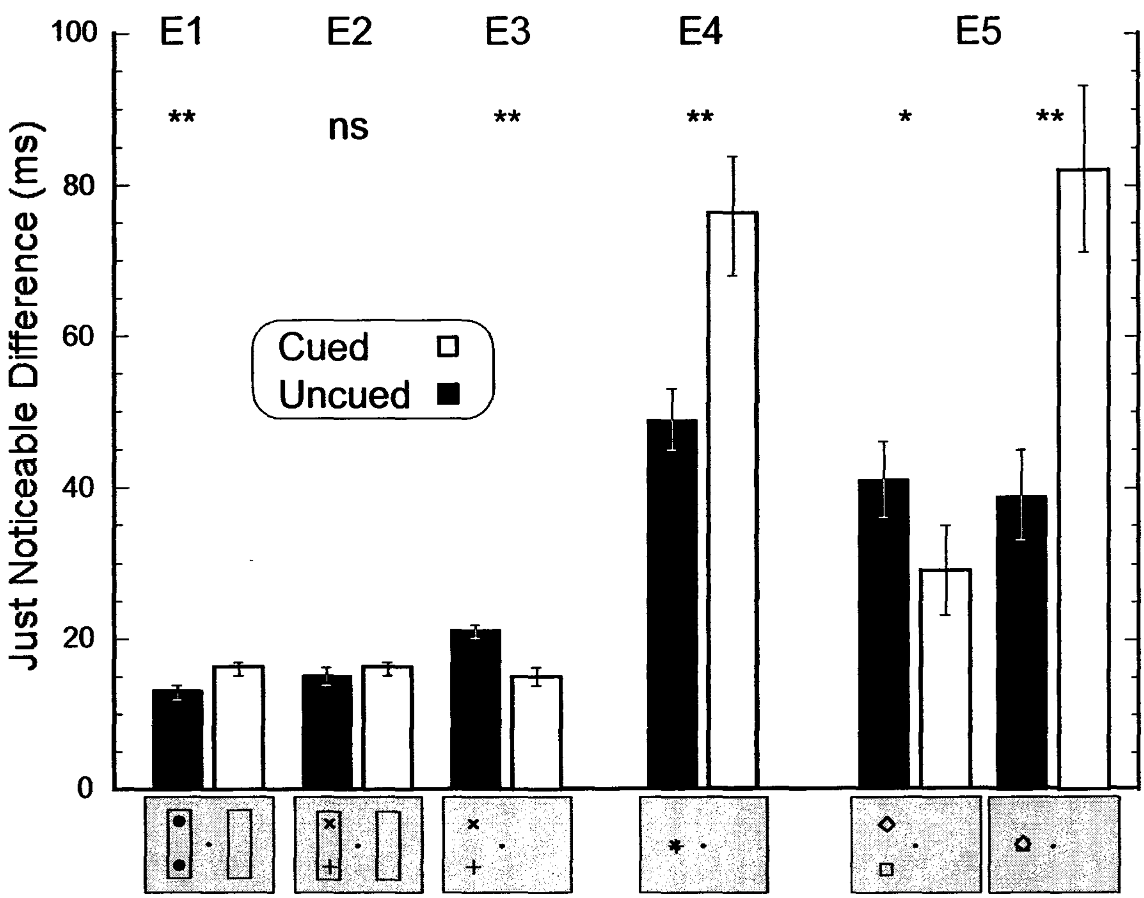
Figure Captions

Figure 1. Sequence of displays used in an experimental trial for Experiments 1 to 4. Experiment 5 was a combination of the displays used in Experiments 3 and 4 with diamonds and squares replacing the plus and x (See Figure 2).

Figure 2. Mean just noticeable differences (JNDs) from all five Experiments for cued (white bars) and uncued trials (black bars). Along the X-axis is a visual representation of the relevant condition for each Experiment (see Figure 1). Experiment 1 (E1) had identical targets and placeholders. Experiment 2 (E2) had non-identical targets (x and +) and placeholders. Experiment 3 (E3) had non-identical targets and no placeholders. Note the qualitative change in the direction of the cuing effect as the identity of the targets and the presence of the placeholdes is manipulated. In all of these Experiments, the items were presented at *different* locations. Experiment 4 (E4) had non-identical targets presented at the *same* location with no placeholders. Experiment 5 (E5) shows a replication of the effects observed across E3 and E4 showing a qualitative shift in the direction of the cuing effect when the targets are presented at the same or different locations. In all cases, the cue (a rectangular shape abruptly onsetting for 100 ms) was the same. *=.05; ** = .01. Error bars reflect one within-subject standard error of the mean for each condition.



Nicol et al. (2008), Figure 1



Nicol et al. (2008), Figure 2

Chapter 3

Nicol, J.R. & Shore, D.I. (submitted). Temporal order judgments reveal different effects of exogenous and endogenous spatial attention on perceptual grouping.

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Abstract

A visual temporal order judgment (TOJ) task was used to examine how exogenous and endogenous spatial attention affect perceptual grouping. Observers were cued to a pair of flanker stimuli on the left or right side of fixation. Two TOJ targets were then presented asynchronously, adjacent to either the attended or unattended flanker pair and observers reported which one appeared first. The stimulus pairs were the same size and shape, and the target pair either grouped or did not group (by pattern similarity or colour) with the flanker pair. A threshold of temporal sensitivity called the just noticeable difference (JND) was used to measure the effect of spatial attention on perceptual grouping. Temporal sensitivity was poorer overall when the TOJ targets grouped with the flankers. This effect was augmented at the attended location by the exogenous cue, but not by the endogenous cue. Grouping did not affect performance at the unattended location for either cue type. The results indicate that attention is required for perceptual grouping, and that exogenous and endogenous cues have distinct effects on grouping. An account based on object-based attention is put forth to explain the differential effects of these two modes of orienting on perceptual grouping.

Introduction

Considering the overwhelming amount of stimulation that constantly inundates the visual perceptual system, successful interaction in our surroundings depends critically on the ability to effectively and efficiently determine which stimulus features belong together, and which do not. According to the Gestalt laws of perceptual organization, the visual system accomplishes this critical task, often referred to as the binding problem, by relying on stimulus grouping characteristics such as similarity, proximity, and good continuity (e.g., Koehler, 1928; Rubin, 1915; Wertheimer, 1923). Although the Gestalt principles have been accepted for nearly a century, the extent to which attention is involved in perceptual grouping is still debated in the literature. Several studies based on dual-task (e.g., Ben-av, Braun & Sagi, 1990; Braun & Sagi, 1991) and inattention paradigms (Mack et al., 1992; Rock et al., 1992), as well as visual search (Beck, 1982; Treisman, 1985) and implicit memory (Lamy, Segal & Ruderman, 2006; Moore & Egeth, 1997) have examined the role of attention on grouping, but surprisingly, no research has examined the effect of spatial cueing (cf. Posner, 1980) on perceptual grouping. The present experiments address this gap in the literature by investigating the effects of endogenous and exogenous spatial cues on perceptual grouping in the context of a visual temporal order judgment (TOJ) task.

Several theories of visual attention posit that perceptual grouping can take place in the absence of attention (e.g., Julesz, 1981; Neisser, 1967; Pomerantz, 1981; Treisman, 1982, 1988). However, Mack and Rock (e.g., Mack et al., 1992; Rock et al., 1992; for a review see Mack & Rock, 1998) argued that the relation between perceptual grouping and attention has not be appropriately investigated because it was procured from tasks in which observers were either actively searching for a target or attending to a stimulus. To address this potential confound they developed a task called the inattention paradigm (Mack et al., 1992; Rock et al., 1992). In the inattention paradigm, the observer's task was ostensibly to report the longer arm of a briefly presented cross. In the first two trials, the cross was surrounded by random patterns of ungrouped elements, but in the critical third trial the surrounding elements grouped into patterns (i.e., based on texture segregation, similarity, or proximity). Immediately following their third line discrimination, observers were unexpectedly asked about the layout of the background elements. Based on their responses, which revealed complete unawareness of any grouping patterns in the background, it was concluded, "that there is *no* perception of texture segregation or Gestalt grouping under conditions of inattention (Mack et al., 1992, p.498)".

Later Moore and Egeth (1997) argued that perceptual grouping may have taken place in Mack and Rock's inattention paradigm, but due to forgetting or to poor encoding, observers simply could not remember the patterns. To test their theory they performed a series of experiments in which they presented two horizontal line segments surrounded by a series of dots that either grouped (giving rise to the Ponzo illusion or the Muller-Lyer illusion) or did not group with the line segments and asked observers to report which line was longer. Line-length judgments were clearly influenced by the two visual illusions even though when asked observers could not report anything about the organization of the background dots. Thus, Moore and Egeth (1997; see also Lamy et al.,

2006) demonstrated an implicit effect on performance produced by the perceptual grouping of unattended stimuli and concluded that grouping does not require attention.

The relation between attention and perceptual grouping is investigated further in the present research using the temporal order judgment (TOJ) task. In a TOJ trial observers are presented with two temporally asynchronous targets and report which one they perceived first. The extent to which observers can correctly judge which target appeared first is an index of their temporal precision, a threshold commonly referred to as the just noticeable difference (JND)—the minimum temporal interval (in milliseconds) required to perform the TOJ task at 75% accuracy.

In a recent TOJ study, it was shown that perceptual grouping impairs visual temporal resolution (Nicol & Shore, 2007). Identical targets were presented to observers in two orientations; one that encouraged them to be perceptually grouped, and one that encouraged them to be perceptually segregated. Despite equidistant spacing between the targets across the two conditions, observers' temporal resolution was worse when the targets were perceptually grouped.

Related findings have been reported in an attentional cueing context (Nicol, Watter, Gray & Shore, 2008). In a series of experiments that also employed the TOJ task the effect of exogenous attention on temporal resolution was shown to be dependent on the physical properties of the target stimuli. Temporal resolution was better at the attended than unattended location when distinct targets were presented at disparate locations. However, when target placeholders were used (i.e., the targets appeared in the cued or uncued placeholder) that effect disappeared. Moreover, when identical targets appeared in the attended placeholder (see also Hein, Rolke & Ulrich, 2006) or when distinct targets were presented at the same spatial location, the effect reversed and temporal resolution became better at the unattended than attended location. These findings were interpreted in a Gestalt grouping framework. It was suggested that when the targets are clearly perceived as distinct stimuli attention improves temporal resolution, but manipulations that decrease target distinctiveness or encourage target grouping degrade temporal resolution (Nicol et al., 2008). Nicol et al. argued that the placeholders produced grouping by common region and closure, identical targets produced grouping by similarity, and that when distinct targets appeared at the same location they became integrated into a single percept.

The present experiments test that conclusion directly by examining whether attention augments the negative effect of perceptual grouping on temporal resolution. The effect of exogenous and endogenous spatial attention on the relation between grouping and temporal resolution will be examined separately. Exogenous attention is an automatic form of orienting that is deployed rapidly in response to stimuli that onset abruptly in the periphery, while endogenous attention is a voluntary form of orienting that is deployed slower, in response to directionally informative, centrally presented stimuli (cf. Jonides, 1981). Recently it was shown that exogenous and endogenous attention have distinct effects on temporal resolution. Using the TOJ task, Hein et al. (2006) showed that exogenous attention decreases temporal resolution and endogenous attention increases temporal resolution.

The different effects of these two modes of orienting on temporal resolution may have arisen because exogenous cues induce object-based attention, but endogenous cues do not (Goldsmith & Yeari, 2003). Since manipulations that encourage the targets to be grouped (i.e., into a single perceptual object) decrease temporal resolution (Nicol & Shore, 2007; Nicol et al., 2008) there is good reason to assume that perceptual grouping attention, promoted by an exogenous cue, would also be negatively associated with temporal resolution. Conversely, it might be assumed that since an endogenous cue does not promote perceptual grouping, will not be detrimental to temporal resolution.

Our predictions regarding the effects of exogenous and endogenous spatial attention on the relation between grouping and temporal resolution are based on the above assumptions. We hypothesize that exogenous attention will augment the effect of perceptual grouping on temporal resolution. It has been shown that in conditions that promote perceptual grouping, exogenous attention impairs temporal resolution (Hein et al., 2006; Nicol et al., 2008; Yeshurun & Levy, 2003). Moreover, the exogenous cue should induce object-based attentional selection (c.f. Goldsmith & Yeari, 2003), which should, in the grouping condition, make perceptual integration of the targets and flankers particularly likely, thereby increase the difficulty of the TOJ and reducing temporal resolution. We also predict an additive effect of endogenous attention and grouping on temporal resolution. However, since endogenous attention enhances temporal resolution (Hein et al., 2006), and does not promote perceptual grouping (c.f. Goldsmith & Yeari, 2003) we hypothesize that it will act in opposition to the grouping effect on temporal resolution. To be clear, since endogenous attention enhances temporal resolution, and perceptual grouping impairs temporal resolution, we do not expect that performance will be different across grouping conditions at the endogenously attended spatial location, because the negative effect of perceptual grouping on temporal resolution will be negated by the positive effect of endogenous attention on temporal resolution.

Experiment 1a & b

The present two experiments investigate the effect of exogenous cueing on the relation between perceptual grouping and temporal resolution. Observers are first presented a pair of vertically aligned diamond-shaped stimuli to the left and right of a central fixation point. We refer to these pairs as flanker stimuli. Following the presentation of the cue, which orients observers' attention to the left or right pair, a pair of horizontally aligned target diamonds appear asynchronously at the cued or uncued location. The observers' task is to judge whether the left or right target appeared first. On half of the trials the targets are the same colour (Experiments 1a) or surface pattern (Experiments 1b) as the flankers, so that they group together to form one large diamond of uniform colour or pattern (i.e., the grouped condition). On the other half of the trials the targets were a different colour or surface pattern as the flankers, so that they did not group together but rather looked like a large diamond comprised of two smaller pairs — the target pair that matched horizontally and the flanker pair that matched vertically (i.e., the ungrouped condition).

We hypothesize that exogenous spatial attention and perceptual grouping will act together in an additive fashion to impair temporal sensitivity (i.e., the magnitude of the JND). Accordingly, we predict that the JND will be worse in the grouped than ungrouped condition at the attended location, and that it will similar across grouping conditions at the uncued location.

Method

Participants

Ten different students (14 female, mean age = 18 years) from the psychology undergraduate research pool volunteered to participated in each version of the experiment in exchange for partial course credit. All had self-reported normal or corrected to normal vision.

Stimuli & Apparatus

Stimuli included a black fixation cross (0.4° x 0.4°), a black diamond-shaped outline which served as the exogenous spatial cue (3.4° wide x 4.2° long) and diamond shaped target and flanker stimuli (1.5° wide x 1.9° long) with bold or thin black vertical lines against a white background (Experiment 1a) or diamond shaped stimuli that were black or white in colour (Experiment 1b). Each flanker pair was vertically aligned and centred on the horizontal meridian 5° to the left and right of fixation and each pair of flankers was presented on the horizontal meridian such that the centre of innermost target and outermost targets were presented 3.5° and 6.5° from fixation (see Figure 1). Stimuli were generated on AppleWorks software version 6.2.2 and the experiment was run using Presentation software version 11.2 on a Dell PC with a Type CRT 17" monitor at a refresh rate of 65 Hz. Responses were made on a keyboard with the left and right arrow keys.

Procedure

Participants sat in a dimly lit room approximately 75 cm away from the screen. They were instructed to maintain their gaze at fixation, while covertly attending to the cued flanker pair. Trials began with the presentation of the fixation cross and two flanker pairs. After 1800 ms the cue appeared in the spatial area around the left or right flanker pair. The cue was presented for 50 ms, then it offset and only the two pairs of flankers and the fixation cross remained on the screen for an additional 150 ms. At 2000 ms the first of two target stimuli appeared at the cued (50% of trials) or uncued (50% of trials) location, contiguously at either the left or right side of the flanker pair. After one of six randomly varying stimulus onset asynchronies (SOAs; i.e., 15, 30, 45, -15, -30, -45 ms, negative SOAs reflect trials in which the right target appeared first) the second target appeared on the opposite side of the same flanker pair (see Figure 1). Participants reported the side that the first target appeared on by pressing the left or right arrow key on the keyboard. All stimuli remained on the screen until a response was made. The next trial began 500 ms after the response was made. Each experimental session comprised 384 trials divided into two equal blocks of 192 trials: 2 cue side (cued or uncued) X 2 first-target location (left or right) X 2 grouping (grouped or ungrouped) X 2 flanker types (experiment 1a: bold-lined or thin-lined; experiment 1b: white or black) X 6 SOAs (15, 30, 45, -15, -30, -45 ms).

Results & Discussion

The threshold of each participant was determined by the JND—the minimum temporal interval required between the onset of the first and second target to perform the TOJ task at 75% accuracy. To derive this index, the proportion of left-first responses was converted to the equivalent z-scores under the assumption of a cumulative normal distribution (cf. Finney, 1964). The best-fitting straight line for each individual was then averaged together to produce the mean JND for each position. The JND was calculated in this same way in the experiments that follow.

Experiment 1a: Pattern grouping

A two-way repeated measures ANOVA performed on the mean JND for each condition on the within-subjects factors: cueing (attended/unattended) and grouping (grouped/ungrouped) revealed that temporal sensitivity was poorer at the attended (M = 17.39 ms, SE = 1.45 ms) than the unattended location (M = 14.44 ms, SE = 0.79 ms; $F (1,9) = 9.93$, $p < .05$), and worse in the grouped (M = 17.84 ms, SE = 1.42 ms) than the ungrouped condition (M= 13.99 ms, SE = 0.82 ms; $F (1,9) = 5.28$, $p< .05$). Critically, a significant cueing X grouping interaction also emerged ($F (1,9) = 9.12$, $p < .05$). Paired comparisons that showed that temporal sensitivity was worse in the grouped (M= 20.72 ms, SE= 2.24 ms) than the ungrouped condition (M= 14.05 ms, SE = 0.66 ms; $t (9) = 2.72$, $p< 0.25$) at the attended location, but it was not different across the grouped (M= 14.95 ms, SE= 0.60 ms) and ungrouped conditions (M= 13.93 ms, SE= 0.98 ms; $t (9) = 0.89$, $p = .40$) at the unattended location (see Figure 2a).

Experiment 1b: Colour grouping

A two-way repeated measures ANOVA performed on the mean JND for each condition on the same within-subjects factors also again indicated that temporal sensitivity was poorer at the attended (M = 18.78 ms, SE = 1.69 ms) than the unattended location (M = 15.54 ms, SE = 2.85 ms; $F (1,9) = 8.41$, $p < .05$), and worse in the grouped

(M = 18.65 ms, SE = 2.54 ms) than the ungrouped condition (M= 15.67 ms, SE = 1.99 ms; F (1,9) = 6.87, p< .05). The critical cueing X grouping interaction also re-emerged (F (1,9) = 12.67, p < .05). Paired comparisons that showed that temporal sensitivity was worse in the grouped (M= 21.66 ms, SE= 1.78 ms) than the ungrouped condition (M= 16.89 ms, SE = 1.59 ms; t (9) = 3.04; p< 0.25) at the attended location, but it was not different across the grouped (M= 16.63 ms, SE= 3.31 ms) and ungrouped conditions (M= 14.44 ms, SE= 2.43 ms; t (9) = 0.74, p = .62) at the unattended location (see Figure 2b).

In support of our predictions, the above findings indicate that exogenous spatial attention augments the effect of perceptual grouping on temporal sensitivity. Performance was poorest (i.e., the JND was largest) when the TOJ targets grouped with the flanker stimuli at the attended location, relative to the other three conditions. These findings also provide an important replication of our previous research showing that perceptual grouping impairs temporal resolution (Nicol & Shore, 2007). Indeed, temporal resolution was more impaired when the TOJ targets grouped, than when they did not group with the flanker stimuli. Also in line with our predictions, these results show under exogenous cueing conditions, perceptual grouping does not affect temporal resolution at unattended locations. This result supports the assertion that perceptual grouping does not occur without focused attention (cf. Mack et al., 1992; Rock et al., 1992).

Experiment 2a & b

In the present two experiments, we employed the same TOJ task and stimuli (i.e., diamond-shaped targets and flankers that are either the same or different pattern or colour) as in Experiment 1a and 1b, but replaced the exogenous cue with an endogenous one (i.e., a predictive, centrally presented arrow cue). Previous research has shown that endogenous and exogenous spatial cues differentially affect temporal resolution. Recall that in contrast to exogenous attention, endogenous attention enhances temporal sensitivity (Hein et al., 2006). Also recall that endogenous cues do not promote object-based attention (Goldsmith & Yeari, 2003), and so, should not necessarily facilitate grouping processes at the attended location. Thus, we suspect that in the present experiments the endogenous spatial cue will reduce the grouping effect at the attended location. Moreover, taken together these effects lead us to predict that temporal resolution at the attended location should be improved in the ungrouped condition. Although we still expect that temporal resolution will be worse in the grouped than ungrouped condition (Nicol & Shore, 2007, and Experiments 1a & 1b).

Method

Participants

Ten different students (12 female, mean age = 18 years) from the psychology undergraduate research pool volunteered to participate in each version of the experiment in exchange for partial course credit. All had self-reported normal or corrected to normal vision.

Stimuli & Apparatus

With the exception of the endogenous black arrow cue (1.2° wide x 0.75° long) used in place of the exogenous cue, the stimuli were identical to what we used in the previous experiments (see Figure 1). In order to be consistent as possible with the research we are expecting to replicate (Hein et al., 2006), the target and flanker stimuli were moved closer to fixation (i.e., 3° to the left and right of fixation instead of 5° as in the exogenous cueing paradigm employed in experiments 1a & 1b). Although no rationale for the difference was offered, in Hein et al.'s (2006) study the closer of the two targets was presented 4.5° from fixation in the exogenous task and 2.4° from fixation in the endogenous. The apparatus and procedure was the same as we used in the previous experiments.

Procedure

Participants sat in a dimly lit room approximately 75 cm away from the screen. They were instructed to maintain their gaze at fixation, while covertly attending to the cued flanker pair. Trials began with the presentation of the fixation cross and two flanker pairs. After 1800 ms an arrow stimulus, pointing to the left or right flanker pair, replaced the fixation cross. At 2000 ms the first of two target stimuli appeared at the cued (75% of trials) or uncued (25% of trials) location, contiguously at either the left or right side of the flanker pair. After one of the same three randomly varying SOAs used in the previous experiments, the second target appeared on the opposite side of the same flanker pair, and participants reported the side that the first target appeared on by pressing the left or right arrow key on the keyboard. All stimuli remained on the screen until a response was made. The next trial began 500 ms after the response was made. Each experimental session comprised 384 trials divided into two equal blocks of 192 trials: 2 cue validity (valid (144 trials: 75%)/invalid (48 trials: 25%)) X 2 first-target location (left/right) X 2 grouping (grouped/ungrouped) X 2 flanker types (experiment 2a: bold-lined/thin-lined; experiment 2b: white/black) X 6 SOAs.

Results & Discussion

Experiment 2a: Pattern grouping

A two-way repeated measures ANOVA performed on the within-subjects factors: cueing (attended/unattended) and grouping (grouped/ungrouped) indicated that temporal sensitivity was poorer in the grouped (M= 23.28 ms, SE = 2.83 ms) than the ungrouped condition (M = 19.74 ms, SE = 2.59 ms; $F(1,9) = 6.22$; $p < .05$), but it did not differ at the attended (M = 21.72 ms, SE = 2.89 ms) and unattended locations (M = 21.30 ms, SE = 2.39 ms; $F(1,9) = 0.25$; $p = .62$). As predicted, a cueing X grouping interaction was not revealed ($F(1,9) = 0.06$; $p = .94$) (see Figure 4a).

Experiment 2b: Colour grouping

A two-way repeated measures ANOVA performed on the same within-subjects factors also indicated that temporal sensitivity was again poorer in the grouped (M= 18.48 ms, SE = 1.79 ms) than the ungrouped condition (M = 15.40 ms, SE = 1.36 ms; $F(1,9) = 5.23$; $p < .05$), and that again it did not differ at the attended (M = 16.97 ms, SE = 1.85 ms) and unattended locations (M = 16.90 ms, SE = 1.30 ms; $F(1,9) = 0.08$; $p = .93$). Also like Experiment 2a, a cueing X grouping interaction was not observed ($F(1,9) = 0.51$; $p = .83$).

The present experiments support our previous research showing that perceptual grouping impairs temporal resolution (Nicol & Shore, 2007; experiments 1a & 1b). Whereas previous research has shown the effect under conditions of focused spatial attention in response to exogenous cues (Experiments 1a & 1b) and when attention is diffuse (Nicol & Shore, 2007), the present extends those findings by demonstrating that this effect also exists under conditions focused spatial attention in response to an endogenous cue. The present results also support our prediction that endogenous attention would not modulate the effect of grouping on temporal sensitivity; indeed, the JND did not differ across grouping conditions at the attended location. Consistent with experiment 1a and 1b, performance also did not differ across grouping conditions at the unattended location. This finding indicates that attentional resources are required for perceptual grouping (Mack et al., 1992; Rock et al., 1992).

General Discussion

Previous research has shown that perceptual grouping impairs temporal resolution (Nicol & Shore, 2007). The present experiments investigated the influences of exogenous and endogenous attention on that grouping effect. Of particular interest to the present research were the questions of whether exogenous and endogenous spatial orienting would differentially affected the relation between grouping and temporal resolution, and also whether the grouping effect would be observed at both attended and unattended locations.

The present results show that exogenous and endogenous attention do indeed have different effects on the relation between perceptual grouping and temporal resolution. On the one hand, exogenous spatial attention augments the effect of perceptual grouping on temporal resolution. We showed that temporal sensitivity was poorer overall when the targets and flankers grouped, than when they did not group, and more importantly, that temporal sensitivity was poorest when they grouped together at the attended location. We believe that this effect can best be explained by appealing to an account of temporal resolution based on object-based attentional selection (Nicol & Shore, 2007; Nicol et al., 2008). Object-based attention enhances spatial perception by promoting the unification (i.e., feature integration) of stimuli that belong to the same object (see Scholl, 2001 for a review). We contend that perceptual grouping, or object-based attentional selection, affects temporal resolution similarly, by binding stimuli over time that belong to the same event. Thus perceptual grouping mechanisms , which are facilitated at the attended location, increase the likelihood that stimuli presented at short SOAs will be perceived as a single event, and in turn decrease temporal resolution. A primary postulate of our object-based theory of temporal processing is that this scenario is particularly likely to take place when the target stimuli are susceptible to perceptual grouping Critically, this process would be encouraged when the target stimuli are can be perceptually grouped. Moreover, since exogenous orienting promotes feature integration (e.g., Briand & Klein, 1987), our theory predicts that the grouping effect on temporal resolution should be augmented at exogenously attended spatial locations, which is precisely what the present findings demonstrate (see also Nicol et al., 2008).

On the other hand, endogenous orienting did not augment the grouping effect on temporal resolution. This pattern of data likely emerged for two reasons, neither of which conflict with our object-based theory of temporal processing. First, endogenous cues do not promote object-based attention (Goldsmith & Yeari, 2003) or facilitate feature integration (Briand & Klein, 1987). These characteristics suggest that endogenous orienting processes are less susceptible to the effect of perceptual grouping. processes and that it may provide the perceptual system with more opportunity to segregate the targets and flankers even when they are similar. Second, endogenous attention enhances temporal resolution (Hein et al., 2006). Thus, the negative effect of grouping on temporal resolution was probably offset by benefit afforded by the endogenous spatial cue.

Our object-based theory can also account for Hein et al.'s (2006) results showing exogenous attention degrades temporal sensitivity while endogenous attention enhances it. In the exogenous cueing version of their TOJ task placeholders were used, but in the endogenous cueing version they were not. It has been argued that placeholders have a strong effect on the nature of the cueing effect, driving attention to segmented objects, rather than unparsed regions of space (Driver & Baylis, 1998). Perceptual grouping factors relating to the placeholders and the cue itself may therefore have reduced temporal sensitivity under conditions of exogenous attention by promoting the integration of stimuli at the attended location into a unified object. Conversely, when the endogenous cue was used and the placeholders were removed, perceptual grouping factors would not be present which would enhance temporal sensitivity at the attended location by allowing the stimuli to remain segregated.

It is surprising that in the present study endogenous attention did not affect temporal sensitivity. Apparently observers did not use the predictive information provided by the cue to shift their attention to the spatial location of the ensuing TOJ targets. This is particularly perplexing considering that we employed a cueing procedure that was almost identical to the one used in the study by Hein et al. (2006)—which found that endogenous orienting enhanced temporal resolution. Nevertheless, Briand and Klein (1987) also failed to observe an effect on performance, when they employed endogenous cues in feature and conjunction search tasks. Indeed, did no find a cueing effect for accuracy in either task; observers performed equally (i.e., made the same number of errors) at validly cued and invalidly cued spatial locations. In interpreting this null result, they suggested that the endogenous orienting system may either be very efficient at extracting or encoding stimulus features (i.e., relative to the exogenous orienting system), or that it may alter the attentional set at the decision making level. Either of those alternatives could be used to interpret the lack of a cueing effect in our studies.

It is worth noting that some researchers have argued that due the ecological validity of arrow cues, they induce exogenous, rather than endogenous, orienting mechanisms (cf., Kingstone, Smilek, Ristic, Friesen & Eastwood, 2003; Ristic, Friesen, & Kingstone, 2002). The results of the present research suggest otherwise. Certainly the lack of a cueing effect indicates that an orienting response to an arrow is not automatic or involuntary. Rather, our results provide another demonstration of the distinctiveness of exogenous and endogenous spatial attention. They are consistent with other studies that have shown that these two that the modes of orienting elicit behavioral differences on performance in spatial cueing tasks (e.g., Briand & Klein, 1987; Funes, Lupianez & Milliken, 2007; Goldsmith & Yeari, 2003; Posner & Cohen, 1984), and they support the notion that these two types of cues engage different orienting systems and different attentional processes (e.g., Briand & Klein, 1987; Funes et al., 2007; Klein & Shore, 2000).

One other important finding that emerged from the present research speaks to the ongoing debate in the literature regarding whether or not attention is required for perceptual grouping. Some argue that focused attention is required for perceptual grouping (e.g., Mack et al., 1992; Rock et al., 1992), while others contend that grouping takes place without focused attention but the effects can only be revealed implicitly (e.g., Lamy et al., 2006; Moore & Egeth, 1997). Since perceptual grouping only affected temporal resolution at the attended location, our results are in disagreement with the later argument. Moreover, our TOJ task represents an implicit measure of the effect of perceptual grouping on performance since our observers did not make explicit grouping-related responses. If grouping took place at the unattended location, but could only be revealed implicitly, then grouping would have affected temporal resolution at the uncued location as well as the cued location.

In sum, we have shown that temporal sensitivity is impaired when targets and flankers perceptually group. This extends previous research showing that temporal sensitivity is degraded when the targets group together (Nicol & Shore, 2007). We have also shown that the grouping effect is augmented by exogenous attention, but not by the endogenous attention. To account for those findings, we appealed to an object-based theory of temporal processing. Finally, we did not show an effect of grouping at the unattended location under conditions of exogenous or endogenous orienting. Thus, it appears that attention is in fact required for perceptual grouping (e.g., Rock et al., 1992).

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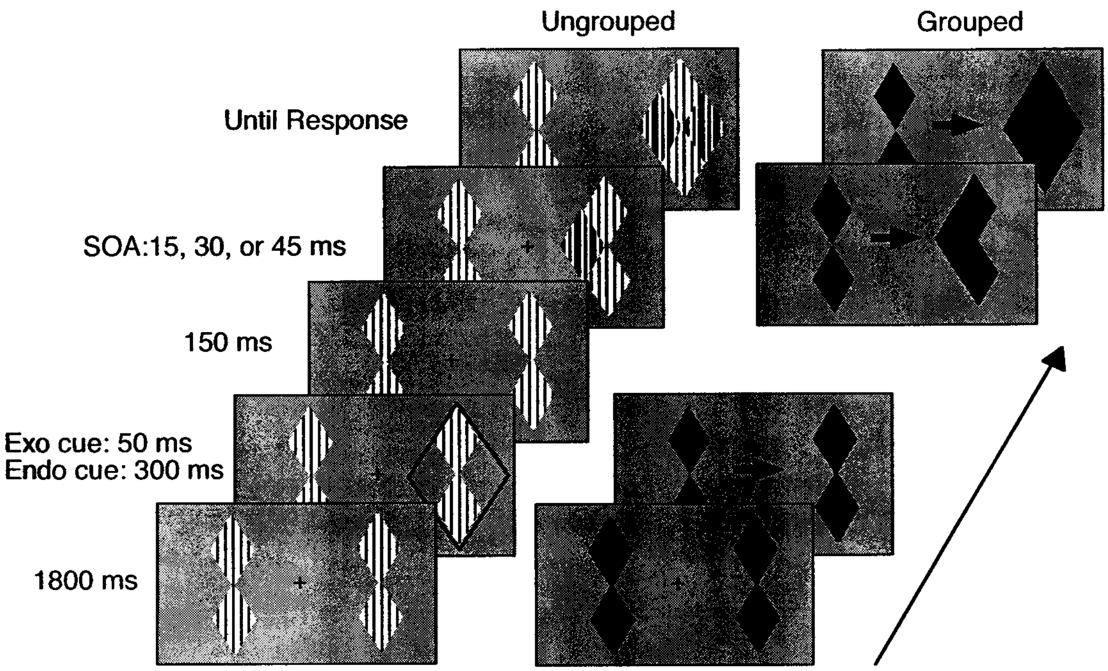
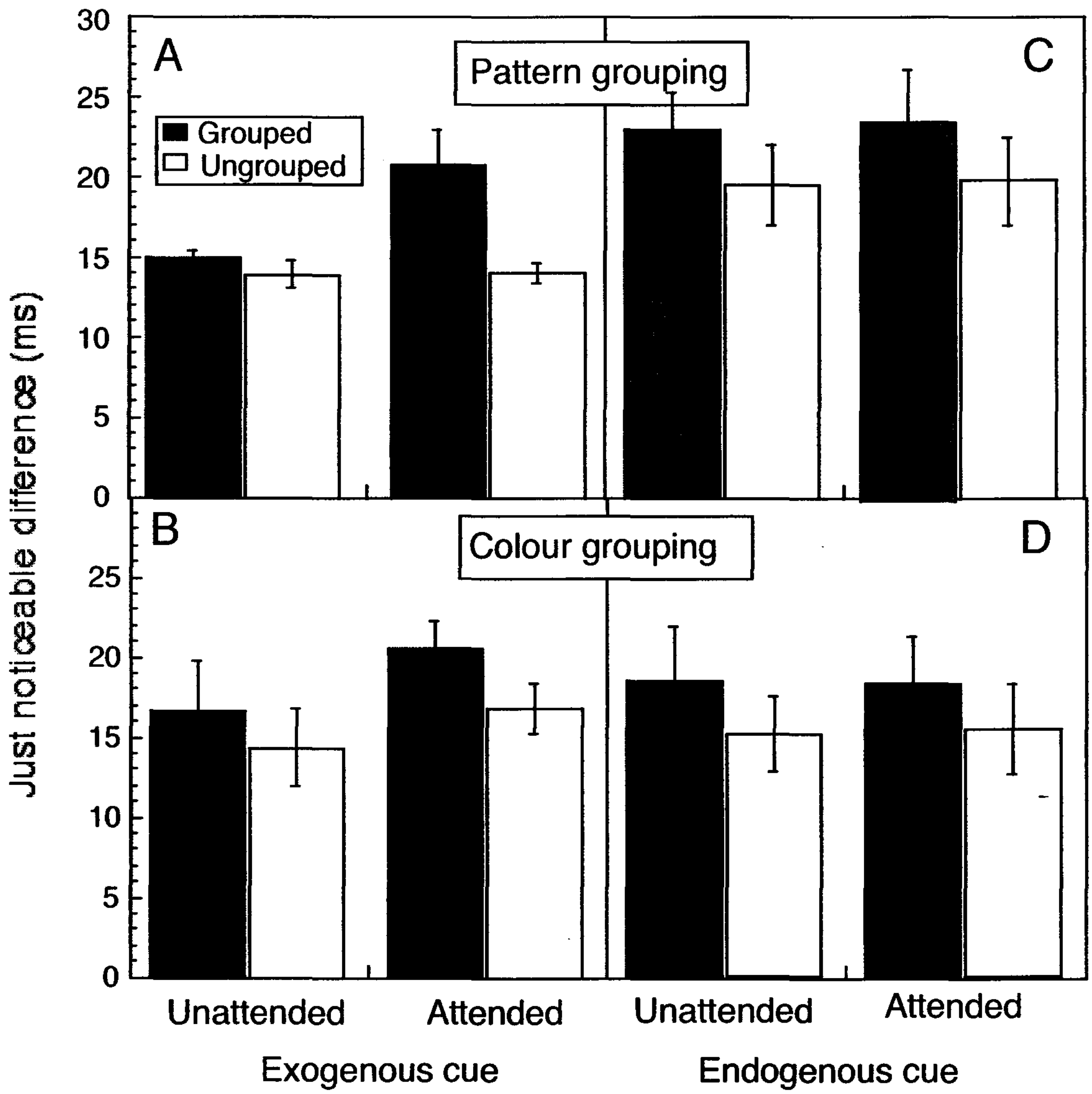
Figure Captions

Figure 1. Example trial sequences for the exogenous (left) and endogenous (right) versions of the task. The left stream illustrates an ungrouped trial from the pattern grouping experiments (1a & 2a) and the right stream illustrates a grouped trial from the colour grouping experiments (1b & 2b). Both types of grouping where examined using both cueing techniques. Note that in the pattern grouping experiments the initial diamond pairs could be thin-lined (shown) or bold-lined, and in the colour grouping experiments they could be black (shown) or white.

Figure 2. Mean just noticeable differences (JND) for experiments 1a and 1b (top left and bottom left panels respectively) and experiments 2a and 2b (top right and bottom right respectively). The exogenous spatial cue augmented the effect of grouping on temporal resolution at the attended location, but not at the unattended location. The endogenous spatial cue did not modulate the grouping effect at either location. Error bars reflect the within-subjects standard error of the mean.



Nicol & Shore (submitted). Figure1.



Nicol & Shore (submitted). Figure 2.

General Discussion

Stimuli at spatially attended locations are perceived differently than stimuli at unattended locations. By increasing the rate at which visual information is processed (Carrasco & McElree, 2001), and as a result of enhanced signal strength (Carrasco et al., 2002; Poggel et al., 2006), attention improves our ability to resolve and perceive the fine details of objects in our surroundings (Parasuraman, 1998; Yeshurun & Carrasco, 1998; 1999). In contrast to this ubiquitous improvement in spatial resolution, research examining the influence of spatial attention on visual temporal resolution has revealed mixed results. Some studies have shown that spatial attention degrades temporal resolution (e.g., Yeshurun, 1994; Yeshurun & Levy, 2003), while others have found that it enhances temporal resolution (e.g., Baek et al., 2005; Poggel et al., 2006). The purpose of this research was to investigate what I posited to be the source of this discrepancy—namely object-based factors of attentional selection. On one hand, I hypothesized that object-based attention impairs temporal resolution in conditions promoting perceptual integration of target stimuli. This is due to the increased likelihood that, at short SOAs, the target onsets are perceived as a single perceptual event (i.e., as one object). And on the other hand, I hypothesized that object-based attention enhances temporal resolution in conditions promoting perceptual segregation of the targets, since the target onsets are perceived as distinct temporal events (i.e., as two objects), even at short SOAs. Thus, I attribute the discrepancies in the literature to psychophysical differences in the experimental stimuli and posit that the performance outcomes (i.e., an increment or a decrement in temporal resolution) are determined by a relative effect of object-based attention particular to each study. I called this proposal the *object-based theory of temporal processing*. Support for the theory was provided by the studies reported in each of the data chapters of this thesis. In the first chapter, it was shown when temporal resolution was worse for two identical targets when they grouped than when they did not group. Since space between targets was held constant across the two grouping conditions, this result must have been an effect of perceptual grouping on temporal resolution. The second chapter also supported theory by indicating that the effect of perceptual grouping on temporal resolution at the attended location. Those results showed as the strength of the perceptual grouping manipulation decreased, so too did the impairment on temporal resolution. In other words, strong grouping effects were associated with large decreases in temporal resolution at the attended location, and weak grouping effects were associated with small decreases in temporal resolution at the attended location. The studies reported in the third chapter refined the theory by demonstrating that the effect of grouping on temporal resolution is only observed in a diffuse, automatically driven attentional state (i.e., exogenous orienting), but not in a focused, voluntarily driven attentional state (i.e., endogenous orienting). This final chapter also confirmed that attention is the critical meditating factor on the relation between perceptual grouping and temporal resolution by showing that performance was unaffected by grouping manipulations at the unattended spatial location.

Thus my theory and its' predictions were confirmed by results showing that Gestalt grouping manipulations indeed modulate the effect of attention on temporal resolution in visual TOJ tasks. The studies showed that good continuity, closure, spatial disparity, and distinctiveness of the targets all represent perceptual grouping mechanisms that affect the relation between spatial attention and temporal resolution. Additional support was provided by our results showing that automatic spatial orienting—a form of attention that purportedly facilitates perceptual grouping (e.g., Briand & Klein, 1984)—mediates the relation between attention and temporal resolution, but voluntary spatial orienting—a form of attention that is not associated with object-based selection or perceptual (e.g., Briand & Klein, 1984)—does not mediate the relation.

These findings provide support for the notion that there is a perceptual tradeoff between spatial and temporal resolution (Poggel et al., 2006; Yeshurun & Levy, 2003). This tradeoff may be the consequence of activation of neurons in the parvocellular visual pathway by spatial attention, which in turn inhibit neural activity in the magnocellular visual pathway (Breitmeyer & Williams, 1990; Tassinari, et al., 1999). This pattern of activation would facilitate spatial processing and impair temporal processing since parvocellular neurons have smaller receptive fields and exhibit more variable onsets and prolonged latencies, relative to magnocellular neurons (e.g., Makela et al., 1994; Raninen & Rovamo, 1987). Some researchers have concluded that this tradeoff explains the negative effect of attention on temporal resolution (Yeshurun & Levy, 2004). However, the independence of the magnocellular and parvocellular visual pathways has been refuted (Logothetis & Schiller, 1990), and the tradeoff between spatial and temporal resolution may not be the result of parvo-magno inhibition, but rather, some other aspect of visual processing.

It has been suggested that attentional control settings may determine the visual system's relative sensitivity to space-based and object-based information (Folk, Remington & Johnston, 1992). Consistent with that proposal, the results of a recent study by Poggel et al. (2006), which like Yeshurun and Levy (2003) was also based on a temporal gap detection (i.e., double-pulse resolution) task, suggests that the effect of attention on temporal resolution is determined by the breadth of the attentional setting. On each trial, eight target discs were presented in a circle, at varying eccentricities, around a centrally presented target disc, one of which contained a temporal gap due to a brief offset, and observers reported the location of the disc with the temporal gap. They found temporal resolution was best for the attended central disc, and that it decreased as the circumference of the array of target discs increased (i.e., they became further away from fixation). That is, temporal resolution decreased for all targets, even the central one, as attention became more diffuse. Accordingly, Poggel et al. (2006) argued that the topographical pattern of temporal sensitivity across the visual field suggests that it is strongly affected by higher order processing in visual cortex, and concluded that, "temporal resolution can be influenced by top-down processes (Poggel et al., 2006; p.3005)." Moreover, they argued that the retina could not be the locus of the attentional effect, since although some re-entrant cortical fibers do extend all the way back to the retina (e.g., Brooke, Downer & Powell, 1965; Wolter & Knobloch, 1965), the main visual structures involved in bottom-up and top-down processing are in the visual cortex (Poggel et al., 2006).

Perceptual grouping mechanisms in visual cortex certainly represent a viable explanation of the grouping effect on temporal resolution. Indeed, I have argued that perceptually integrated targets tend to be represented as one object, which in turn impairs the ability of the visual system to temporally discriminate them (Nicol & Shore, 2007, submitted; Nicol et al., 2008). At the same time, I surmise that bottom-up visual processes could also influence the effect of grouping on temporal resolution. In primary visual cortex, objects are represented by pulses of neuronal activation (e.g., Fain & Cornwall, 1993; Ikeda, 1986; Watson, 1986). Stelmach and Herdman's (1991; Stelmach, Herdman & McNeil, 1994) temporal-profile model proposes that attention affects the neural temporal response function associated with the visual processing of a stimulus. According to this model, visual processing is associated with a rise and fall of neural activity in visual cortex, and the temporal course of this response function is modulated by attention (i.e., the profile of the function is sharper for attended relative to unattended stimuli). Grouped stimuli may further influence the effect of attention on the time course of the neural response functions by facilitating the ease of perceptual processing. This assumption is consistent with Treisman et al.'s (1983) assertion that, "filtering costs are reduced and concurrent processing facilitated by perceptual grouping or integration of separate objects (p.531)." Thus in our TOJ tasks, at short SOAs, the ease of processing associated with grouped stimuli may permit the neural response function associated with processing of the second target to be confused with the neural response function associated with processing of the first target. If true, and the feed forward information about grouped targets was more likely to gain access to awareness in higher levels of the visual system at approximately the same time (see Stelmach & Herdman, 1991, and Thomas & Weaver, 1975, and my Introduction for a discussion of a "temporal comparator" in the brain), then in addition to top-down effects, influences from bottom-up perceptual processes may also contribute to impairment to temporal resolution for grouped stimuli impair one's ability to temporally discriminate the two targets. Abrams and Law (2000) also argued that the effect of information about perceptual objects takes place early in visual processing, and prior to the temporal order comparator. Taken together, the proposed mutual influences of top-down and bottom-up processing on the relation between grouping, attention, and temporal resolution are consistent with theories of visual processing based on re-entrant pathways and iterative loop systems between higher and levels of the brain (e.g., Di Lollo et al., 2000).

Effects of Re-Entrant Pathways in Visual Cortex on Temporal Processing

The visual system is comprised of a vast neural network with an immensely vast number of synaptic connections. Despite early acceptance by researchers in the field that that information is passed in a unidirectional feed-forward fashion from primary visual cortex up to higher levels of visual cortex (e.g., Hubel & Wiesel, 1968, 1977), recent advances in neuroscience have revealed that visual processing is also characterized by horizontal connections within areas, and feedback connections which send information from higher levels of visual cortex back down to lower areas (e.g., Felleman & Van Essen, 1991; Lamme & Roelfsema, 2000; Zeki, 1993). In fact, all major areas of visual cortex have feedback connections to area V1, where information first enters the visual cortex (Bullier, McCourt & Henry, 1988; Mignard & Malpelli, 1991) and these connections may represent the predominant form of communication between brain areas (DiLollo, Enns & Rensink, 2000; Edelman, 1992). According to re-entrant theories of visual processing (e.g., DiLollo et al., 2000; Edelman, 1989, 1992), information that ascends from lower to higher levels of the visual system becomes part of an iterative loop that is in turn sent back down to lower levels as a part of a visual hypothesis testing process. Simple information (i.e., featural, colour, orientation) acquired by early visual areas is passed in a rapid feed-forward fashion to higher areas of visual cortex where it is convolved into a meaningful percept, or working hypothesis about the identity of the inducing stimulus (Felleman & Van Essen, 1991). This information is in turn sent back down the system via reentrant connections, to determine if the hypothesis is consistent with the actual stimulus. This comparative process is required because "the previous ascending signal may have activated more than one initial representation, or equivalently, because the initial representation may be unclear or ambiguous" (Di Lollo et al., 2000, p.497). This is a scenario that may be particularly characteristic of grouped targets, since they may confuse the perceptual system and produce more uncertainty, relative to ungrouped stimuli, regarding which target appeared first.

Neurons in both lower and higher areas of visual cortex remain active beyond their initial participation in the initial volley of feed forward processing, and the latency of these responses permit information from re-entrant visual processes to be incorporated into subsequent ongoing stimulus processing (Lamme & Roelfsema, 2000). This pattern of neural activity can produce a discrepancy between ongoing low level neural activity and the representation of a stimulus being formulated in higher levels of visual cortex, which Di Lollo et al., (2000) have shown through object-substitution masking experiments, causes the initial percept to be overwritten by the onset of a subsequent stimulus presented at the same location. The additional noise (i.e., perceptual uncertainty) associated with grouped stimuli may enhance or hasten detection of the discrepancy revealed by re-entrant visual processes, which could also partly account for the effect of perceptual grouping on temporal resolution. In fact, it has been suggested that prolonged activation of horizontal connections involved in re-entrant processing plays a critical role in modulations of visual processing related to perceptual grouping (Gilbert, 1993). First, in the context of a visual TOJ task, the presentation of the second target, which is both spatially and temporally contiguous to the first target, would interrupt the iterative loop process (i.e., due to the change in the visual signal at the attended location). Since perceptual grouping facilitates stimulus detection (Dodd & Pratt, 2005) and storage in working memory (i.e., objects that are grouped together are stored together; Woodman, Vecera & Luck, 2003), targets that group may interrupt reentrant processing sooner and cause the iterative loop process to curtail prematurely. If perceptual grouping disrupted iterative processing before higher areas of visual cortex had sufficient opportunity to encode the initial percept (i.e., the first target), and encouraged the visual system to process the two targets as one stimulus, then some uncertainty may arise regarding which "part" of the object appeared first. In contrast, re-entrant processes may be less affected by targets that do not group, in which case the visual percept would produce less confusion or uncertainty in regard to what target appeared first, because the targets would be perceived as distinct objects.

This notion that distinct objects are more easily perceived is supported by the results of experiments involving a technique known as backward masking (e.g., Breitmeyer, 1984; Enns & Di Lollo, 2000). The appearance of a masking stimulus in close temporal succession (i.e., less than 100 ms), at the same spatial location, significantly impairs perception of a target stimulus, to the point that the target can actually be rendered fully invisible (Breitmeyer, 1984; Di Lollo et al., 2000). Rolls and Tovee (1994) showed that the amount of neuronal spiking evoked during the initial volley of feed forward processing—relating to visual processing of the target— is suppressed by the presence of the mask. Thus, "information that enters the visual system later in time can have large effects on the awareness of earlier stimuli" (Lamme & Roelfsema, 2000; p.577). Although the presentation of the second target in our TOJ tasks would not mask the perception of the first target, the comments above suggest that it would nevertheless interfere with processing by reducing the amount of neuronal activity associated with the first target. I hypothesize that this *reduction* in neural activity related to processing of the first target may be larger when the two stimuli perceptually group, thereby making temporal resolution poorer in our TOJ tasks in the grouped relative to the ungrouped condition. In other words, by making it easier to process both targets in parallel, perceptual grouping of the two targets reduce the amount of resources available to process the first target exclusively.

Our primary finding that perceptual grouping and object-based attention impairs temporal resolution is also consistent with the Reverse Hierarchy Theory of visual processing posited by Hochstein and Ahissar (2002). According to the reverse hierarchy theory, conscious, explicit, visual perception follows a reverse hierarchy, from top to bottom, rather than bottom to top as classical feed forward theories of vision assert. Ahissar and Hochstein do not dispute that initial processing is feedforward, but they do suggest that the information carried by bottom-up processes is implicit and unavailable to consciousness. Indeed, reverse hierarchy theory proposes that explicit visual perception does not begin until the product of this information accrual process reaches higher visual areas and proceeds, in a top-down, or re-entrant, manner down the hierarchy of visual cortex. Furthermore, they suggest conscious perception is the product of two modes of visual processing: *vision at a glance* and *vision with scrutiny.* First, the gist of the visual scene is processed through vision at a glance, which is performed by higher areas of visual cortex. Then feedback connections to low levels of the visual system convey information regarding the conscious percept so that details of the stimulus can be scrutinized. Interestingly, and particularly germane to our data, Ahissar and Hochstein (2002) attribute the top-down effects of attention on low levels of the visual system to object-based perception that takes place initially in higher levels of the cortex. Thus, reverse hierarchy theory is consistent with our finding that object-based attention impairs temporal resolution because it suggests that individual targets are first processed consciously in higher visual areas where, if perceptual grouping between them is encouraged, they are integrated into a unified percept.

The reverse hierarchy theory may also offer a plausible explanation for why the results of many of our TOJ experiments differ from Yeshurun & Levy's (2003) results using temporal gap-detection tasks. It may be that observers are able to use Ahissar and

Hochstein's (2002) vision at a glance mode of the visual processing when they perform the less demanding, albeit possibly purer, index of temporal resolution; and that they must rely on vision with scrutiny when they perform more demanding, and potentially less pure, indexes of visual temporal resolution such as the TOJ task. If this is true, then it would vision at a glance affords better temporal resolution than vision with scrutiny.

Since the TOJ task is more difficult than temporal gap detection, it is possible that even though observers are aware that the two targets appeared asynchronously that once the parts had been integrated into a single object that we can no longer report which part appear first (Y. Yeshurun, personal communication, November 3, 2008). Thus, TOJs may be a less pure form of temporal resolution since they require assess to a stored percept in addition to the simple detection of asynchrony.

Effects of Exogenous and Endogenous Spatial Cues on Attentional Selection and Temporal Processing

A considerable amount of research has been conducted to examine the relation between the two putative modes of attentional orienting and the two models of attentional selection. A seminal investigation by Egly et al. (1994) found evidence for both space-based and object-based selection at attended spatial locations. However, Egly et al.'s (1994) spatial cue comprised elements associated with both exogenous orienting (i.e., an abrupt onset in the periphery) and endogenous orienting (i.e., predictive of the target location and long cue – target SOA). Given that these two forms of attentional orienting have been shown to produce distinct behavioural responses (e.g., Berger, Henik & Rafal, 2005; Briand & Klein, 1987; Maylor, 1985), Macquistan (1997) subsequently conducted a study that examined the effects of pure exogenous and endogenous spatial cues on attentional selection, independently. The study revealed that exogenous cues enhanced perceptual grouping at the attended location, but endogenous cues did not (Macquistan, 1997; but see Abrams & Law, 2000, and Law & Abrams, 2002).

Recently, it was reported that exogenous and endogenous spatial orienting also produces differential effects on temporal resolution—a decrement and an enhancement, respectively (Hein et al., 2006). Hein et al. (2006) suggested that the difference in temporal resolution could be explained by Klein and colleagues' hypothesis that automatic (exogenous) and voluntary (endogenous) shifts of attention are performed at different levels of the visual system (Briand & Klein, 1987; Klein, 1994; Klein, Kingstone & Pontefract, 1992). That hypothesis contends that low levels of the visual system control exogenous shifts, and high levels of the visual system perform endogenous shifts (Briand & Klein, 1987). Hein et al. (2006) then assumed that attentional effects must therefore interfere with processing at low levels, and facilitate processing at higher levels of the visual system.

I argue that the object-based theory of attentional selection represents a more parsimonious account of the differential effects of exogenous and endogenous orienting on temporal resolution. Researchers have previously asserted that object-based selective attention is obligatory under conditions of diffuse attention, while space-based selection is the default mode when attention is focused (e.g., Kahneman & Henik, 1981). Moreover, it has been reported that temporal resolution increases with a narrower attentional focus (Poggel et al., 2006). Since exogenous cueing encourages a diffuse attentional setting (i.e., because the cue could appear on either side of fixation), and endogenous cueing encourages a highly focused attentional setting (i.e., because the cue always appears at fixation), we can infer that exogenous cues induce object-based attentional selection and endogenous cues induce space-based attentional selection. Our theory is entirely consistent with Hein et al.'s (2006) results since it posits that object-based attentional selection degrades temporal resolution (c.f. Nicol & Shore, 2007; Nicol & Shore, submitted; Nicol et al., 2008).

The present research also revealed differential effects of exogenous and endogenous spatial attention on temporal resolution (Nicol & Shore, submitted). More specifically, I showed that these modes of orienting modulate the relation between perceptual grouping and temporal resolution differently: exogenous attention augments the grouping effect and endogenous attention does not. This pattern of data also supports our object-based theory of temporal processing if it is interpreted as resulting from the additive effects of the relation between mode of orienting and selection, and the effect of mode of orienting on temporal resolution. On one hand, exogenous spatial cues induce object-based selection (c.f., Briand & Klein, 1987; Goldsmith & Yeari, 2003), and impair temporal resolution in conditions that encourage perceptual grouping of targets (Hein et al., 2006; Nicol et al., 2008; Yeshurun & Levy, 2003). According to our theory, object-based selection interferes with temporal processing, so in this instance the effects of attentional cueing and attentional selection work additively to augment the negative effect of grouping on temporal resolution. On the other hand, endogenous spatial cues are not associated with object-based selection (c.f. Goldsmith & Yeari, 2003), and do not promote feature integration (Briand & Klein, 1987) or degrade temporal resolution (Hein et al., 2006). Therefore, it is reasonable to assume that in this instance the attentional effect worked in opposition to the grouping effect (i.e., the effects were additive, but the negative effect of grouping was offset by the positive effect of endogenous attention), and as a result, endogenous orienting did not modulate temporal resolution.

Implications for Space-based and Object-based Theories of Attentional Selection

Our understanding of space-based and object-based selection has important implications for models of the attentional system (Law & Abrams, 2002). The goal of seminal studies was often to demonstrate the existence of either object-based or space-based attentional selection, and sometimes to refute the existence of the other (e.g., Duncan, 1984; Posner, 1980). A plethora of subsequent research has made it abundantly clear that both mechanisms of selection coexist in the visual system. Accordingly, although this research was aimed at revealing an effect of object-based attention on temporal processing, we certainly do not deny the important influences of space-based effects on temporal resolution (c.f., Keetels & Vroomen, 2007; Spence, Baddeley, Zampini, James & Shore, 2003; Zampini, Shore & Spence, 2003). Rather, my thinking aligns with the growing number of vision researchers who argue that space-based and object-based attentional selection are interactive, or at least not mutually exclusive (e.g., Duncan, 1984; Farah, Wallace, & Vecera, 1993; Humphreys & Riddoch, 1993; Law & Abrams, 2002; Lavie & Driver, 1996; Ward, Goodrich & Driver, 1994). Instead of a single method of extracting or selecting information from the environment, these theorists posit that the visual system is able to engage in either object-based or space-based attention selection. For example, visual selection could operate on grouped spatial arrays making it subject to both object-based and space-based influences (e.g., Gibson & Egeth, 1994; Kramer & Jacobson, 1991). There have been a variety of differing proposals concerning the ways in which these two mechanisms may mutually influence each other, but they all posit that spatial and object-based selection mechanisms operate serially. Law and Abrams (2002) argue "spatial selection operates prior to the point in processing at which objects can exert their effects (p.1027)", while Kahneman (1973) and Neisser (1967) assert that object-based effects are due to processes that entirely precede the effects of spatial attentional selection.

Vecera and Farah (1994) suggested that whether space-based or object-based selection is used depends on the demands of, and visual representations used in particular experimental tasks. Indeed, in their study titled "Does visual attention select objects or locations?" they concluded that visual attention selects both (Vecera & Farah, 1994). Similarly, it has been contended that the induction of object-based or space-based attention can be determined by whether the task is based on attentional *selection* or attentional *expectancy* (Duncan personal communication cited in Vecera & Farah, 1994). On one hand, tasks involving attentional expectancy, such as those with spatial precues, may engage space-based selection, and on the other hand, tasks that require selective discriminations of stimuli would likely show the effects of object-based attention (Vecera & Farah, 1994). Findings from research conducted by Lavie and Driver (1996) support this distinction. An object-based effect (i.e., a benefit to spatial resolution) was produced when the task required observers to make same or different discriminations, however, when observers were precued to expect targets in particular spatial locations the object–based effect was eliminated (Lavie & Driver, 1996). From this pattern of data, Lavie and Driver (1996 suggested that object-based factors influence the distribution of attention, and space-based factors influence object-based effects (Lavie & Driver, 1996). Specifically, they concluded that spatial attention eliminates, or overrides, object-based attention, and "that selection ultimately takes place within a spatial medium, albeit under the influence of object-based factors" (Lavie & Driver, 1996, p. 1249).

Clearly, this selection-expectancy distinction fits well with our data as well. In our preliminary investigations of the effect of grouping on temporal resolution, when spatial cues were not used, a robust object–based effect was revealed (Nicol & Shore, 2007). However, in our subsequent research that examined the effect of attention (i.e., spatial precues) on that relation, some evidence of space-based selection emerged (Nicol et al., 2008; Nicol & Shore, submitted).

Challenges and Future Directions

The present research was met with a number of issues and obstacles along the way. Generally, it was a challenge to design target stimuli that were identical across grouping conditions. Indeed it was difficult to induce and examine object-based factors of temporal processing while simultaneously controlling for spatial separation between the targets. The problem was: How can I present two stimuli at different locations, and at different onset times, and make it possible that they will be perceived as a single event or object? In the first study (Chapter 2: *Perceptual grouping impairs temporal resolution*) for example, although the targets were identical, their respective presentation orientations (i.e., one-object or two-objects) produced different amounts of apparent motion (due to their asynchronous, spatially contiguous, onsets). I controlled for the illusory motion confound in a subsequent experiment, which indeed provided support for an object-based rather than a motion-based interpretation of the data, but the grouping manipulation did differ across experiments: in the first experiment observers were presented with two targets that grouped or did not with each other, while in the control task they were presented with two targets that grouped or did not group with another stimulus. Thus, it is possible that observers relied on two different strategies to perform the two tasks.

It is also important to note that in the in third experiment of Chapter 2: Perceptual grouping impairs temporal resolution, that the data did not entirely support our predictions. In that experiment we sought to rule an effect of distance between targets as an explanation for the findings in Experiment 2 of that study. In the control version of that task, the data came out as expected in that temporal resolution became increasingly poorer as the spatial disparity between targets increased (i.e., in an approximately linear fashion). In contrast, we predicted when the targets grouped with the fixation stimulus (i.e., the middle distance condition) that performance would be poorest, and it would be relatively unimpaired and not different when the targets appeared at the inside and outside of the fixation stimulus. Somewhat unfortunately for our predictions, performance in the outside condition did not differ across the grouping (middle) and outside condition. Clearly, our explanation of this pattern of data was sufficient to meet the approval of the peer reviewers of that article, but it is nevertheless a somewhat problematic aspect of that study.

The main issue that emerged in the reviews of my second study (Chapter 3: *Object-based processing mediates the effect of exogenous attention on temporal resolution*) regarded the possibility that the first target (i.e., the correct response) was backward masked by the onset of the second target when they were presented at the same spatial location. It was suggested that the effect (i.e., better temporal resolution at the attended location for spatially separated targets, and worse temporal resolution of at the attended location for spatially overlapping targets) was due to the presence of masking when the targets appeared at the same location, but not when they appeared at different locations. That criticism is seemingly dismissible on the grounds that the effects of masking are reduced by attention (Di Lollo, Enns, & Rensink, 2000; Ramachandran & Cobb, 1995). But nevertheless, the method of presentation when the targets appeared at the same location was similar to technique used to reveal to the negative compatibility effect (NCE) (Enns & Lleras, 2004; Klapp & Hinkley, 2002). The NCE is a counterintuitive phenomenon whereby observers are slower at reporting the identity of a target (a left or right pointing arrow) when the target and a briefly presented masked prime (also a left or right pointing arrow) are the same (i.e., the prime and target arrows point in the same direction) than when they are different (i.e., the prime and the target arrows point in opposite directions). According to one account, this surprising effect occurs because the target arrow masks the prime arrow (i.e., through object-substitution) when they are different, but not when they are the same (Lleras & Enns, 2004). In other words, observers are responding to the new perceptual information that is available when the target arrow is different than the prime arrow. If this were true, it may provide a plausible account of for the pattern of data we observed in our same-location TOJ task. Observers may have responded to the new perceptual information associated with the appearance of the second target, which would of course lead to an incorrect response. Critically, however, the NCE is observed only when an intervening mask is presented between the prime and target arrows, which the TOJ tasks used in my study did not include. Thus, Lleras and Enns' (2004) object-substitution account of the NCE may not be applicable to the data after all.

Obviously, the lack of a cueing effect in the endogenous orienting experiments is problematic for my last study (Chapter 3: *Temporal order judgments reveal different effects of exogenous and endogenous spatial attention on perceptual grouping*). Although the pattern of results in those experiments did come out as predicted, they required an assertion and interpretion the null hypothesis. As mentioned, it is perplexing that I was not able to produce a cueing effect, given that I essentially conducted a replication of Hein et al.'s (2006) study, which did observe an effect of endogenous cueing on temporal resolution. It would be interesting to conduct additional research on this issue, to attempt to reveal the source of the discrepancy.

I also plan to conduct future research in this area that will focus on the issue of the potential trade-off between spatial and temporal processing, produced by attentional cues (c.f. Yeshurun & Levy, 2003). This was the topic of a recent study conducted by Correa and Nobre (2008). In a dual-task procedure, they asked observers to make a temporal (duration) and spatial (size) discrimination about the same stimulus. Before the brief presentation of the target stimulus they presented observers with a cue that validly (75%)

predicted the task-relevant dimension (i.e., spatial or temporal) that they would be asked to report on at the end of the trial. Performance was better on validly cued trials for both temporal and spatial discriminations, suggesting that observers were able to prioritize spatial or temporal processing depending on the cue they were presented with. Correa and Nobre (2008) concluded that they had demonstrated a dissociation, but not a trade-off, between spatial and temporal processing. I am very interested in examining this issue further by adding a spatial cueing manipulation to this design, and by asking observers to make discriminations about both dimensions (temporal and spatial) of the target stimulus on each trial. In particular, I plan to adopt the stimuli used in Shore et al. (2001) and ask observers to report whether the horizontal and vertical line segment appeared simultaneously or not, and whether they were the same size or not. The target line segments would appear briefly at exogenously and endogenously (between experiments) cued or uncued locations and would be followed by a masking stimulus until their responses were made. Comparing performance on the exogenous and endogenous versions of the task would hopefully yield further evidence for the independence of these two modes of orienting (c.f., Briand & Klein, 1987; Funes et al., 2007). I would also like to run two versions of each spatial cueing task (i.e., exogenous and endogenous). In one version I would adopt Correa and Nobre's task-relevant precueing technique, and in the other it would not include a task-relevant precue, but instead prompt discrimination responses, in random order, and the end of each trial (i.e., either first spatial then temporal, or first temporal then spatial). Of interest, in the latter technique would be the extent to which observers could make accurate discriminations on both dimensions, given that each dimension was of equal priority. I believe this design, in particular, would be a true test of the hypothesis that there may be an inherent trade-off between spatial and temporal resolution.

Conclusions

Our research has demonstrated that visual temporal processsing is impaired by object-based attention (Nicol & Shore, 2007, submitted; Nicol et al., 2008). We contend that many of the discrepancies that exist in the literature concerning the nature of the relation between attention and temporal resolution—some studies report an attention-related enhancement and others an attention related impairment—can be resolved by interpreting the results through our proposed *object-based selection theory of temporal processing*. Briefly, this theory posits that conditions that promote object-based attention degrade temporal resolution, while conditions that promote space-based attention enhance temporal resolution.

Our object-based theory emerged from the intuition that the visual system automatically groups stimuli that make coherent objects, and interprets them as a single perceptual event. One function of attention is therefore to facilitate integration of stimuli that co-occur in space and time. Thus attention affects temporal resolution by promoting the binding of stimuli over time that likely belong to the same event, just as it affects spatial resolution in ways that promote uniting stimuli that likely belong to the same object. This attentional effect makes ecological sense since it would usually produce a veridical subjective percept of the environment. Indeed, "given that we live in a world in which parts of objects usually do not exist in isolation from the objects themselves, it is perhaps not surprising that objects can exert such a strong effect on our attentional selection mechanisms (Law & Abrams, 2002, p.1027)".

As mentioned at the outset, in contrast the straightforward, beneficial effect of spatial attention on spatial resolution, studies that have investigated the effect of spatial attention and temporal resolution have yielded equivocal results—some report that attention enhances temporal resolution and others report that attention degrades temporal resolution. The unique contribution of this thesis is that it provides a theory of temporal processing that can be used to account for and unify the seemingly contradictory results that have been reported in regard to the nature of the relation between spatial attention and visual temporal resolution. In short, the research that comprises my thesis provides compelling evidence that object-based attentional selection is a critical mediator of the relation.

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