

Semantic Influences on Overt and Covert Visual Attention

by

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Abstract

People are constantly confronted by a barrage of visual information. Visual attention is the crucial mechanism which selects for further processing, subsets of information which are most behaviourally relevant, allowing us to function effectively within our everyday environment. This thesis explored how semantic information (i.e., information which has meaning) encountered within the environment influences the selective orienting of visual attention. Past research has shown semantic information does affect the orienting of attention, but the processes by which it does so remain unclear. The extent of semantic influence on the visual attention system was determined by parsing visual orienting into the tractable components of covert and overt orienting, and capture and hold process stages therein. This thesis consisted of a series of experiments which were designed, utilising well-established paradigms and semantic manipulations in concert with eye-tracking techniques, to test whether the capture and hold of either overt or covert forms of visual attention were influenced by semantic information. Taking together the main findings across all experiments, the following conclusions were drawn. 1) Semantic information differentially influences covert and overt attentional orienting processes. 2) The capture and hold of covert attention is generally uninfluenced by semantic information. 3) Semantic information briefly encountered in the environment can facilitate or prime action independent of covert attentional orienting. 4) Overt attention can be both preferentially captured and held by semantically salient information encountered in visual environments. The visual

attentional system thus appears to have a complex relationship with semantic information encountered in the visual environment. Semantic information has a differential influence on selective orienting processes that depends on the form of orienting employed and a range of circumstances under which attentional selection takes place.

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I would like to dedicate this thesis to the memory of Cyril “Pop” Weaver (1917-2010) and to Rex McGill.

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“Life is a path lit only,
by the light of those I’ve loved.”
(Tom Waits)

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Foreword

Attention is the mechanism which allows for the selective processing of one source of information over other, simultaneously available sources. Because of the limited-capacity of our processing resources, attention is crucial for functional perception and action in an everyday dynamic environment where we are constantly confronted by a barrage of sensory input. It is used to orient our limited resources to prioritise, for further processing, small excerpts of sensory information which are most behaviourally relevant. This thesis explores how semantic information encountered within the environment influences the selective orienting of visual attention.

Differing theories have argued visual attention as being allocated to either locations in space (spatial attention; e.g., Duncan, 1984; Vecera & Farah, 1994) or to objects (object-based attention; e.g., Erikson & Hoffman, 1973; Posner, 1980) within the visual field (see reviews, e.g., Lauwereyns, 1998; Mozer & Vecera, 2005). This thesis focuses on the allocation of spatial attention.

The orienting of spatial visual attention has been variously compared to the shifting of a spotlight (Posner, Snyder, & Davidson, 1980; Remington & Pierce, 1984), a zoom lens (Eriksen & St. James, 1986; Eriksen & Yeh, 1985; Müller, Bartelt, Donner, Villringer, & Brandt, 2003), or the repositioning of an attentional gradient (LaBerge & Brown, 1989). Central to such descriptions is the conception that, when attentional resources are allocated to a location in the visual field, processing of sensory information at this location is enhanced (see reviews, e.g., LaBerge, 1995; Van der

Heijden, 1992). Spatial attention is thus considered critical for scene perception and everyday tasks such as reading or driving.

Attention is oriented in response to the complex interplay between external signals generated from the visual field (exogenous control) and internal signals generated from within the individual, based on knowledge, goals and expectations (endogenous control; see reviews, e.g., Burnham, 2007; Lauwereyns, 1998; Rauschenberger, 2003). Exogenous control of attention is considered to be automatic or reflexive in that it is involuntarily driven by the physical salience of visual information. Endogenous control, however, is slower (Jonides, 1980; Müller & Rabbitt, 1989) and represents a voluntary initiation of attentional resource deployment. This distinction is examined further in Chapter 1, but with respect to the thesis as a whole, Chapters 1 to 3 used paradigms that employed exogenous control of attention, while Chapter 4 primarily involved endogenous control.

Overt and Covert Orienting of Attention

The selective orienting of attention can occur by either overtly or covertly shifting attentional resources (see reviews, e.g., Klein, 2004; Wright & Ward, 2008). Overt orienting is achieved by directing gaze towards a selected location using a directly observable combination of eye, head and body movements. It is most commonly accomplished (and researched) by making rapid eye movements, or *saccades*. Gaze is directed in order to train the high-acuity properties of the small fovea, contained in the centre of the retina, to locations for purposes of finely detailed perceptual processing.

These stable periods of gaze, occurring between saccades, are referred to as *fixations*.

Chapter 4 addresses overt orienting in more detail.

Covert orienting, variously described as “the mind’s eye” (Jonides, 1981), “looking out of the corner of the eye”, or “using peripheral vision” (Wright & Ward, 2008), is defined as shifts of attention in the absence of directly observable movement, whereby attentional resources are internally assigned to a location for enhanced (in terms of speed and reduced threshold; Posner & Petersen, 1990; Posner, Walker, Friedrich, & Rafal, 1984) perceptual processing (Klein, 2004). Consequently, its occurrence can only be indirectly measured by inferring from performance after preventing overt orienting. Covert orienting occurs faster than overt orienting (Hoffman, 1975), and while not useful for fine-grained perceptual analyses, it does make use of parafoveal properties, which include a high sensitivity to abrupt onsets, and changes in luminance and motion.

Covert and overt forms of attentional orienting are often considered to be tightly linked. Orienting of covert attention is shown to typically precede saccades to the same location, both in response to endogenous (Posner, 1980; Remington, 1980) and exogenous signals (Hoffman & Subramaniam, 1995; Shephard, Findlay, & Hockey, 1986). However, beginning with the first systematic explorations of covert attention by Helmholtz (1867/1925), and later influential studies by Posner (1978; 1980), researchers have demonstrated the ease with which covert orienting can be dissociated from overt orienting. Subsequent research has suggested that, despite the anatomical overlap of the brain areas responsible for overt and covert orienting processes (e.g., Corbetta et

al., 1998), they appear to represent isolable and functionally independent systems (Corbetta & Shulman, 2002; Fischer, 1999; Kingstone & Klein, 1993; Klein, 1980; Klein & Taylor, 1994; Stelmach, Campsall, & Herdman, 1997; Wright & Ward, 2008).

Capture and Hold Stages of Orienting

Regardless of whether occurring covertly or overtly, or accomplished under either endogenous or exogenous control, orienting of attention has been proposed to consist of three primary operations (Posner et al., 1984): a disengagement from the currently attended location, a shift towards a new location, and then engagement at the new location. Based on these operations, Stolz (1996) conceptualised two stages of visual orienting; capture and hold. Capture involves the shifting of attention towards, and subsequent engagement at, a new location, while hold reflects the disengagement of attention and subsequent shifting away from the currently attended location. Despite sharing the *shift* operation, capture and hold are considered to represent separate mechanisms or processes in the orienting of attention.

The Spatial Cuing Paradigm

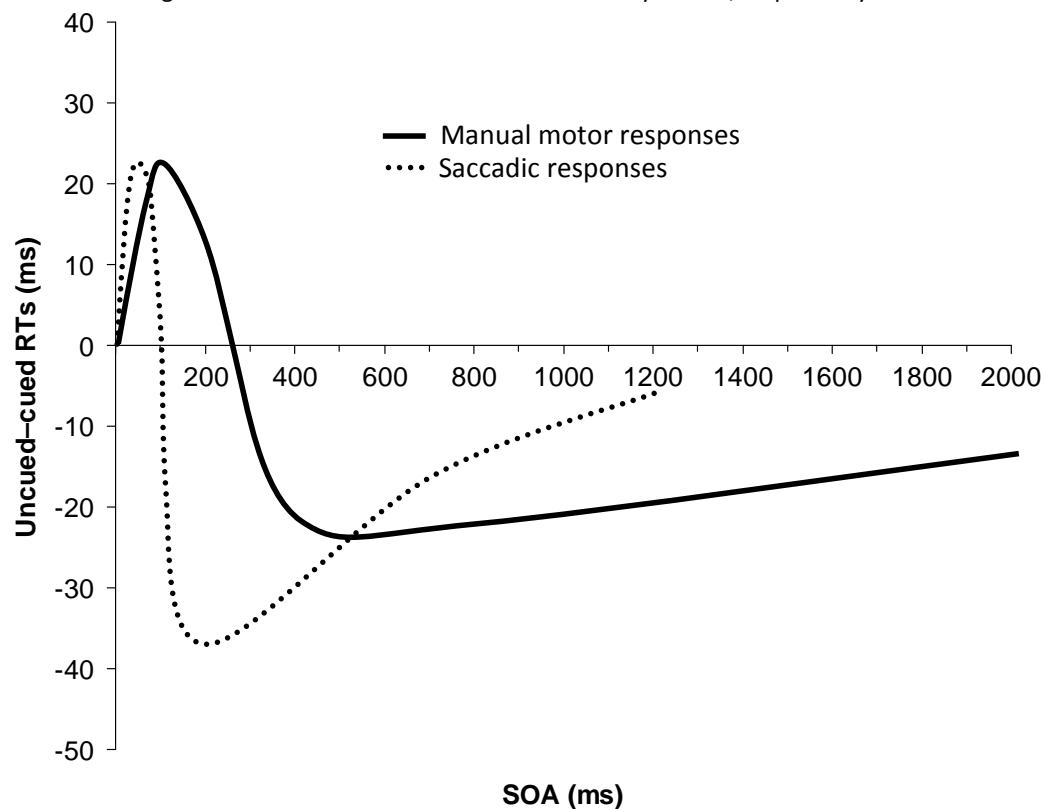
A multitude of paradigms have been developed for investigating the spatial orienting of attention. One of the most useful and commonly used remains Posner's (1980) spatial cuing paradigm. In a typical example of this paradigm, observers are asked to maintain gaze on a central point while a central (e.g., an arrow) or peripheral (e.g., a luminance or abrupt-onset) cue is presented, indicating the likely location of a target probe to which participants are to respond. Reaction time (RT) performance tends to be

faster for cues which correctly indicated the location of the target (i.e., valid cues) and slower following cues which incorrectly indicated the target location (i.e., invalid cues), compared to a control condition where no cues were presented. Posner inferred these RT benefits and costs to reflect attention orienting to the indicated location, so that resources were either already aligned in the case of validly cued targets (allowing for facilitated detection of the subsequent target stimulus) or required reorienting to align with an invalidly cued target presented at an alternative location. To summarise, a spatial cue is used to induce the orienting of attention, which is then measured by recording RTs to a target presented in either the correctly (valid) or incorrectly (invalid) indicated location. This thesis will only be concerned with spatial cuing involving peripheral cues.

A critical variable for observing these typical facilitative RT effects (alternatively referred to as positive cuing effects or cue validity effects) from peripheral cues, is the temporal interval between the onset of the cue and the target; the stimulus onset asynchrony (SOA). It has generally been shown that facilitative effects peak at approximately 100 ms following the cue onset, and fade between 200 and 300 ms (e.g., Cheal & Lyon, 1991; Klein, 2000; Posner & Cohen, 1984). Following SOAs of 300 ms, Posner and Cohen (1984) were first to observe development of inhibitory effects, whereby RTs were slower for validly, relative to invalidly, cued targets. These *negative* cuing effects are known as *inhibition of return* (IOR) and can last up to several seconds following the cue onset (Samuel & Kat, 2003). It is thought to reflect a bias against reorienting attention towards the recently attended cue location (Chapter 1 will

introduce IOR in more detail; for a review, see Klein, 2000). The specific timing of facilitative and inhibitory effects can vary according to paradigm parameters such as task complexity, response modality (see Figure F1) and physical salience of cues (for more examples, see Samuel & Kat, 2003).

Figure F1 Typical pattern of reaction time cuing effects (uncued–cued RTs; ms) for manual versus saccadic responses following peripheral nonpredictive cues as a function of stimulus onset asynchrony (SOA; ms). Positive and negative values refer to facilitative and inhibitory effects, respectively.



The spatial cuing paradigm is an especially effective method for studying covert attention. It can be used to separate overt from covert attentional orienting by asking participants to maintain gaze on a central fixation, thereby ensuring only covert orienting can possibly occur in response to the peripheral cue. Any effects from the cue on RT performance can then be attributed to covert attentional orienting. The paradigm

is also an important tool for measuring capture and hold orienting processes. Using short, facilitation-inducing SOAs within the spatial cuing paradigm, Stolz (1996) operationalised capture as being reflected by RTs following valid cues, that is, the time to shift attention towards the cued location and engage resources to process the validly cued target. Hold processes were operationalised as being reflected by RTs following invalid cues, that is, the time to disengage attention from the invalidly cued location and shift towards the target presented at the alternative location. These operationalisations enable comparison of the attentional priority status allocated to various visual objects, by comparing their abilities as cues to capture and hold attention. A complementary implication is that by manipulating properties of cue objects, one can assess which of capture and hold mechanisms of attentional orienting are affected. In this way, the spatial cuing paradigm, along with key distinctions between capture and hold processes, and overt and covert forms of orienting, represents an invaluable tool for investigating how semantic information influences the orienting of attention.

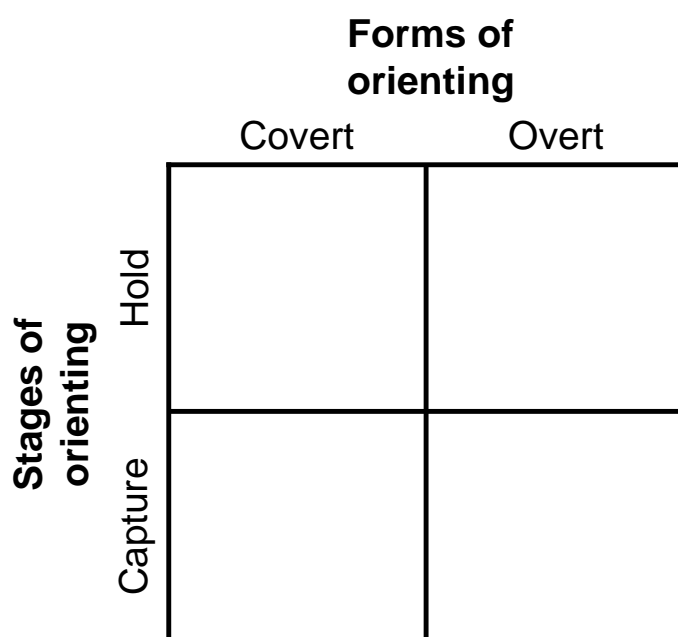
Semantic Influence on the Orienting of Attention

Semantic information within the environment plays an important role in the selective orienting of attention. When endogenously orienting attention, processing of semantic information is necessary to assess which locations require attentional resources according to current goals and expectations. Exogenous orienting, however, was initially considered to be uninfluenced by semantic information, and instead only affected by the low-level physical characteristics of the peripheral stimuli (e.g., Briand & Klein, 1987). Using the spatial cuing paradigm, Stolz (1996) challenged this notion by

discovering that manipulations of the semantic relation between a word cue and a word at fixation influenced the holding of exogenous attentional orienting. Subsequent research has repeated this finding of semantic influence on hold processes by manipulating the emotional valence (Fox, Russo, Bowles, & Dutton, 2001; Fox, Russo, & Dutton, 2002; Okon-Singer, Tzelgov, & Henik, 2007) and threat-value (e.g., Yiend & Mathews, 2001) of cues. Research has also proposed an influence on capture processes using manipulations of threat (Bradley et al., 1997; Mogg, Mathews, & Eysenck, 1992; Yiend & Mathews, 2001) and sociobiological significance (Bindemann, Burton, Langton, Schweinberger, & Doherty, 2007; Theeuwes & Van der Stigchel, 2006). However, as further outlined in Chapter 1, the concern with much of this research (with the exception of Theeuwes & Van der Stigchel, 2006) is the often muddy distinction regarding whether semantic effects reflect influence on overt or covert shifts of attention. Additionally, some research (e.g., Bindemann et al., 2007; Bradley et al., 1997; Mogg, Mathews, Eysenck, 1992; Yiend & Mathews, 2001; see also Bradley, Mogg, & Millar, 2000; Mogg, Millar, & Bradley, 2000) used relatively long cue presentation durations which precluded accurate distinction between capture and hold mechanisms (see, e.g., Fox et al., 2001, for further explanation). The ambiguity over which processes are influenced by semantic information is not only limited to exogenous tasks. Ro, Russell, and Lavie (2001) showed sociobiologically significant stimuli received attentional priority in a change detection task, but noted that it was unclear whether this priority reflected the superior capture or hold of attention. Thus, while there now

appears plentiful evidence to indicate that semantic information influences the orienting of visual attention, the processes by which it does so remain unclear.

Figure F2 Two \times two matrix parsing visual attentional processes into orthogonal forms of orienting (covert and overt) and stages of orienting (capture and hold) dimensions.



Thesis Scope

The current thesis seeks to explore how semantic information influences visual attentional orienting. This will be achieved by first considering the two separate distinctions of overt versus covert forms, and capture versus hold process stages, as representing two orthogonal dimensions involved in the orienting of visual attention. From this, a 2×2 matrix can be constructed, parsing elements of attentional orienting into a tractable set of processes (see Figure F2). Such a matrix serves as a useful framework for organising existing research and designing prospective studies. This thesis consists of experiments which have been designed, utilising well-established

paradigms in combination with eye-tracking techniques, to test each of the overt/covert and capture/hold combinations for evidence of semantic influence. Evidence has primarily been determined by examining whether performance which reflects attentional orienting differs as a function of the semantic value of visually presented stimuli. It could be that the initial orienting of attentional resources (i.e., capture) is influenced by semantic information from unattended locations in the visual field, where the information is used to assess relevant locations for further processing. Alternatively, it may be that the initial orienting of attention to a location is impervious to such semantic information, and that it is not until a location has first been oriented that semantic information influences the degree to which stimuli at the currently attended location is then prioritised for further processing (i.e., hold). These two possible hypotheses are not mutually exclusive as it is possible that both capture and hold processes may both be similarly influenced by semantic information. Moreover, any pattern of semantic influence may differ based on whether attentional resources are oriented overtly or covertly. Therefore, by using this approach, it is proposed that the role of semantic information within the visual attentional system may be better understood.

Paradigms Used

The spatial cuing paradigm is used to measure the impact of semantic information on the covert orienting of attention, while the free-viewing flicker paradigm (Rensink, O'Regan, & Clark, 1997) is used to measure influence on overt attentional orienting.

The Eye-Tracking Technique

Eye-tracking techniques were employed throughout this thesis as an effective means to measure both covert and overt orienting, and constituent capture and hold mechanisms. The EyeLink® 1000 Tower Mount Head Supported System (SR Research Ltd., Ontario, Canada) was used. Overt attention was directly measured using corneal reflection and the pupil to determine gaze (i.e., eye position) within a spatial accuracy of up to 0.01° and sampling at a rate of 1000 Hz. Mechanisms of capture and hold within a free-viewing paradigm could thus be determined by directly measuring eye-movement variables reflecting the speed and likelihood of initial fixations on objects (i.e., capture) and the duration and number of fixations and re-fixations on objects (i.e., hold).

Eye tracking is also an effective technique for separating covert from overt shifts of attention, which allows for the measurement of purely covert orienting. This was achieved by monitoring eye position to confirm eyes remain fixated, thereby controlling overt shifts of attention, while allowing only covert attentional orienting to occur. Combined with a spatial cuing paradigm, any effects from cues on performance could thus be attributed to purely covert attentional orienting processes. Effects on capture and hold processes of covert attention were then able to be inferred via performance following valid and invalid cues.

Semantic Manipulation

It should be noted that, for the purposes of this thesis, the definition of *semantic* is not limited to its use as a linguistic term (which only pertains to words and symbols). Instead, it is employed in its original broader definition of "having meaning". Therefore,

information is considered *semantic*, to the extent that it refers to, or is associated with, higher-order information (i.e., not merely physical or sensory information), including category membership and various representations in memory.

To study the impact of semantic information on the capture and hold mechanisms of overt and covert orienting of attention, it is necessary to use a semantic manipulation which has already shown strong evidence of impacting attention. To this end, the sociobiological significance inherent in faces was used as the primary (but not sole; see, e.g., Chapter 3) semantic manipulation.

Humans are social beings. They are strongly motivated by, and adapted for, social living (Brewer, 2004). One of the most important sources of social information useful for effective interactions is contained in the face. While faces share a similar configuration (e.g., two eyes, a nose and a mouth), they convey an enormous amount of information (e.g., sex, age, race, identity, emotion and gaze/attention direction).

Because of our effectiveness in perceiving such subtle yet extensive information, face perception has been considered one of the most highly developed visual skills (Haxby, Hoffman, & Gobbini, 2000). Evidence from single-cell recordings (e.g., Perrett, Hietanen, Oram, & Benson, 1992), neuroimaging (e.g., Clark et al., 1996; Kanwisher, McDermott, & Chun, 1997; McCarthy, Puce, Gore, & Allison, 1997; Sergent & Signoret, 1992) and neuropsychology (Allison, Puce, Spencer, & McCarthy, 1999; Bentin, Allison, Puce, Perez, & McCarthy, 1996; De Renzi, 1986; Lu et al., 1991; Sams, Hietanen, Hari, Ilmoniemi, & Lounasmaa, 1997; Warrington & James, 1967) show specific brain areas

are more responsive to faces than to other stimuli (for a review, see Haxby, Hoffman, & Gobbini, 2000). Such findings indicate the biological importance of faces.

Faces are thus considered as both socially and biologically relevant stimuli. Consequently, this sociobiological salience (or significance) might be expected to represent important semantic information factored into assessing which stimuli should receive attentional priority for purposes of further processing. Indeed, previous research across a range of behavioural paradigms have shown an attentional priority for faces, including visual search (e.g., Ro, Friggel, & Lavie, 2007), spatial cuing (e.g., Bindemann et al., 2007; Theeuwes & Van der Stigchel, 2006), flicker, (Ro et al., 2001), go/no-go (e.g., Bindemann, Burton, Hooge, Jenkins, & de Haan, 2005) and inattention blindness paradigms (Devue, Laloyaux, Feyers, Theeuwes, & Brédart, 2009; Mack, Pappas, Silverman, & Gay, 2002; Mack & Rock, 1998; Shelley-Tremblay & Mack, 1999). Preferential allocation of attention for faces has also been exhibited in newborns (Goren, Sarty, & Wu, 1975), infants (Morton & Johnson, 1991) and in a detection task by visual neglect patients (Vuilleumier, 2000). To increase their ecological validity, photographic faces were used as stimuli throughout the thesis, because they convey more information than less-realistic schematic faces.

In Chapters 1, 2, and 4, the stimuli used were taken directly from Ro et al.'s (2007) research. The face stimuli in these chapters were all female, unfamiliar, tended to be facing the front and wore different hairstyles and either neutral or smiling expressions. In addition to faces, these stimuli included photographs of appliances, musical instruments and clothing. Ro et al. selected the stimuli to minimize low-level

visual within-category differences for face stimuli, but maximize such within-category differences for the other stimuli. A critical point is that Ro et al. failed to replicate the attentional priority found for face stimuli when they were inverted (see Yin, 1969), thus showing the attentional priority enjoyed by faces over the other stimulus categories in their study was not due to low-level image properties.

Some researchers have proposed the existence of specialised modules dedicated to the processing of faces (e.g., Farah, 1995; 1996; Farah, Rabinowitz, Quinn, & Liu, 2000; Tsao & Livingstone, 2008). Other researchers contend that our remarkable configural sensitivity to faces is merely a well-refined version (from repeated experience) of what occurs when perceiving other objects (e.g., Gauthier & Tarr, 1997). This thesis bypasses the debate over whether the attentional priority enjoyed by faces is due to innate or well-learned processes by only considering and using their recognised sociobiological significance as a well-established manipulation in which to measure the influence of semantic information on attention. Whether face processing is mandatory or strategic (i.e., whether faces are still deemed intrinsically relevant even when such priority is inappropriate to current goals) is another issue which has received much consideration (for a review, see Palermo & Rhodes, 2007), and one that is further addressed in Chapter 4.

Summary and Preview

The research focus of this thesis was on discovering which visual attention selection processes within covert and overt forms of orienting are influenced by semantic information. This question was approached by using a clear framework and

operational definitions, eye-tracking techniques, and well-established paradigms and semantic manipulations in order to directly test for evidence of semantic influence. This research is a step towards understanding how and why we give priority in attending to certain visual stimuli. Such knowledge of how we process visual information and guide our attention can give us important insights into a wide variety of everyday visual inspection and detection tasks, and into understanding how we visually experience the world on a daily basis. It also has important applications for a range of applied settings involving engineering and skill acquisition, from the design of in-vehicle displays to the development of training programmes for diagnosis on the basis of visual materials (e.g., scans or X-rays).

In Chapter 1, the semantic impact on capture and hold mechanisms of covert attention involved in IOR is explored over five experiments, using stringent eye-control procedures within a spatial cuing paradigm. The sociobiological salience of peripheral cues was manipulated and saccades response latencies towards subsequently presented targets were measured. A robust IOR effect and a recurring influence from the semantic value of the cue were observed across numerous methodological variations. Cue objects of high sociobiological salience (i.e., faces) briefly reduced saccade latencies independently of attentional allocation. When eye-control criteria were relaxed, allowing oculomotor confounds on otherwise purely covert orienting of attention to cues, semantic effects were reduced. Results suggest a short-lived semantic priming effect, speculated to have a neural basis within the basal ganglia. It shows the limited

influence of semantic information on covert attentional mechanisms involved in oculomotor IOR.

Because of differences in underlying neural circuitries between saccadic and manual motor responses, differing expressions of semantic influence on attentional orienting might also be expected. Chapter 2 examines how semantic information from peripheral cues impact manual motor responses. Again, using a similar spatial cuing methodology, the sociobiological salience of cues was manipulated in one- and two-cue presentations. Participants discriminated target symbols by making manual motor responses. Facilitated performance was observed only when targets were validly cued by a sociobiologically salient cue (i.e., a face) in competition with a neutral cue (e.g., an item of clothing). This indicated that the semantically salient cue preferentially captured attention, but only when competing for attention. No attentional cuing effects were observed. It appeared that a trade-off occurred, between the role of semantic information and low-level physical features on the allocation of attention, which depended on whether cues were competing for attention. The findings highlight differences in how various response systems express semantic influence on visual attention.

Chapter 3 investigates whether the nature of the task set determines the extent of semantic influence from a brief peripheral cue on the allocation of covert visual attention. A spatial cuing paradigm with eye-control was used, where cues were either first names (male or female) or emotionally charged words (positive or negative) followed by a target face. Participants discriminated either the gender (male or female)

or emotion (positive or negative) of the face. When there was high information overlap between cue and task set, responses were faster when the cue and target value were semantically congruent versus incongruent. Moreover, these effects did not interact with attentional allocation. It was concluded that these cues primed a task-influencing response, showing semantic influence from brief peripheral cues to depend on the degree of information overlap between cue and task set, and to occur independently of spatial attention allocation processes.

In Chapter 4, a move away from the relatively constrained spatial cuing paradigm sees the question of semantic influence on mechanisms of overt attention being addressed using the more naturalistic free-viewing flicker paradigm. Semantic influence was examined by measuring oculomotor correlates of the RT and accuracy advantage for faces in the change detection task. A brief account of the importance of eye movements in attentional research is provided, and capture and hold mechanisms are re-operationalised to enable their measure when overtly orienting attention within a free-viewing paradigm. Whether the face advantage was due to mandatory processing of faces or represented an idiosyncratic participant strategy was also investigated by manipulating preknowledge of the object category in which to expect a change. An RT and accuracy advantage was found for detecting changes in faces compared to other objects of less sociobiological significance in the form of greater attentional capture and hold. The faster attentional capture by faces appeared to overcompensate for the longer hold, to produce faster and more accurate manual responding. Preknowledge did

not eliminate the face advantage, suggesting that faces receive mandatory processing when competing for attention with less semantically salient stimuli.

An afterword is then provided, summarising the main experimental findings from each chapter and exploring the resulting theoretical implications. Unresolved and emergent questions are identified and directions for future research offered.

Chapter 1

On the Limited Role of Semantic Information in Oculomotor

Inhibition of Return

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On the Limited Role of Semantic Information in Oculomotor Inhibition of Return

In our daily environment, we are inundated with a multitude of visual objects which constantly vie for our attention. Because of our limited processing resources, how and where we orient our visual attention to select objects for further information processing has important consequences for how effectively we interact with our environment. A critical question is how does semantic information, associated with objects in our visual environment, influence what we prioritise for further processing? Or more specifically, which mechanisms of attentional orienting are influenced by such semantic information?

Spatial visual attention refers to the selective orienting of resources to a location in our visual field for further information processing (LaBerge, 1995; Lauwereyns, 1998; Van der Heijden, 1992), in a manner considered analogous to a spotlight (Posner, Snyder, & Davidson, 1980) or zoom lens (Eriksen & St. James, 1986). Accordingly, when visual attention resources are spatially aligned to a particular location in space, processing of visual information at this location is enhanced.

Stolz (1996) conceptualised the parsing of attentional orienting into the two mechanisms of capture and hold, based on the operations of orienting outlined by Posner, Walker, Friedrich, and Rafal (1984). Capture was defined as the shift of attention towards, and engagement at, a location in space, while hold processes reflect the attentional dwell time at a location, influencing the disengagement and movement from the currently attended location. This useful distinction allows for the

measurement of the separate operations of disengagement, shifting and engagement of spatial visual attention.

The orienting of attention can be controlled either endogenously or exogenously. Endogenous control of attention is considered voluntary, whereby strategic orienting of attention is determined by an individual's current goals, knowledge and expectations. In contrast, exogenous control of attention is thought to be involuntary and stimulus-driven, in that it is determined by characteristics of the environment, independent of individual intentions. A typical example would be the reflexive shift of attention to a location in response to the sudden appearance of an object in a visual scene. While endogenous attention, by definition, tends to be directed to those visual objects which are semantically interesting or informative based on their relevance to an individual's goals, it is only a recent development (e.g., Fox, Russo, Bowles, & Dutton, 2001; Fox, Russo, & Dutton, 2002; Okon-Singer, Tzelgov, & Henik, 2007; Stolz, 1996; Theeuwes & Van der Stigchel, 2006) that exogenous attention has been considered to be influenced by more than just the physical (low-level) characteristics embedded in a visual scene (Briand & Klein, 1987). The focus of the present study was to expand on this emerging research by investigating the influence of semantic information on the attentional mechanisms involved in exogenous control of covert attention. With respect to the scope of the thesis outlined in the Foreword (see Figure F2, left column), the present study was designed to test capture and hold stages within covert orienting of visual attention for evidence of semantic influence.

Note that a third type of attentional control has been posited (e.g., Klein, 2004; Klein & Shore, 2000) that may reflect a hybrid of exogenous and endogenous control components, that is, a form of involuntary attentional orienting based on high-level factors. Such an example is commonly observed in spatial Stroop tasks (for a review, see Lu & Proctor, 1995), where attention is automatically allocated to locations in response to irrelevant and uninformative semantic location information embedded in, for example, arrows, direction words (e.g., “left”, “right”, “up”, or “down”; Hommel, Pratt, Colzato, & Godijn, 2001) or the gaze direction of a conspecific (Langton & Bruce, 1999; Driver et al., 1999; Friesen & Kingstone, 1998). Such a hybrid would be similar to exogenous attention in that it occurs in a mandatory fashion, but while purely exogenous attention responds only to salient low-level physical information (e.g., onset transients), a hybrid type of attentional control would also respond to well-learned, but potentially task-irrelevant, semantic information (e.g., reading words, interpreting arrows or following a person’s gaze).

Exogenous orienting is often studied using Posner’s (1980) spatial cuing paradigm, where it can be induced by abruptly presenting, or changing an existing feature of, an object in an observer’s periphery (i.e., a cue). The allocation of attention is then inferred by measuring reaction times (RTs) to a subsequent target presented at either the same (valid) location as the cue or an alternative (invalid) location. Posner (1980) observed that RTs were faster for targets following valid cues and slower when following invalid cues, compared to a control condition without cuing. These results were interpreted as reflecting the exogenous orienting of attention towards the cued

location, where, following a valid cue, spatial attentional resources were reflexively aligned with the location of the upcoming target. By confirming that the eyes remained centrally fixated during cue presentation, these exogenous shifts in visual attention were shown to be achieved covertly. Research by Jonides (1981), further established features of exogenous orienting by observing that it occurred regardless of a cue's ability to predict the target location (i.e., proportion of valid vs. invalid cues) and even when participants have been explicitly instructed to ignore the cues. Based on these early findings, exogenous control of attention was originally proposed to be automatic and impervious to influence from semantic information (e.g., Briand & Klein, 1987).

The question of semantic influence on exogenous covert attention can be investigated within the spatial cuing paradigm by manipulating the semantic value of the cue object. Distinguishing between influence on the attentional mechanisms of capture and hold can then be determined by examining RTs following valid and invalid cues, respectively. Faster capture by semantically salient cues would be reflected by faster RTs to validly cued targets, indicating faster orienting towards and engagement at the cued (and thus target) location. Conversely, longer hold of attention by semantically salient cues would be reflected by slower RTs to invalidly cued targets, where attentional resources, once engaged at a cued location, take longer to disengage and shift away from the invalid cue to process the target at the alternative location. Stolz (1996) manipulated the semantic relation of a peripherally presented word cue to a context word at fixation, and found that when they were related, RTs were slower to invalidly cued targets, indicating that the semantic relatedness rendered the cue more

interesting, causing attention to be held longer. Fox et al. (2001), by manipulating the emotional valence of words and faces used as cues, found that for high state-anxious participants, threatening (vs. neutral or positive) cues produced slower RTs in the invalid trials. A superior hold effect for negative pictures was similarly found by Okon-Singer et al. (2006), who, using a semantically neutral cue, instead manipulated the emotional valence of a picture presented simultaneously at the location opposite to that of the target (as such, only disengagement and shifts away from validly cued pictures could be measured; equivalent to measuring only invalid trials in Fox et al., 2001, and Stolz, 1996). The present investigation proposed to build on these studies through convergent research that utilises three critical methodological variations within the spatial cuing paradigm. These variations include the measurement of saccadic responses, focus on inhibition of return (IOR) and employment of strict eye-control procedures.

First, all abovementioned studies finding semantic influence on exogenous covert attention measured manual responses to target stimuli. For the present study, saccadic (rapid eye-movement) responses were measured, which rely on neural mechanisms of motor control that are vastly different compared to those involved in manual movement, and which tend to produce crisp RT distributions with mean values that are typically several hundreds of milliseconds faster than those obtained with manual responses.

Second, the phenomenon of IOR has recently been shown to be a useful alternative tool to explore semantic influence on exogenous control of covert attention within a spatial cuing paradigm (Fox et al., 2002; Theeuwes & Van der Stigchel, 2006).

First discovered and investigated by Posner and Cohen (1984; and thereafter by Maylor, 1985; Maylor & Hockey, 1985; Posner, Rafal, Choate, & Vaughan, 1985; Rafal, Calabresi, Brennan, & Sciolto, 1989; see also Klein, 2000, for a review), IOR refers to the finding that, after attention has been exogenously cued and then withdrawn from a location, attention is biased against returning to the region, as indicated by inhibited processing of stimuli at (or near) the previously *attended* location relative to previously *unattended* locations. This follows the initial period of facilitative processing enjoyed while attention still resides at the cued location, before being withdrawn. It is upon this subsequent withdrawal of attention that IOR is thought to develop (or at least become evident). Such a phenomenon is thought to promote efficient foraging behaviour, by biasing attention in a visual search towards processing novel visual objects, and away from returning to locations which have already received recent attentional processing (Klein, 1988; Klein & MacInnes, 1999; Tipper, Weaver, & Watson, 1996).

In the spatial cuing paradigm, IOR can be induced by extending the stimulus onset asynchrony (SOA) between the cue and target onset. Posner (1980), Stolz (1996), and Fox et al. (2001) used relatively short SOAs in their research which consequently tapped into the earlier facilitatory component for validly cued targets. However, with longer SOAs (up to approximately three seconds; Samuel & Kat, 2003), RTs in response to valid targets become slower compared to invalid targets, indicating evidence of IOR.

Fox et al. (2002) used IOR to explore semantic influence on hold processes, finding a reduced IOR effect following angry (vs. neutral and happy) face cues. They argued that this reflected a longer hold of attention by angry face cues based on the

logic that IOR does not begin to develop until attention has disengaged from the cued location, and so a longer attentional dwell time at the cued location will be reflected by a reduced IOR effect (in terms of magnitude) over the same time scale.

When using a single cue in the spatial cuing paradigm, IOR is not a sensitive measure of attentional capture. This is because any differences in capture are unlikely to be detected by the longer SOAs necessary to induce the IOR effect. However, Theeuwes and Van der Stigchel (2006) overcame this concern by utilising a two-cue variation to show superior capture of attention by human faces compared to objects of less social and biological significance. They simultaneously presented two cues (a face and a neutral cue) on opposing sides of fixation, and found a small but significant effect showing slower saccadic responses were made towards locations previously containing a face. This finding was interpreted by Theeuwes and Van der Stigchel as reflecting an IOR effect for the face location, which indicated to the authors that faces, due to their high sociobiological salience, preferentially captured attention in an exogenous manner analogous to that induced by an asymmetric single-cue onset. This logic was based on the tenet that IOR occurs only after attention has been reflexively (and not voluntarily) oriented towards the cued location (Posner & Cohen, 1984). However, the subsequent saccadic responses towards cue locations could be considered to reflect an involuntary allocation of attention, not in response to physical transient differences between either side of fixation (i.e., an asymmetric abrupt onset as seen from a single cue presentation), but in response to semantic differences between the presented objects (as physical transients occurred on both sides of fixation). As such, it could be argued

that the attentional capture generated by faces in the Theeuwes and Van der Stigchel (2006) paradigm might reflect a hybrid model of attentional control, characterised by the reflexive orienting of attention in response to the well-learned semantic category of faces, as opposed to occurring in a truly exogenous fashion. Nevertheless, Theeuwes and Van der Stigchel did find evidence of capture using IOR in a spatial cuing paradigm.

Taken together, IOR has been demonstrated to be an effective measure of hold processes using single-cue presentations, and of capture processes when presenting two cues in competition. These approaches are combined in the present study to utilise IOR as a convergent measure of the impact of semantic information on capture and hold mechanisms involved in the covert orienting of attention. The inclusion of the two-cue (competition) trials provided a subset of trials where the physical transients on either side of fixation effectively cancelled each other out. As a result, in contrast to single-cue trials, there was not a strong physical transient available in two-cue trials to reflexively capture attention.

In addition to using a longer SOA comparable to that of Theeuwes and Van der Stigchel (800–1,000 ms; 2006), and Fox et al. (960 ms; 2002), a shorter SOA of 200 ms was also included in line with evidence that this provides saccadic IOR effects of a greater magnitude (Klein, 2000; Li & Lin, 2002). Note that the transition from facilitation to IOR effects occurs earlier for saccadic versus manual responses, such that the same 200 ms SOA can show a facilitation effect for manual responses, but an IOR effect for saccadic responses (Briand, Larrison, & Sereno, 2000; Khatoon, Briand, & Sereno, 2002). It is proposed that a greater IOR effect might be more sensitive to influence from the

semantic value of cues, in which case larger semantic effects would be expected at the short SOA (compared to the 11 ms effect observed by Theeuwes & Van der Stigchel, 2006).

The third critical methodological variation introduced in the present study was the employment of strict eye-control techniques to avoid potential confounds of overt attention (i.e., eye movements) when measuring covert shifts of attention. A common feature of previous studies exploring the influence of semantic information on exogenous attention (with the notable exception of Theeuwes & Van der Stigchel, 2006) was the lack of precise control for eye movements to ensure saccades were not made to the cues. Instead, an assumption that cues appeared parafoveally and so could only have been processed covertly was made based on instructing participants to maintain fixation while cues were presented peripherally for durations and SOAs (i.e., 100 ms SOAs in Stolz, 1996; 150–300 ms SOAs in Fox et al., 2001) considered too brief to elicit an eye movement before the target appeared. However, such an assumption does not take into account the possible occurrence of microsaccades or anticipatory saccades, the latter which include those already initiated (but not necessarily completed) before the target appearance, in spite of fixation instructions. Microsaccades, first discovered by Dodge (1907), are small saccades that occur involuntarily during an intentional fixation, usually along horizontal and vertical planes (for a review, see Rolfs, 2009). There is evidence that, in the spatial cuing paradigm, they are closely correlated with (but not causally related to; e.g., Horowitz, Fine, Fencsik, Yurgenson, & Wolfe, 2007) covert attentional shifts in response to both informative (Laubrock, Engbert, & Kliegl,

2005; Rolfs, Engbert, & Kliegl, 2004, 2005) and uninformative (Galfano, Betta, & Turatto, 2004; Betta, Galfano, & Turatto, 2007) peripheral cues. Their occurrence, therefore, would present a confound, in that RTs may partially reflect the overt attentional consequences of these microsaccades. This issue become even more prominent when considering the modest eccentricity from fixation with which Stolz (1996) presented cues (2.75°) and targets (1.95°), such that any microsaccades or anticipatory saccades may have caused these objects to be foveated (i.e., fall within the 2° area of foveal vision). Okon-Singer et al. (2007) used longer SOAs, and so had an experimenter watch participants' eye movements from the next room (using a video camera) as a means of verifying fixation maintenance. Such a method of control may be even more subject to overt attentional confounds. The general lack of eye-control in these studies, and potential consequent contamination of covert attentional shifts with oculomotor confounds, may have influenced the findings obtained to the extent that they partially (or even solely, in some cases) reflected semantic influence on overt, rather than covert, attention.

In the present study eye movements were measured to examine and control for potential shifts in overt attention. This eye-tracking technique allows for the examination of purely covert attentional orienting by confirming that eyes remain fixated until the target appears, while covert attention shifts to the peripheral cue. Control for microsaccadic bias was attempted by imposing conservative criteria for fixation maintenance. If concerns regarding overt attentional contamination were

founded then reduced (or even absent) semantic effects would be expected when employing strict eye-movement control.

Experiment 1

To assess semantic influence in the present study, the sociobiological significance of cues were manipulated, like Theeuwes and Van der Stigchel (2006), by comparing photographs of human faces to objects of less sociobiological significance. Other than combining one- and two-cue trials in the same experiment, the present study differs from Fox et al.'s (2002) in that the sociobiological significance (vs. emotional valence) of cues was manipulated, saccadic responses measured, and strict eye-control procedures employed. It differs from that of Theeuwes and Van der Stigchel's (2006) in the use of shorter SOAs intended to reveal larger semantic effects via the measurement of stronger IOR.

Participants were asked to make a simple saccadic localisation response to the target. The location and semantic value of the cues were not predictive of the target location. This was to reduce endogenous incentives to maintain attention at cued locations, which would eliminate IOR by way of attention remaining on, rather than withdrawing from, the cue (Klein & Taylor, 1994; see also Tepin & Dark, 1992; Theeuwes, 1991; Yantis & Jonides, 1990, for evidence that exogenous orienting can be modulated by observer processing intentions).

Both SOAs were expected to produce an IOR effect, reflected by longer RTs in valid versus invalid single-cue trials, but predicted this effect to be larger at the short SOA (Klein, 2000; Li & Lin, 2002). For evidence of semantic influence on exogenous

control of attention, either a reduced IOR effect for face cues compared to neutral cues in the single-cue trials (indicating superior hold; Fox et al., 2002), or slower RTs following valid face (vs. neutral) cues when in competition (indicating superior capture; Theeuwes & Van der Stigchel, 2006) would be expected. Furthermore, it was hypothesised that any semantic effects evident for both single-cue and competition trials would be larger at the short SOA, because of the increased sensitivity afforded by the larger IOR effect. Faster RTs overall were expected in the longer SOA trials due to the increased temporal predictability of the target appearance (Gabay & Henik, 2008).

Method

Participants

Twenty-nine Victoria University of Wellington students participated in the experiment in exchange for course credit. All participants had normal or corrected-to-normal vision. Participation was voluntary, with informed consent given, and all procedures were approved by the School of Psychology Human Ethics Committee. After preliminary data analyses, one participant was excluded due to making excessive errors on trials (see trial rejection criteria below). The remaining 28 participants (16 female, 23 right-handed) had a mean age of 19.21 years. Participants were unaware of the experimental purpose but were debriefed following the experiment.

Stimuli and Apparatus

The experiment was programmed using the SR Research Experiment Builder (version 1.4.128 RC) and conducted on a 3-GHz Pentium D computer. Stimuli were

presented on a 21" monitor at a resolution of $1,024 \times 768$ pixels and with a refresh rate of 60 Hz. Participants were seated facing the monitor screen at eye-level at a viewing distance of 57 cm, maintained by a forehead and chin rest.

Using the EyeLink® 1000 Tower Mount Head Supported System (SR Research Ltd., Ontario, Canada), eye position and movements were tracked with a spatial resolution of 0.01° by measuring the corneal reflection and dark pupil with a video-based infrared camera. The signal was sampled and stored at a rate of 1000 Hz. While viewing was binocular, recording was monocular, measuring left-eye movements only.

A small black fixation dot with a diameter of 0.5° was presented at the centre of the screen. Cue stimuli consisted of four categories of greyscale photographs (faces, appliances, musical instruments and clothing), each consisting of six objects taken from Ro, Russell, and Lavie's (2001) study; the same source as used by Theeuwes and Van der Stigchel (2006). Faces were all female and unfamiliar. The appliance category included a fan, blender, iron, toaster, telephone and oven. The musical instrument category included a violin, harp, harmonica, guitar, accordion and piano. The clothing category included a shoe, blouse, trench coat, t-shirt, trousers and jacket. Each object subtended $2.9^\circ \times 2.9^\circ$ and was presented with the inner edge 9.7° either left or right of fixation. Targets were either an "&" or "%" symbol written in black 36-point Arial font, vertically subtending 1.4° and presented at the centre of the same location as the cue stimuli. All stimuli were presented on a white background. Participants held an EyeLink© button box with both hands, below, out of eyesight, and pressed a button with their right thumb to initiate trials.

Procedure

Participants were tested individually over a 40-minute session. Before starting each trial, a screen displaying “ready?” was presented along with an instruction to press a button to begin the trial. Trials were self-paced, however if no button was pressed, the trial would start after 5,000 ms had elapsed.

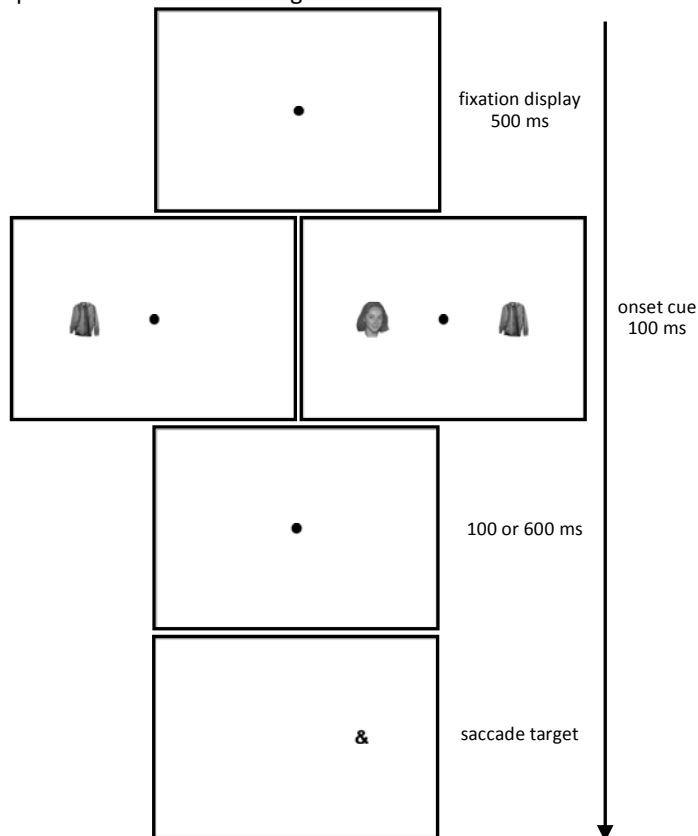
The trial sequence is presented in Figure 1.1. Each trial began with a centrally presented fixation point, requiring a fixation from participants for 500 ms. Following this, one or two cues were presented for 100 ms to either the left, right or both (when two cues appeared) sides of fixation. After a variable cue-target SOA of 200 ms or 700 ms, a saccade target (“%” or “&”) would appear to the left or right. Participants were asked to ignore the peripherally presented cues and to maintain fixation until the target appeared. Upon its appearance, the fixation point disappeared and participants were to make a saccade toward, and fixate on, the target as quickly as possible. The target remained onscreen until it had been fixated for 200 ms or 6,000 ms had elapsed.

If participants broke fixation before the target appeared, a screen displaying the words “TRIAL ABORTED!!” and a reminder to maintain fixation until the presentation of the target was shown. The participant pressed a button to display the fixation point for 2,000 ms, after which they were required to repeat the trial by re-initiating fixation for 500 ms.

The experiment consisted of a practice block of 12 trials during which visual and verbal feedback was given. This was followed by six experimental blocks of 40 trials,

providing a total of 240 analysable trials. Calibration and validation of eye position was performed before practice and each block of experimental trials.

Figure 1.1 Task sequence. Participants fixated the central point for 500 ms, after which either one or two objects were presented to the left, right, or both sides of fixation for 100 ms. Following a variable delay of 100 or 600 ms a target symbol appeared either to the left or right of fixation. Participants executed a speeded saccade to the target.



Design

The dependent variable of interest was saccadic reaction RT, that is, the time taken to initiate the first saccade following target presentation. The experiment used a within-participants factorial design consisting of 12 conditions intermixed within each trial block. These included two SOAs (200 ms and 700 ms) \times three cuing conditions (single-cue valid, single-cue invalid, and two-cue competition) \times two semantic cue values (face and neutral).

The SOA from the onset of the cue to the presentation of the target had an equal probability of being either 200 ms or 700 ms across all three cuing conditions. The semantic value of the cue could either have a high (a face) or a low (i.e., neutral; appliances, musical instruments and clothing) sociobiological significance. Three cuing conditions of single-cue valid, single-cue invalid, and two-cue competition were used. In the first two conditions, only one cue was presented at a time. These single cues could be either valid (96 trials), where the subsequent target was presented in the same location as the cue, or invalid (96 trials), where the target appeared in the alternative location to that of the cue. Because single cues had an equal probability of being either invalid or valid, there was no incentive for participants to attend to the cues. The semantic cue value was sociobiologically salient on 25% (and neutral on the remaining 75%) of single-cue trials. Thus, all four cue categories and all six instances within each category (each repeated twice) were presented with equal probability for both valid and invalid conditions and for both SOA lengths.

The competition cuing condition, consisting of the remaining 48 (20%) trials, involved the presentation of two cues simultaneously, one on either side of fixation. One cue was always a face while the other was always neutral (any of the three non-face categories, with equal probability). Of these two-cue trials, either the face cue would be valid, correctly indicating the upcoming target location (24 trials), or the neutral cue would be valid (24 trials). Note that in this latter case, the face cue paired with the valid neutral cue could effectively be considered as invalid and vice-versa. As

such, the semantic cue value in the competition cuing trials refers to which of the two (face or neutral) cues were valid in indicating the subsequent target location.

All 12 conditions were further counterbalanced with respect to the two target symbols used and the two cue (or the face cue in the two-cue trials) and target locations, both equally likely to appear in either hemifield. The trial order was pseudo-random with the constraint that no more than three face cues (or four of a specific neutral cue category) were presented in a row. Similar constraints were placed in that no more than four of the same cuing conditions, SOAs, or locations of cues or targets, were presented successively. Two trial orders (one reversed) were constructed and counterbalanced across participants.

Data Analysis

Saccade RT was measured as the time taken from the presentation of the target to the initiation of the first saccade. A saccade was defined as a shift in eye position of at least 2.0° in amplitude and of a velocity greater than $30^\circ/\text{s}$ or acceleration greater than $8,000^\circ/\text{s}^2$. A saccade to the target was recorded if it landed within a square interest area ($3.7^\circ \times 3.7^\circ$) centred on the target. Fixation was marked as long as eye position shifted no more than 0.1° per 100 ms. Fixation initiation and maintenance was measured as a constant fixation anywhere within 3.7° of the central fixation point. Consequently, if the participant ended fixation, *anywhere* within this interest area before the target had appeared, the current trial would abort and then restart. Based on the parameters that have been used to identify microsaccades in the past (e.g., shifts less than 2.0° in amplitude, and of velocities greater than $3^\circ/\text{s}$; see Martinez-Conde, Macknik, & Hubel,

2000), the parameters imposed in the present study were considered to control for the occurrence of microsaccades during fixation and their potential to be mistakenly defined as a saccade response. An eye-blink was defined as a full or partial occlusion of the pupil by the eyelid for more than 12 ms, as observed in the eye-camera image.

Trials were rejected for any of the following reasons: a) fixation was not maintained until the appearance of the target (note that the restarted trial following the trial abort screen was also rejected), b) an eye-blink occurred anytime from the presentation of the cue until an appropriate saccade response was made, c) a saccade was initiated within 100 ms of the target presentation onset (i.e., considered an anticipative saccade) or after three standard deviations above mean saccade latency (i.e., considered a late saccade). One participant had more than 30% of their trials rejected based on these rejection criteria and so was excluded from further analyses. Of the remaining 28 participants, a total of 8.13% of trials were not included in subsequent analyses. Mean RTs were calculated for each remaining participant from their acceptable (non-error) trials for each of the 12 conditions. Data were collapsed across trial order, target symbol, and presentation hemifield of the cue and target as they were not of theoretical interest.

For the single cue conditions, a three-way repeated measures analysis of variance (ANOVA) was conducted on mean saccade RTs using within-participants factors of SOA (200 ms vs. 700 ms), cuing condition (valid vs. invalid), and semantic cue value (face vs. neutral). If a significant interaction between SOA and cuing condition was revealed, two-way repeated measures ANOVAs were to be run separately for each SOA,

using cuing condition and semantic cue value as within-participants factors. If an ANOVA revealed a significant interaction, a paired-samples *t* test was planned to compare the size of the IOR effect (i.e., valid - invalid RTs) for face versus neutral single-cue trials. For the competition cuing condition, RTs were submitted to a two-way repeated measures ANOVA, using SOA (200 ms vs. 700 ms) and semantic cue value (face vs. neutral) as within-participants factors. If a significant interaction was revealed, then two paired-samples *t* tests were planned to compare, at each SOA, RTs for the valid face cues with the valid neutral cues in the competition condition.

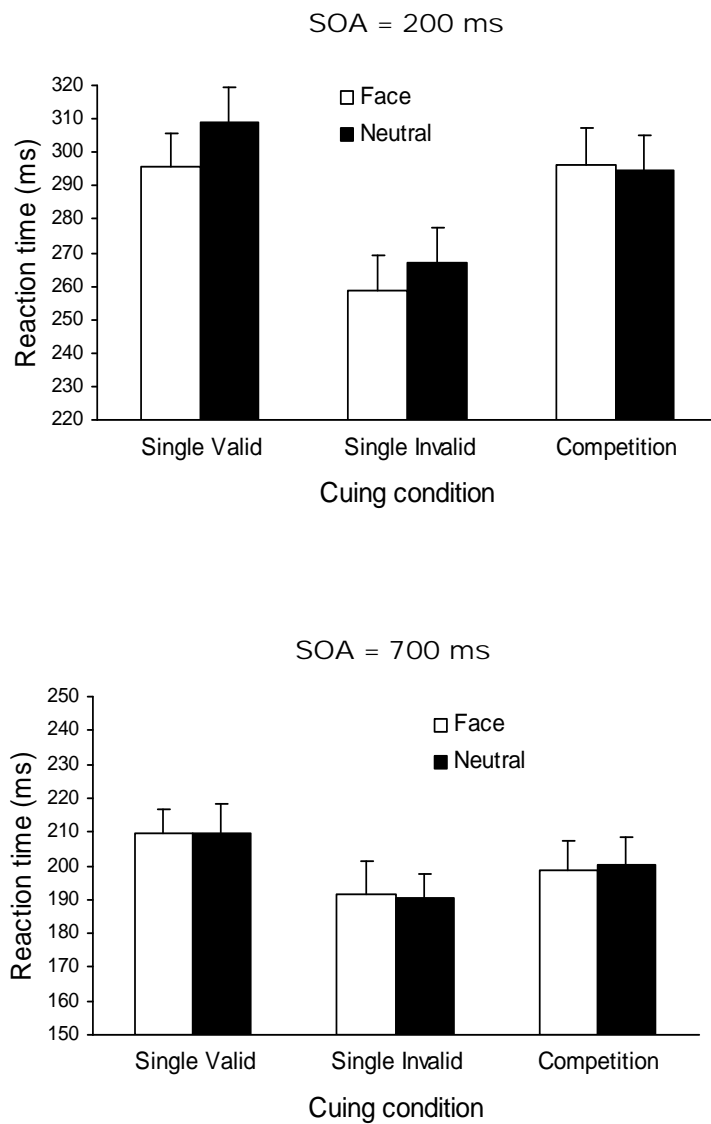
An alpha level of .05 was used for all inferential statistical tests and all *t* tests were two-tailed. The degrees of freedom used were based on assumed sphericity, unless Mauchly's Test of Sphericity was significant (indicating a violation of this assumption), in which case the more conservative Greenhouse-Geisser (if the epsilon was > .75) or Huynh-Feldt (if the epsilon was < .75) corrected values were used. Reported means collapsed across other factors were weighted based on trial proportions for each collapsed condition rather than estimated marginal means due to the unequal number of trials making up each condition.

Results

Figure 1.2 presents the mean RTs and standard errors for saccade responses as a function of semantic cue value and cuing condition, separately for the 200 ms and 700 ms SOA conditions. The RTs appeared faster following invalid versus valid single cues at both SOAs (but more so at 200 ms) suggesting IOR occurred. While the size of IOR did not seem to differ between face and neutral single cues, RTs appeared faster following

face cues at 200 ms SOAs. Reaction times did not look to differ as a function of semantic cue value in the competition cuing condition.

Figure 1.2 Mean saccade reaction times (ms) and standard errors for face and neutral cue trials as a function of cuing condition and stimulus onset asynchrony (SOA; ms) in Experiment 1. Each SOA condition is presented in a separate panel. The cue category in the competition cuing condition represents the valid cue.



Single Cuing Condition

The $2 \times 2 \times 2$ ANOVA revealed a robust significant main effect of SOA, $F(1, 27) = 137.64$, $MSE = 2,738.22$, $p < .001$, $\eta^2 = .84$, indicating RTs were, on average, 82 ms faster in the 700 ms, rather than the 200 ms, SOA condition. An interaction between SOA and cuing condition was also apparent, $F(1, 27) = 17.54$, $MSE = 350.16$, $p < .001$, $\eta^2 = .39$. Accordingly, subsequent 2×2 repeated measures ANOVAs on RTs were conducted for each SOA, reported in separate paragraphs below.

SOA of 200 ms. Analyses for the 200 ms SOA yielded a main effect of semantic cue value, $F(1, 27) = 17.93$, $MSE = 179.46$, $p < .001$, $\eta^2 = .40$, whereby saccades were initiated faster following sociobiologically salient cues ($M = 277$ ms) than neutral cues ($M = 288$ ms). A significant main effect of cuing condition was also found, $F(1, 27) = 41.91$, $MSE = 1,042.23$, $p < .001$, $\eta^2 = .61$, in which RTs to single invalid cues (263 ms) were significantly faster than to single valid cues (302 ms) indicating an IOR effect. No interaction was observed between semantic cue value and cuing condition ($F < 0.6$).

SOA of 700 ms. Analyses for the 700 ms SOA condition showed a significant main effect of cuing condition on saccadic RTs, $F(1, 27) = 24.03$, $MSE = 401.07$, $p < .001$, $\eta^2 = .47$. Saccades were slower toward targets following a single valid cue (210 ms) versus a single invalid cue (191 ms) indicating an IOR effect. There was no significant main effect of semantic cue value, nor an interaction between semantic cue value and cuing condition (remaining F values < 0.1).

Competition Cuing Condition

The two-way ANOVA for RTs in the competition cuing condition revealed a significant main effect of SOA, $F(1, 27) = 144.69$, $MSE = 1,781.26$, $p < .001$, $\eta^2 = .84$, where RTs were, on average, 96 ms faster in the 700 ms (vs. 200 ms) SOA condition. No significant main effect of semantic cue value, nor an interaction between semantic cue value and SOA was evident (remaining F values < 0.3).

Discussion

Results showed an IOR effect for the single-cue trials, which was larger for the 200 ms SOA (39 ms) than at 700 ms (19 ms). The semantic value of the cue influenced RTs, in that responses to targets following single face cues (vs. neutral objects) were faster, but only at the shorter SOA. Interestingly, this face advantage did not interact with the obtained IOR effect, indicating that it was not due to superior attentional hold (i.e., there was no interaction between semantic cue value and the single cuing conditions). Neither was superior capture evident for face stimuli, as RTs in competition cuing condition did not significantly differ as a function of semantic value of the valid cue. In line with predictions, RTs were faster overall when there was a longer delay between cue and target onset.

The IOR effect obtained for the single-cue trials at the 200 ms SOA was more than twice that observed at the 700 SOA. While this might reflect a larger IOR magnitude at the shorter SOA, it also could have been an unintentional methodological consequence of having the cue and target locations spatially overlap. When presented in the same spatial location on the display, the preceding cue in the 200 ms SOA condition may have masked the perception of the target stimulus (compared to a target

presented in an uncued location) resulting in slower RTs. This might have increased, or even caused, the observed IOR effect by inflating valid compared to invalid RTs.

Experiment 2 addressed this concern by removing the cue-target spatial overlap.

Experiment 2

Experiment 2 was a replication of Experiment 1, only with the cue-target spatial overlap removed by presenting the targets at a lesser eccentricity than the cues. It was designed to confirm that the results obtained in the previous experiment reflected true oculomotor IOR and were not instead due to (or artificially inflated by) forward-masking from the preceding cue on the target in valid trials. A secondary purpose of Experiment 2 was to attempt to replicate the findings from Experiment 1 with a new set of participants. If forward-masking effects were a significant factor in Experiment 1, then a reduced (or even absent) IOR effect at the 200 ms SOA should be observed in Experiment 2.

Method

Participants

Thirty-one Victoria University of Wellington students were selected as before to take part in the current experiment. None had taken part in Experiment 1. After preliminary data analyses, one participant was excluded due to excessive trial errors (> 30% of trials). The remaining 30 participants (23 female, 26 right-handed) had a mean age of 21.60 years.

Stimuli and Apparatus

The same setup was used as in Experiment 1, except that target symbols were not presented within the same spatial screen coordinates as the cue stimuli. Instead targets were presented with their innermost point at an eccentricity of 7.9° to either the left or right of fixation, that is, they were more central than the cue locations. As such, there was no spatial overlap between cues and targets (a gap of 0.3° or 0.8° was present on valid cue conditions, depending on the target symbol used).

Procedure and Design

The procedure and design was identical to that of Experiment 1.

Data Analysis

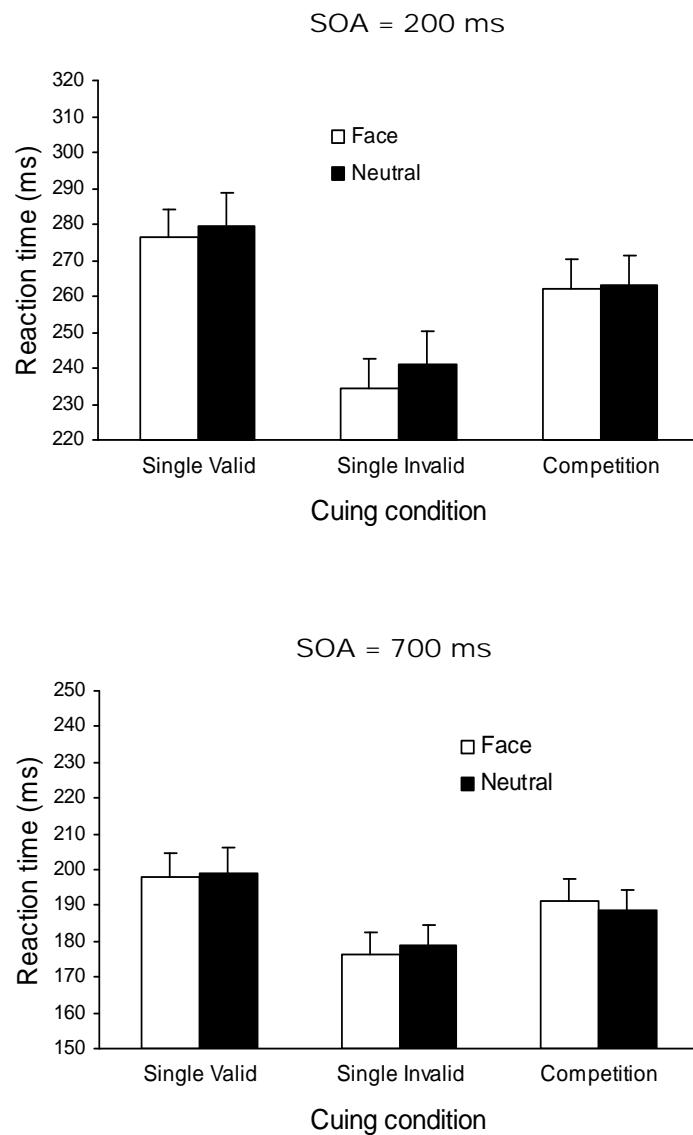
Data analyses were the same as for Experiment 1, except that the ($3.7^\circ \times 3.7^\circ$) interest area used to record a saccade to the target was now closer to fixation, in line with the lesser target eccentricity. Following preliminary error examination, 9.39% of trials were not included from the 30 participants whose data were subsequently analysed.

Results

Mean RTs and standard errors are presented in Figure 1.3 as a function of semantic cue value and cuing condition for each SOA. Overall, RTs appeared to be shorter than in Experiment 1. As for the previous experiment, the RTs for invalidly single-cued trials appeared faster than those for the validly single-cued trials, especially at the 200 ms SOA. Again the size of this IOR did not look to differ depending on the

semantic cue value. The RTs did not seem to differ following valid face versus neutral cues in competition.

Figure 1.3 Mean saccade reaction times (ms) and standard errors for face and neutral cue trials as a function of cuing condition and stimulus onset asynchrony (SOA; ms) in Experiment 2. Each SOA condition is presented in a separate panel. The cue category in the competition cuing condition represents the valid cue.



Single Cuing Condition

The three-way ANOVA showed a main effect of SOA, $F(1, 29) = 219.64$, $MSE = 1,336.01$, $p < .001$, $\eta^2 = .88$, where responses were, on average, 70 ms faster in the 700

ms (vs. 200 ms) SOA condition. An SOA and cuing condition interaction was revealed, $F(1, 29) = 24.95$, $MSE = 223.38$, $p < .001$, $\eta^2 = .46$, prompting further ANOVAs to be carried out, again reported in separate paragraphs below for each SOA.

SOA of 200 ms. A significant main effect of cuing was revealed, $F(1, 29) = 87.64$, $MSE = 549.12$, $p < .001$, $\eta^2 = .75$, showing an IOR effect characterized by faster RTs on invalid ($M = 238$ ms) versus valid ($M = 278$ ms) single-cue trials. There was no main effect of semantic cue value, or an interaction between cuing condition and semantic value (remaining F values < 3.7).

SOA of 700 ms. Analyses showed a main effect of cuing condition for the 700 ms condition, $F(1, 29) = 51.56$, $MSE = 251.08$, $p < .001$, $\eta^2 = .64$. As for the 200 ms SOA condition, invalid single-cue RTs ($M = 178$ ms) were faster than valid single-cue RTs ($M = 198$ ms) indicating an IOR effect. A main effect of semantic value and an interaction between semantic value and cuing condition both did not approach significance (remaining F values < 0.5).

Competition Cuing Condition

Analyses revealed a significant main effect of SOA, $F(1, 29) = 277.74$, $MSE = 566.98$, $p < .001$, $\eta^2 = .91$, where RTs were, on average, 72 ms faster in the 700 ms (vs. 200 ms) SOA condition. No significant main effect of semantic cue value, nor an interaction between semantic cue value and SOA was evident (remaining F values < 0.6).

Discussion

Inhibition of return effects were observed for Experiment 2, which were once more larger in the 200 ms SOA condition. Therefore, it appeared the IOR effects

obtained in Experiment 1 did not reflect forward-masking on valid trials. While no difference was again observed between RTs for valid faces versus neutral trials in competition, there was a reduction in the general semantic effects evident in Experiment 1. In addition, the data suggested an overall drop in RTs from Experiment 1. This was confirmed by running two post-hoc independent-samples *t*-tests comparing RTs between Experiments 1 and 2 for each SOA. In Experiment 2, RTs were 27 ms faster for the 200 ms SOA, $t(56) = 2.28$, $SE = 12.01$, $p < .05$, but not significantly different at 700 ms SOAs ($t < 1.3$). This RT benefit may have been due to the increased perception of targets resulting from their presentation at locations distinct from cue locations (i.e., no longer overlapping). However, because this benefit was observed regardless of cuing condition, it was more likely a reflection of reduced target eccentricity (i.e., targets were presented more centrally).

Overall, results suggest that the IOR effect observed in Experiment 1 was not due to forward-masking from valid cues on targets, although masking may have contributed to the independent semantic effect observed at 200 ms SOAs. Across both experiments, faces showed no indication of capturing or holding attention differently from neutral cues, contrary to expectations. This is not to say, however, that semantic effects on attentional processes do not occur, just that they were not observed using the current methodology. For example, although the null RT effect observed in Experiments 1 and 2 between valid face and neutral cues in competition might have been because both cues were equally likely to capture attention (thereby generating equivalent IOR effects), it could also have resulted from attention not being captured by either cue, and thus not

producing an IOR effect at all. What would happen then if attentional orienting to cues was facilitated? Or when using relaxed eye-control criteria more comparable to previous research? Would a semantic influence on covert attention now be observed? Such questions prompted the design of Experiment 3.

Experiment 3

Experiment 3 aimed to assess whether semantic influence from cues on attentional orienting processes might be observed in the current paradigm when attention was more likely to orient towards the cues or when using more liberal eye-control criteria (as in Fox et al., 2001; Stolz, 1996). To facilitate exogenous orienting to cues, the immediate feedback on fixation maintenance was removed (i.e., the trial no longer aborted when fixation was broken prior to the target appearance). With no ongoing feedback informing participants of their failures to maintain central fixation, the intensity of fixation should reduce in a manner similar to that observed in the gap effect (where the fixation point is removed; e.g., Saslow, 1967). This reduced engagement at central fixation will allow for easier disengagement of attention, causing covert attentional resources to be more susceptible to capture by cues in competition, allowing more opportunity for IOR to develop and for any semantic influence to be observed. The single-cue IOR was expected to remain unchanged, because the SOAs employed should not be sensitive to differences in attentional capture by a single asymmetric cue resulting from feedback removal.

Having the trial no longer abort when overt attention was prematurely shifted enabled the impact of allowing anticipatory saccades and microsaccades on analyses to

be measured. The more tightly controlled “pure” measures (data analysed as before) were compared with “contaminated” measures (data re-analysed after including trials excluded from the pure analyses) to more directly determine the impact that less-stringent eye-control, one which allows for potential oculomotor contamination, might have on observed semantic effects. Allowing the potential contamination of overt with covert attentional shifts was not expected to reduce IOR, as the coordinates of inhibition for IOR are mapped onto environmental locations rather than coded retinotopically (Posner & Cohen, 1984).

Method

Participants

Thirty-four new Victoria University of Wellington students participated, selected as in previous experiments. The participants (29 female, 31 right-handed) had a mean age of 21.68 years.

Stimuli and Apparatus

The stimuli and apparatus were identical to that used for Experiment 2 (i.e., there was again no spatial overlap between cue and target stimuli presentation).

Procedure

The procedure was similar to both Experiment 1 and 2, with one exception. While participants were still required to initiate each trial with a central fixation, which they were instructed to maintain until the target appeared, there was no immediate feedback given during the trial as to how successfully participants were maintaining this

fixation. That is, if participants broke fixation early, the screen displaying “TRIAL ABORTED!!” would *not* appear and the trial would *not* restart (unlike previous experiments). Instead, the target would be presented and the trial continued to its conclusion.

Design

The design was the same as for the previous experiments.

Data Analysis

Pure measures. The same trial rejection criteria as in previous experiments were used. Note that trials where participants did not correctly maintain fixation were still not included in subsequent analyses (although see contaminated measures below), despite these trials no longer aborting and restarting. However, the trial immediately following this incorrectly fixated trial was included. Data from 9.01% of trials were excluded from subsequent analyses.

Contaminated measures. In addition to the above analyses, results were re-examined according to more relaxed criteria for eye-control by including trials that were excluded from the tightly controlled pure measures. These contaminated measures included those trials where fixation was not maintained during the cue-target SOA (causing the trial to abort in previous experiments) or RTs were faster than 100 ms (anticipatory responses). A value of 0 ms was assigned to trials when, at target onset, eye position was outside of the fixation area. Trials with eye-blinks and RTs over three standard deviations above the mean latency were still excluded from these analyses. Using these criteria, data from 2.05% of trials were excluded from subsequent analyses.

To assess whether relaxing criteria for eye-control produced a measurable effect of overt contamination, mean deviance (in pixels) of eye position from fixation at time of target onset was compared between pure and contaminated, by running two paired-samples *t* tests, one for each SOA. All other analyses were the same as for the pure measures.

Results

Figure 1.4 shows the pure mean RTs and standard errors for each SOA in Experiment 3 as a function of semantic cue value and cuing condition. An IOR effect was apparent at both SOAs for the single cuing conditions, although more pronounced at the 200 ms SOA. Valid single face cues appeared to produce faster reaction times than valid single neutral cues, suggesting that the IOR may be smaller for single face (vs. neutral) cues. Participant RTs did not seem to differ as a function of semantic cue value for the competition cuing condition.

Single Cuing Condition

A main effect of SOA was significant in the initial three-way ANOVA, $F(1, 33) = 378.91$, $MSE = 722.03$, $p < .001$, $\eta^2 = .92$, showing that RTs were 63 ms faster in the longer SOA condition. An interaction between SOA and cuing condition was also significant, $F(1, 33) = 30.00$, $MSE = 249.76$, $p < .001$, $\eta^2 = .48$. As such, the subsequent ANOVAs conducted are reported separately below.

SOA of 200 ms. Analyses yielded a main effect of semantic cue value, $F(1, 33) = 4.17$, $MSE = 167.46$, $p < .05$, $\eta^2 = .11$, showing saccades were initiated faster following sociobiologically salient cues ($M = 254$ ms) than neutral cues ($M = 259$ ms). A main effect

of cuing condition was also observed, $F(1, 33) = 145.85$, $MSE = 439.64$, $p < .001$, $\eta^2 = .82$, revealed to be driven by a typical IOR effect of faster RTs in the invalid single-cue condition (235 ms) compared to the valid single-cue condition (278 ms). An interaction between semantic cue value and cuing condition was not significant ($F < 1.1$).

SOA of 700 ms. Analyses showed a significant main effect of cuing, $F(1, 33) = 85.58$, $MSE = 199.94$, $p < .001$, $\eta^2 = .72$. On average, RTs in invalid single-cue trials (182 ms) were faster than valid single-cue trials (204 ms) indicating an IOR effect. There was no main effect of semantic cue value, nor any interaction between semantic value and cuing condition (remaining F values < 0.8).

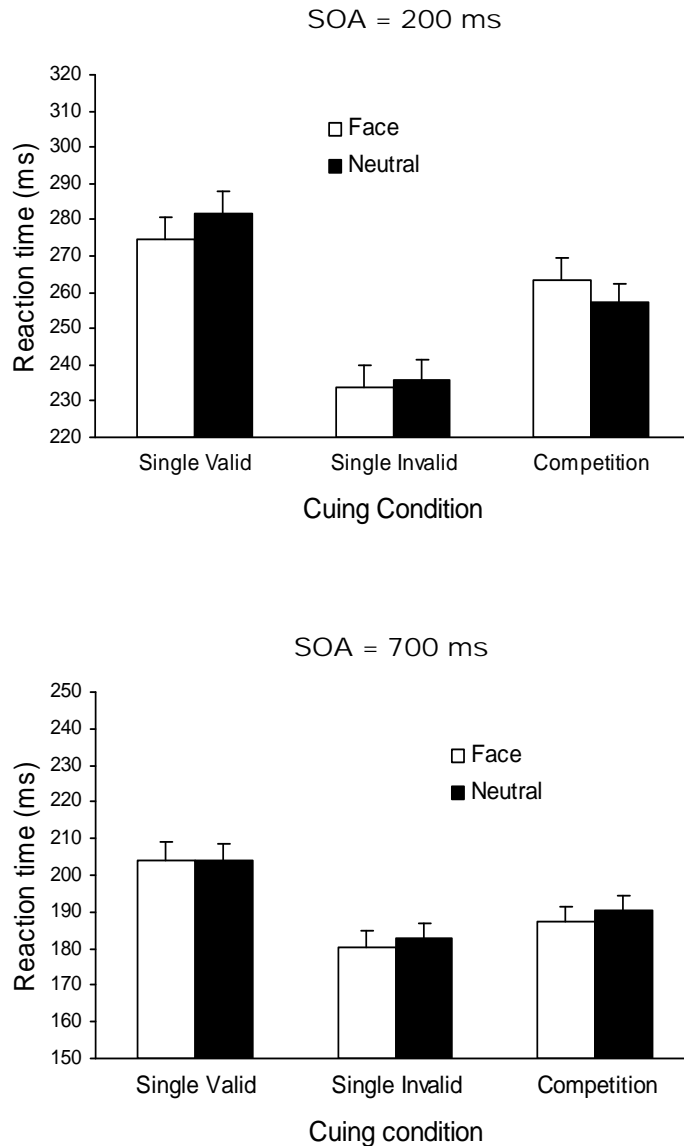
Competition Cuing Condition

Analyses showed a significant main effect of SOA, $F(1, 33) = 386.18$, $MSE = 447.94$, $p < .001$, $\eta^2 = .92$, whereby RTs were 71 ms faster at SOAs of 200 ms versus 700 ms. An interaction was also revealed between semantic cue value and SOA, $F(1, 33) = 5.57$, $MSE = 112.45$, $p < .05$, $\eta^2 = .14$. Planned contrasts revealed no significant differences between RTs for valid face versus neutral cues in competition at either SOA (t values < 1.8). No main effect of semantic cue value was apparent ($F < 0.5$).

Contaminated Analyses

Significantly more fixation deviance at target onset was observed for the contaminated (vs. pure) measures at both 200 ms (.67 pixels), $t(33) = -3.02$, $SE = 0.22$, $p < .01$, and 700 ms SOAs (.55 pixels), $t(33) = -3.17$, $SE = 0.17$, $p < .01$. This shows evidence of overt contamination when using less stringent criteria for eye-control. In all other respects, however, findings did not differ between pure and contaminated analyses.

Figure 1.4 Mean pure saccade reaction times (ms) and standard errors for face and neutral cue trials as a function of cuing condition and stimulus onset asynchrony (SOA; ms) in Experiment 3. Each SOA condition is presented in a separate panel. The cue category in the competition cuing condition represents the valid cue.



Discussion

A robust IOR effect was found for single cues, which like previous experiments, was approximately twice as large at SOAs of 200 ms (43 ms) versus 700 ms (22 ms). An interaction was not found between single cuing conditions and semantic cue value for either SOA, again indicating no evidence of superior attentional hold. However, a return

of the main effect of semantic cue value independent of IOR at 200 ms SOAs (as initially observed in Experiment 1) was evident, albeit smaller at 5 ms. While an interaction was apparent between semantic cue value and SOA for the competition cuing condition, there was no difference between valid face- and neutral-cue RTs at either SOA, indicating no evidence of superior attentional capture. This latter finding provides evidence supporting the interpretation that faces and neutral cues in competition produced IOR effects of an equivalent magnitude, suggesting that faces, despite their sociobiological significance, were not superior in their ability to capture covert attention.

Contaminated RT analyses did not reveal any different findings to those observed in the pure analyses. Finding that using less stringent eye-control had little impact on results, indicates a lack of evidence to support initial suggestions that previous research findings (Fox et al., 2001; Okon-Singer et al., 2007; Stolz, 1996) might reflect semantic influence on overt rather than covert attention.

It is interesting that, unlike previous research (Fox et al., 2001; Fox et al., 2002; Stolz, 1996), a semantic influence on hold processes of spatial attention was not found. It could be that the inclusion of competition trials (vs. only single-cue trials) in the current paradigm led participants to employ different target detection strategies which rendered attention less susceptible to semantic influences. Experiment 4 addressed this possibility by only presenting single cues.

Experiment 4

In the previous three experiments, participants could expect on any given trial to be presented with either an irrelevant single cue (on one side of fixation) or two cues (one on either side of fixation). This may have caused participants to develop different strategies for detecting targets than if only single cues were presented. Such strategies may have depended more on utilising low-level physical transient information to distinguish between cue and target onsets. Because targets were characterised by an asymmetric onset, whether cues were also characterised by asymmetric (i.e., single cues) or symmetric (i.e., two cues) physical transients may have been a more important factor than semantic value in dismissing irrelevant cues. As such, a primary strategy based on using the symmetry of the physical transient onsets may have preceded or replaced any processing of semantic information. However, if only single cues were presented, the symmetry of physical transients would no longer provide important information as to whether a cue or a target was being presented. Greater efficiency might then be obtained from more extensive processing of the cue's semantic value in order to effectively distinguish its asymmetric onset from the target. To this end, a semantic influence characterised by a reduced IOR effect for faces compared to neutral cues would be expected. It might also be that under such circumstances, contaminated analyses could produce inflated semantic effects, in line with initial suggestions.

Method

Participants

Thirty-nine new participants from Victoria University of Wellington were selected as before. Data from three participants were excluded following preliminary

data analyses due to excessive trial errors (> 30%). The remaining 36 participants (28 female, 33 right-handed) had a mean age of 19.25 years.

Stimuli and Apparatus

The same stimuli and apparatus as in Experiments 2 and 3 were used in the current experiment.

Procedure

The procedure differed from previous experiments in that only a single cue (either valid or invalid) was presented on each trial. Because no competition trials were included in the current experiment, participants completed only 10 practice trials and 192 analysable trials, separated into four blocks of 40, and a final block of 32, trials.

Design

Except for having only two cuing conditions (single-cue valid and single-cue invalid), resulting in eight (rather than 12) conditions, the experimental design was the same as for the previous experiment.

Data Analysis

Contaminated analyses were again conducted as before.

Pure measures. From the data of the 36 participants submitted to further analyses, a total of 12.20% error trials were excluded.

Contaminated measures. None of the 39 participants had more than 30% error trials when using the less conservative contaminated trial rejection criteria. A total of 1.54% of trials were excluded from the subsequent contaminated analyses. The

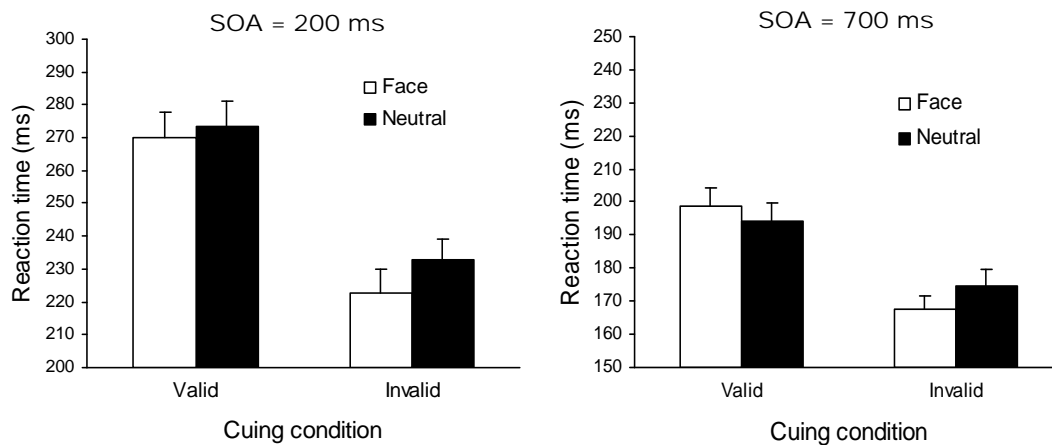
participants involved in these analyses (30 female, 36 right-handed) had a mean age of 20.23 years.

The analyses were conducted similar to previous experiments, however, because there were no competition cuing conditions in the current experiment, they were only conducted on RTs from single cuing conditions.

Results

Mean RTs and standard errors used in the pure analyses are presented in Figure 1.5. An IOR effect was apparent (again appearing more pronounced at 200 ms) from faster RTs following invalid versus valid cues. The IOR appeared larger for face versus neutral cues at the 700 ms SOA. For the 200 ms SOA, RTs seemed faster following face cues.

Figure 1.5 Mean pure saccade reaction times (ms) and standard errors for face and neutral cue trials as a function of cuing condition and stimulus onset asynchrony (SOA; ms) in Experiment 4. Each SOA condition is presented in a separate panel.



Single Cuing Condition

The three-way ANOVA again indicated a main effect of SOA, $F(1, 35) = 237.32$, $MSE = 1,322.22$, $p < .001$, $\eta^2 = .87$, where participants responded 58 ms faster following

the long (vs. short) cue-target SOA. Additional two-way ANOVAs were conducted for each SOA (reported separately below) as a consequence of finding an interaction between SOA and cuing condition, $F(1, 35) = 23.59$, $MSE = 255.57$, $p < .001$, $\eta^2 = .40$.

SOA of 200 ms. Analyses revealed a main effect of semantic cue value, $F(1, 35) = 8.56$, $MSE = 200.15$, $p < .01$, $\eta^2 = .20$. Participants' responses to targets following single face cues (246 ms) were faster than those to single neutral cues (253 ms). An IOR effect was observed, indicated by a main effect of cuing condition, $F(1, 35) = 80.12$, $MSE = 865.08$, $p < .001$, $\eta^2 = .70$, where invalid single-cue RTs (228 ms) were faster than valid single-cue RTs (272 ms). However, there was no interaction between the semantic cue value and cuing condition on RTs ($F < 2.0$).

SOA of 700 ms. Unlike the shorter SOA, no main effect of semantic cue value was apparent at the 700 ms SOA condition ($F < 0.6$). There was however a main effect of cuing condition, $F(1, 35) = 80.89$, $MSE = 291.17$, $p < .001$, $\eta^2 = .70$, indicating an IOR effect, whereby single cues which were invalid (171 ms) produced faster RTs than those which were valid (197 ms). An interaction between semantic value and cuing condition was also apparent, $F(1, 35) = 11.43$, $MSE = 101.89$, $p < .01$, $\eta^2 = .25$. A planned t test showed that the IOR effect for faces was greater (31 ms) than that for neutral cues (20 ms), $t(35) = 3.38$, $SE = 3.36$, $p < .01$.

Contaminated Analyses

A main effect of SOA and an interaction between SOA and cuing effect was found for the initial three-way ANOVA on contaminated RTs. Similar to the pure analyses, IOR effects (i.e., main effects of cuing condition) were observed for both SOAs.

However, contaminated analyses findings differed from those in the pure analyses with respect to finding no main effect of semantics for the 200 ms condition ($F < 0.2$).

Discussion

An IOR effect was again observed, approximately twice as large at the shorter SOA. Even when processing of the semantic value of the cue was more likely (and under more similar circumstances to previous research), an effect of semantic information on attentional hold processes was still not found, as would be characterised by a reduced IOR in face compared to neutral cue conditions. The main effect of semantic cue value independent of IOR at 200 ms SOAs was again evident, as too was a semantic effect in the 700 ms SOA, characterised by a *greater* IOR effect for faces than neutral objects (opposite to predictions). Contaminated analyses showed that when oculomotor confounds were introduced, influence of semantic information observed on purely covert attention was reduced at SOAs of 200 ms.

The recurrent finding of a main effect of semantic cue value that is only apparent in the 200 ms SOA condition and which is independent of the single-cuing condition, is intriguing; a finding which was deemed to merit further investigation. Experiment 5 examined whether this effect, both in terms of its independence from cue validity and occurrence only at shorter SOAs, represents a robust phenomenon or a mere artefact of intermixing different SOA lengths within trial blocks.

Experiment 5

Fox et al. (2001), Fox et al. (2002) and Stolz (1996) employed an unchanging cue-target SOA within each experiment, in contrast to the variable SOA (of either 200 ms or 700 ms) used in the current methodology. Could this simple methodological difference account for the divergent results from previous research finding semantic influences on the hold of attention?

Intermixing SOA conditions within trial blocks makes the timing of the target appearance following the cue uncertain. This might have produced the main effect of semantic influence observed only at the 200 ms SOA and independent of cuing. Under such conditions, participants might be taking advantage of the 700 ms SOA condition being more temporally predictive of target onset (i.e., after 200 ms had elapsed from cue onset, the target could then only be presented at 700 ms; see Gabay & Henik, 2008). Consequently, attentional resources might be prioritising the processing of temporal rather than spatial information, such that any semantic influence on attention would more likely be moderated by manipulations of temporal expectancy of the target rather than its spatial relationship with a preceding cue.

Experiment 5 sought to investigate whether the recurrent main semantic effect reflects a robust new phenomenon or whether, once temporal uncertainty is removed, making each SOA condition equally predictive of the timing of target onset, a comparable semantic influence would now be found, that is, one evident across both SOAs and that interacts with cuing condition. The two SOA conditions were separated out so that a participant could always expect a target to appear at a fixed SOA on a

particular block of trials. The IOR magnitude was expected to remain unchanged from the previous experiments (Gabay & Henik, 2008).

Method

Participants

Thirty-seven new Victoria University of Wellington students participated in the current experiment. Following preliminary analyses, seven participants were excluded due to making excessive errors (> 30% trials). The remaining 30 participants (24 female, 26 right-handed) had a mean age of 20.97 years.

Stimuli and Apparatus

The same stimuli and apparatus were used as for Experiments 2 to 4.

Procedure

The only difference from the previous experimental procedure was that the 192 experimental trials were now separated into four blocks of 48 trials.

Design

The primary methodological difference from previous experiments was that for the current experiment, the two SOA conditions were no longer intermixed within the same trial block. Instead, the different SOAs were separated into blocks so that the first two blocks of the experiment would be at one SOA and the second two blocks at the alternative SOA. The order of these two SOAs (and the two trial blocks within each SOA) was then counterbalanced across participants. The design was the same as the previous experiment in all other respects.

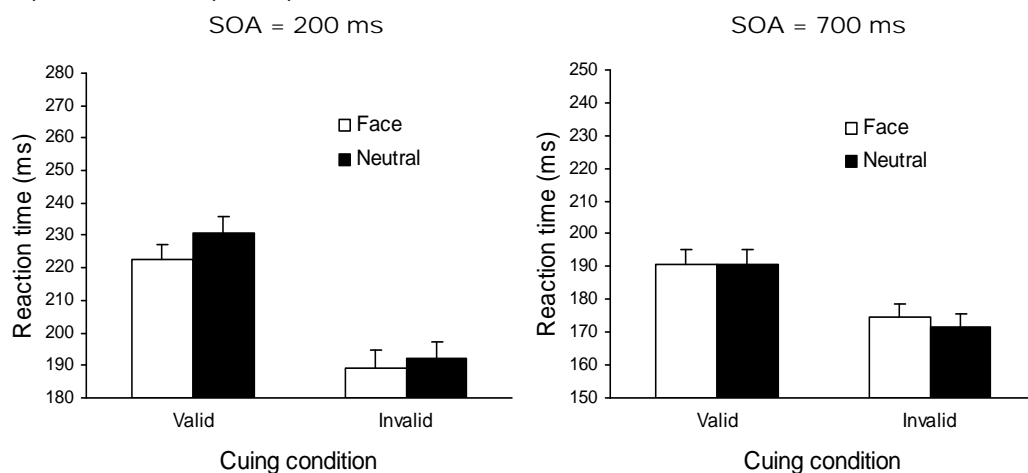
Data Analysis

Pure measures. From the 30 participants included in further analyses, a total of 12.55% of trials were excluded.

Contaminated measures. No participants were excluded based on excessive error trials, but 1.38% of trials were excluded from subsequent contaminated analyses. The 37 participants included in these analyses (29 female, 31 right-handed) had a mean age of 20.68 years.

Data analyses were conducted in the same manner as in the previous experiment.

Figure 1.6 Mean pure saccade reaction times (ms) and standard errors for face and neutral cue trials as a function of cuing condition and stimulus onset asynchrony (SOA; ms) in Experiment 5. Each SOA condition is presented in a separate panel.



Results

Figure 1.6 shows the pure mean RTs and standard errors for each SOA as a function of semantic cue value and cuing condition. An IOR effect was again suggested, looking more prominent at 200 ms SOAs. While the size of the IOR did not seem to differ

as a function of semantic cue value for either SOA, faster RTs following face cues were yet again apparent in the 200 ms SOA condition.

Single Cuing Condition

A main effect of SOA was significant in the three-way ANOVA, $F(1, 29) = 46.31$, $MSE = 929.51$, $p < .001$, $\eta^2 = .61$, whereby the 700 ms (relative to the 200 ms) SOA condition experienced a 20 ms RT benefit. A significant SOA \times cuing condition interaction, $F(1, 29) = 22.69$, $MSE = 229.65$, $p < .001$, $\eta^2 = .44$, prompted two two-way ANOVAs to be conducted for each SOA.

SOA of 200 ms. A significant main effect of semantic cue value was found, $F(1, 29) = 6.04$, $MSE = 153.00$, $p < .05$, $\eta^2 = .17$, where RTs to single face cues were faster (206 ms) than to single neutral cues (212 ms). A significant main effect of cuing was also found, $F(1, 29) = 102.68$, $MSE = 381.51$, $p < .001$, $\eta^2 = .78$, showing an IOR effect from RTs to invalid single cues (191 ms) being faster than to valid single cues (227 ms). No significant interaction between semantic cue value and cuing condition was observed ($F < 2.1$).

SOA of 700 ms. There was no evidence of a main effect of semantic cue value in the 700 ms SOA trials ($F < 0.8$). An IOR effect was observed, reflected by a significant main effect of cuing, $F(1, 29) = 31.78$, $MSE = 288.98$, $p < .001$, $\eta^2 = .52$, where RTs following invalid cues (173 ms) were faster than those following valid cues (191 ms). There was no interaction between semantic cue value and cuing condition ($F < 0.6$).

Contaminated Analyses

The only difference in findings between analyses on contaminated (vs. pure) RTs was the lack of a main effect of semantic cue value in the 200 ms SOA condition ($F < 1.4$).

Discussion

Comparable IOR effects to the previous experiments were observed, but more importantly the same semantic effect at 200 ms SOA trials was found as in Experiments 1, 3 and 4. Furthermore, this effect was again independent of cuing and absent at the 700 ms SOA. These results thus indicate a robust semantic influence on RT performance, still observed after numerous methodological variations. The observed semantic effect was again absent in the contaminated analyses.

Further evidence of this robust influence was observed by running, for each SOA, separate split-plot ANOVAs on RTs across all five experiments, using within-participants factors of cuing condition (single-cue valid vs. invalid) and semantic cue value (face vs. neutral), and Experiment as a between-subjects factor. For the 200 ms SOA condition, a main effect of cuing condition was evident, indicating IOR, $F(1, 153) = 395.42$, $MSE = 653.04$, $p < .001$, $\eta^2 = .72$, as too was a main effect of semantic value, $F(1, 153) = 36.95$, $MSE = 181.10$, $p < .001$, $\eta^2 = .19$, showing faster RTs following face cues (248 ms) versus neutral cues (254 ms). Moreover, this semantic effect did not interact with the cuing condition ($F < 0.3$). For the 700 ms SOA condition, only a main effect of cuing condition was evident, $F(1, 153) = 243.49$, $MSE = 282.87$, $p < .001$, $\eta^2 = .61$. Neither main effect of semantic value, nor an interaction between semantic value and cuing condition approached significance at this longer SOA (remaining F values < 1.8). No significant

interactions were observed between within-participants factors and the between-participants factor of Experiment for either ANOVA (F values < 2.2).

Table 1.1 Mean pure saccade reaction times (ms) and standard errors for face and neutral cue trials as a function of cuing condition and stimulus asynchrony (SOA) in Experiments 1 to 5

Semantic Cue Value	SOA = 200 ms						SOA = 700 ms					
	Valid		Invalid		Competition		Valid		Invalid		Competition	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
<i>Experiment 1</i>												
Face	296	9.96	258	9.28	296	9.67	210	6.55	192	8.59	199	7.06
Neutral	309	9.60	267	9.09	295	9.71	210	7.09	191	6.25	200	7.81
<i>Experiment 2</i>												
Face	276	8.17	235	7.79	262	8.40	198	6.65	176	5.95	191	6.26
Neutral	280	8.86	241	8.91	263	8.56	199	7.17	179	5.79	189	5.66
<i>Experiment 3</i>												
Face	275	5.99	234	6.45	263	6.13	204	4.96	180	4.36	188	3.71
Neutral	282	6.22	236	5.70	257	5.07	204	4.75	183	4.15	190	3.89
<i>Experiment 4</i>												
Face	270	8.07	223	6.92	-	-	199	5.42	168	3.97	-	-
Neutral	274	7.62	233	6.37	-	-	194	5.53	175	5.09	-	-
<i>Experiment 5</i>												
Face	223	4.28	189	5.37	-	-	191	4.63	175	4.09	-	-
Neutral	231	4.98	192	5.02	-	-	191	4.48	172	4.01	-	-

Note: The cue category in the competition cuing condition represents the valid cue.

General Discussion

The results of Experiments 1 to 5 can be summarised as follows (a summary of pure mean RTs and standard errors for each semantic cue value as a function of cuing condition and SOA across all five experiments is presented in Table 1.1). Experiment 1 asked participants to maintain fixation while one or two uninformative peripheral cues were presented and then make a saccade response to a subsequent target appearing at one of the two cue locations. Large IOR was observed for single-cue trials, characterised by slower RTs in the valid versus invalid conditions. Participants were faster to respond to targets following face (vs. neutral) cues at 200 ms SOAs, where IOR was especially prominent. Interestingly, this semantic effect did not interact with the IOR generated

from either single-cues or cues in competition. These results were taken to indicate that the semantic value of the cue influenced RTs, but not via the attentional mechanisms of capture and hold. However, it was noted that the IOR effect observed (particularly at 200 ms SOAs) might have been due to forward-masking from valid cues on targets, inflating RTs on valid trials.

In Experiment 2 cues and targets no longer shared the same spatial locations. The IOR (but not the semantic) effect was replicated, indicating that IOR in the current paradigm was not an artefact of forward-masking. Again, no semantic influence from cues on attentional mechanisms was observed, contrasting with previous research.

Experiment 3 attempted to find evidence of semantic influence on attention by removing immediate feedback on fixation maintenance to increase the likelihood of attentional orienting towards cues. Also, to make conditions more comparable to previous research, criteria for eye-control were relaxed by including trials with potential oculomotor confounds in analyses. With attentional orienting facilitated, the IOR effect was replicated, but semantic cue value still did not interact with attentional mechanisms. Instead, similar to Experiment 1, a main effect of semantic cue value, independent of attentional orienting, was observed at 200 ms SOAs. Relaxing the eye-control criteria made no difference to findings, suggesting that introducing overt attentional confounds on covert attentional orienting may not increase semantic effects from the cue.

A potential reason noted for the continual lack of semantic influence on spatial attention observed across Experiments 1 to 3, was the intermixing of one- and two-cue

presentations. This might have led to different participant strategies which more greatly relied on low-level information, than if only single-cues were presented (as in previous research). Experiment 4 tested this notion by employing only single-cue presentations. In addition to finding the typical IOR effect, the predicted semantic effect on spatial attention was again absent. However, the independent main effect of semantic cue value was yet again observed at 200 ms SOAs. A semantic effect interacting with attentional orienting at the 700 ms SOA was in the opposite direction to predictions (i.e., indicating that neutral cues held attention longer than faces). Unlike Experiment 3, these semantic effects were no longer apparent when relaxed eye-control criteria analyses were conducted.

Experiment 5 tested whether the previously obtained main effect of semantic value was independent of attentional orienting and only observed at the short SOA because of the temporal uncertainty of the target appearance resulting from intermixed SOA lengths. However, even when SOAs were separated into blocks to remove objective temporal uncertainty, both the IOR and the short-lived independent main effect of semantic cue value remained. Furthermore, as in Experiment 3, the effect was absent when eye-control was relaxed. This suggests a robust phenomenon that remains evident after numerous changes to methodological parameters, but that may somewhat depend on only having purely covert attention available to process the cue.

Taken together, the results from the present study show robust effects of IOR which, for single-cues, was approximately twice as large at SOAs of 200 ms. Such IOR effects confirm that covert attentional orienting processes were employed in response

to the cue presentation. Attention was first exogenously captured by the abrupt onset of the cue, and after withdrawing, took longer to subsequently return to a cued versus uncued location. Effects of semantic cue value tended only to occur at short SOAs and independently from measures of attentional orienting (i.e., IOR). This means that while there was evidence that the semantic value of the peripheral cue was processed, no evidence was observed to suggest that its subsequent impact on RTs was achieved via influence on spatial attentional orienting mechanisms. Instead faces, due to their sociobiological significance, briefly facilitated saccadic responses to all target locations *regardless* of whether attention had previously shifted to the same location in response to the preceding cue. This indicates that face cues, either alone or in competition, were not superior in their ability to capture or hold attention. Conducting contaminated analyses, based on relaxed eye-control criteria, if anything, actually reduced evidence of semantic processing, contrary to initial suggestions. This suggests that such analyses, combining overt confounds with covert attentional orienting, were less sensitive to semantic influences from peripheral cues.

It is surprising that such effects of semantic cue information, independent of attentional orienting, would be found in a spatial attention task, especially after multiple variations to the methodology. The finding contrasts with previous research (Fox et al., 2001; Fox et al., 2002; Okon-Singer et al., 2006; Stolz, 1996,) showing semantic effects on exogenous covert attentional mechanisms. Such conflicting results might be reconciled by considering that past research measured manual motor responses, while the present study examined oculomotor responses which have a very different

underlying neural basis. Another crucial difference was that instead of manipulating the semantic relatedness (Stolz, 1996) or emotional valence (Fox et al., 2001; Fox et al., 2002; Okon-Singer et al., 2006) of cues, the present study manipulated their sociobiological salience to measure semantic impact on attention. It is in regards to this latter point of difference that the current results, while surprising, might not be considered without precedent. For example, Friesen and Kingstone (2003) used a schematic face simultaneously as both an abrupt-onset cue and an uninformative gaze-direction cue, and found that reflexive attentional orienting to gaze direction and reflexive inhibition to the abrupt-onset location of the same cue appeared to occur independently. While this may represent an eloquent dissociation of purely exogenous from a more hybrid form of attentional control, it nevertheless illustrates that orienting to sociobiologically significant stimuli may be unique and distinct from typical concepts of attentional orienting (see also Friesen & Kingstone, 1998; Kingstone, Friesen, & Gazzaniga, 2000; Ristic, Friesen, & Kingstone, 2002, for similar conclusions).

In the present study, the mere abrupt presence of a face in the periphery was sufficient to facilitate saccadic responding to targets, irrespective of where attentional resources were spatially allocated. Such a semantic influence from a cue, occurring independently of attentional orienting processes and only lasting briefly following its presentation, may suggest a short-lived form of social facilitation (Triplett, 1898; Allport, 1920/1967). Because we may learn that it is necessary to be prepared to react to the unpredictable demands produced by social contexts (i.e., drive theory, Zajonc, 1965, 1980), the sudden appearance of a face (even a passive observer, Dashiell, 1935) may

induce a higher level of alertness and readiness to respond to subsequent events (such as a saccade target).

How might such an effect operate in terms of underlying neural mechanisms? Because the semantic influence appears brief (i.e., only observed at 200 ms SOAs), independent of attention and may be constrained to only saccadic responses, the involvement of the basal ganglia system is speculated. The basal ganglia exert influence on the production of saccades via a double-inhibitory process which serves to modulate projections sent from cortical eye fields to the oculomotor networks responsible for generating saccades. The neurons within the basal ganglia output station of the substantia nigra pars reticulata (SNr) typically have a sustained inhibitory effect on the intermediate layer of the superior colliculus (SC; the key structure receiving cortical projections and responsible for generating saccades). When the basal ganglia input neurons within the caudate nucleus (CD) are activated, they have an inhibitory effect on the SNr. Thus, the input stations inhibit output stations, and output stations inhibit signals sent to the oculomotor network (Hikosaka, Takikawa, & Kawagoe, 2000). Lauwereyns, Watanabe, Coe, and Hikosaka (2002) used single-unit recordings to discover that increased neuronal activity in the CD may be responsible for the response bias associated with reward observed in monkey saccades. They proposed that such an increase in activity inhibited neurons in the SNr, which, in turn, temporarily removed the tonic inhibition from the SNr onto the SC. This would allow greater projections from the SC, resulting in faster saccades and thus producing the observed response bias.

Such an interpretation may similarly explain the current findings. It is feasible that faces are intrinsically rewarding due to their sociobiological significance and so their sudden peripheral appearance might have caused an increase in CD activity similar to that induced by expectation for an upcoming reward. A temporary increase in the firing of CD neurons would have resulted in the temporary removal of sustained inhibition from the SNr on the SC, potentially causing a general increase in SC neuronal activity. A higher baseline of activity in SC neurons would mean less cortical projections from the frontal eye field (FEF), in response to a peripherally presented target (Curtis & D'Esposito, 2003), would be required to the SC in order to reach the necessary threshold to execute a saccade. This would have resulted in the faster initiation of saccades, thus creating a spatially non-specific response bias. The general SC activity increase from such disinhibition would only be temporary due to the phasic nature of CD neuronal firing (Hikosaka et al., 2000) and so would be expected to return back to baseline as the delay between the face presentation and a required saccade increases (e.g., at 700 ms SOAs). In summary, it is proposed that the double-inhibitory process within the basal ganglia modulates activity within the SC to facilitate timely responding in the context of sociobiologically significant stimuli such as faces.

Research has also shown the likely involvement of the SC in the occurrence of IOR (Danziger, Fendrich, & Rafal, 1997; Posner et al., 1985; Rafal et al., 1989; Rafal, Posner, Friedman, Inhoff, & Bernstein, 1988; Sapir, Soroker, Berger, & Henik, 1999). The specific expression of IOR, however, is thought to be the result of reduced spatially selective inputs from the cortical eye fields and lateral intraparietal area (LIP) onto SC

neurons (Dorris, Klein, Everling, & Munoz, 2002; Godijn & Theeuwes, 2004). This could explain why IOR and semantic effects were additive rather than interactive in the present study. The initial reflexive orienting of covert attention to the cue would inhibit overt attention returning to the cued location by reducing location-specific input from the LIP in the cerebral cortex (i.e., IOR; Godijn & Theeuwes, 2004). This might function independently of a more general modulatory effect on the SC, induced by the temporary removal of tonic inhibition from the basal ganglia in response to the sociobiological salience of the cue.

Future research should focus on exploring the obtained semantic influence from peripheral cues by making specific variations to the current paradigm. Such research might examine the impact that different semantic manipulations have on both saccadic and manual responses. This would test whether the present effect is limited to faces, to sociobiological stimuli, or to any semantically meaningful stimuli as long as a saccadic response is involved. Saccade trajectory deviations represent an alternative measure of attentional allocation (Van der Stigchel & Theeuwes, 2007) and so could be utilised to confirm the validity of the interpretation that such semantic influence is expressed within the basal ganglia. Deviations in saccade trajectory are thought to result from location-specific inhibition on the SC from the FEF or dorsolateral prefrontal cortex (Godijn & Theeuwes, 2004). Finding no difference between saccade trajectory deviations in response to face versus neutral cues in the presence of a main RT effect of semantic cue value would lend further support to the interpretation that the face advantage for saccadic RTs is due to disinhibition within the basal ganglia.

It is interesting that across three experiments, there was a failure to find a significant difference between saccadic RTs for valid face versus neutral cues when in competition, in contrast to Theeuwes and Van der Stigchel (2006). This indicates that, in the current paradigm, faces did not receive attentional priority when competing with objects of less semantic salience. These differing results may be a reflection of intermixing trials with one- and two-cue presentations (thereby potentially inducing altered participant strategies) or be because different methods were employed to signal a required saccadic response. Theeuwes and Van der Stigchel used central pointers to indicate a saccade was to be made, while in the present study, responses were prompted by the sudden onset of a target symbol in the periphery, creating an exogenous event similar to that caused by a single cue. Perhaps this latter method contributed to the large IOR effect, because many of oculomotor processes associated with reflexive orienting would be involved in both the initial covert and subsequent overt attentional shifts. Such a large IOR might have then swamped any subtle differences (e.g., 11 ms in the Theeuwes & Van der Stigchel study) between the size of the respective IORs generated by face and neutral cues. A study that manipulated whether two-cue trials were solely presented or intermixed with single-cue trials and whether an exogenous event or central pointer was used to signal a saccadic response would assist in specifically isolating under which conditions Theeuwes and Van der Stigchel's effect may be observed.

The other issue addressed by the present study was how differing methods used to measure orienting of covert attention can impact findings. Controlling for the

occurrence of eye movements towards cued locations by presenting peripheral cues very briefly or by observing participants' eyes with a video camera may not prevent microsaccades or anticipatory saccades from occurring undetected. It was initially suggested previous semantic effects obtained using such oculomotor control techniques may have thus reflected the measurement of semantic influence on a combination of overt and covert attention, rather than on purely covert attention. The present study compared analyses based on strict eye-control (i.e., using eye tracking to confirm eyes remained centrally fixated) versus more relaxed criteria that allowed premature termination of fixation and anticipatory saccades. Across the three experiments in which analyses were compared, it was observed that semantic effects obtained using strict eye-control criteria were often no longer apparent once criteria were relaxed. This provides strong evidence indicating that the introduction of oculomotor confounds actually renders measures of covert attentional orienting *less* sensitive to effects from the semantic value of a cue.

It could be that minor overt attentional shifts from microsaccades or anticipatory saccades generated noise which masked semantic effects on covert attention. This would be consistent with research (Rolfs, 2009) suggesting that while microsaccades can be considered a correlate of spatial attention, their occurrence in a spatial cuing paradigm would have a minimal influence on RTs over and above influence from covert attentional shifts in response to the cue. Post hoc implications for previous research (Fox et al., 2001; Okon-Singer et al., 2007; Stolz, 1996) are that their interpretations and conclusions need not be altered because of using relaxed eye-control techniques which

potentially introduced oculomotor confounds. If anything, it instead provides even stronger evidence for their findings, in that effects of semantic influence were successfully obtained despite using a similar level of eye-control to that which reduced semantic effects in the present study. Based on the current findings, however, it is suggested that future research should take advantage of strict eye-control procedures when measuring purely covert attention as it appears to make a marked difference in the sensitivity of the attentional measure to semantic influence.

Figure 1.7 Visual attention findings.

		Forms of orienting	
		Covert	Overt
Stages of orienting	Hold	no semantic effect	
	Capture	no semantic effect	

In summary, the present study shows, across numerous variations to a spatial cuing paradigm, a recurring influence of semantic information embedded in peripherally presented cues on subsequent saccadic responses. Cue objects of high sociobiological salience reduced saccade latencies towards subsequently presented targets. Importantly, this facilitation of saccadic responses appeared to operate independently of covert attentional orienting mechanisms of capture and hold. As such, no evidence of semantic influence was observed on the capture and hold processes of covert visual attention (see Figure 1.7). It instead suggests a short-lived semantic priming or social

facilitation effect which may have a neural basis in the double-inhibitory processes within the basal ganglia. This effect was reduced by introducing, via relaxed eye-control criteria, oculomotor confounds on otherwise purely covert attentional shifts in response to peripheral cues.

Chapter 2

**Capture in Competition: The Manual Motor Expression of
Semantic Influence on Covert Attentional Orienting**

Capture in Competition: The Manual Motor Expression of Semantic Influence on Covert Attentional Orienting

The previous chapter documented a series of experiments providing evidence that a semantic influence from sociobiologically significant cue stimuli can briefly facilitate saccadic responses. This influence was additive to a consistent inhibition of return (IOR) effect, that is, the finding of delayed responding to target stimuli at locations where attention had been reflexively allocated. Accordingly, this indicated evidence of a semantic influence on performance that was independent from mechanisms involved in allocating covert attentional resources in response to a preceding cue, contrary to what has been found previously (e.g., Fox, Russo, Bowles, & Dutton, 2001; Fox, Russo, & Dutton, 2002; Okon-Singer, Tzelgov, & Henik, 2007; Stolz, 1996). It is proposed that the departure of the current results from previous research could be accounted for by the use of sociobiological salience (vs. relatedness or emotional valence) as the primary semantic manipulation and the measurement of saccadic (versus manual) responses.

A neural explanation for the observed independent effects implicated the role of the superior colliculus (SC; the key mid-brain structure for saccade generation) in the expression of both a location-specific IOR effect (caused by reduced input received from the frontal cortex; Dorris, Klein, Everling, & Munoz, 2002; Godijn & Theeuwes, 2004) as well as a general facilitation effect from the mere presence of sociobiological stimuli (via disinhibition of neural activity from the basal ganglia) on saccadic response latency. A central premise of this interpretation was that the expression of such semantic effects

would have to rely on the oculomotor neural circuitry, specifically the SC, suggesting that these obtained effects may be unique to saccade responses. The focus of the present study was to investigate how semantic influence from sociobiologically salient cues would be expressed in a manual motor task which involves responses that do not rely on oculomotor circuitry.

Different underlying premotor circuitries and effectors are employed depending on whether manual motor or saccadic responses are made to visual targets (Glimcher, 1999; Scheiber, 1999). These differences have been used to primarily explain findings of attentional effects that differ depending on whether manual or saccadic responses are measured. Research has shown that saccadic IOR effects are larger (Kingstone & Pratt, 1999; Li & Lin, 2002; Pratt & Neggers, 2008) and develop earlier (Briand, Larrison, & Sereno, 2000; Khatoon, Briand, & Sereno, 2002) than IOR for manual motor responses. This has been argued to be due to IOR accessing the same oculomotor system (specifically, affecting the same oculocentric spatial saccade map represented by SC neurons) responsible for generating saccadic responses (Godijn & Theeuwes, 2004; Rafal, Calabresi, Brennan, & Sciolto, 1989; Taylor & Klein, 1998). Manual IOR effects are smaller and develop later because manual motor circuitry is argued to play a smaller role (i.e., less SC involvement) in the expression of IOR (Bekkering, Pratt, & Abrams, 1996; Pratt & Neggers, 2008, but see Sumner, Nachev, Vora, Husain, & Kennard, 2004). Thus it can be proposed that attentional effects may depend on the response modality used for their expression (see also premotor theory; Rizzolatti, Riggio, & Sheliga, 1994).

Because of such differences, it is proposed in the present study that the influence of semantic information on manual motor responses, which do not rely on the same neural circuitry implicated in saccadic responses, might also be different. Would semantic priming effects from sociobiologically salient cues still be observed if oculomotor circuitry (particularly SC activity) was not necessarily invoked by the response modality? Might the pattern of cortical neural activity associated with attentional orienting interact (in a more location-specific manner) with semantic effects expressed via a manual motor response system? As in the previous chapter, the present study was concerned with testing for evidence of semantic influence on capture and hold processes of covert forms of attention (see Figure F2, left column), but differed in its use of a different response modality to investigate such an influence.

Previous research measuring manual motor responses within a spatial cuing paradigm has gone some way to answering these questions. Stolz (1996) compared the semantic relatedness of a word cue to a context word using manual discrimination responses, finding influence on attentional hold mechanisms. Okon-Singer et al. (2006), also using a manual discrimination task, manipulated the emotional valence of a distracter picture presented simultaneously with the target, discovering that, once cued to its location, negative pictures held attention longer. Similar findings of an influence from emotional valence (although from cues) on attentional hold were found in manual motor discrimination tasks (Fox et al., 2002), and in manual detection and localisation tasks for high state-anxious participants (Fox et al., 2001). The present study intended to

extend these studies by examining the influence of sociobiological significance, which is speculated as contributing to the unique findings observed in the previous chapter.

A common feature of the past research was the presentation of only single cues. Because objects are rarely experienced in isolation, and based on research suggesting that the influence of sociobiological stimuli may depend on whether they are in competition for attention with other objects (e.g., Ro, Russell, & Lavie, 2001), it was deemed it important to explore the possibility that the expression of semantic influence might not only depend on what underlying response system was employed, but also whether there was competition for attention. To this end, the present study also investigated the role semantic information plays in the competition for attention when involving manual responses which do not rely on oculomotor neural circuitry.

Two studies have manipulated sociobiological significance of cues under conditions of competition within the spatial cuing paradigm. Theeuwes and Van der Stigchel (2006) presented two cues in opposing hemifields, comparing a face cue with a sociobiologically neutral object cue. They found a greater IOR effect on saccade responses for face cues, indicating faces preferentially received attention when in competition with neutral cues. Similar research (Bindemann, Burton, Langton, Schweinberger, & Doherty, 2007) has also compared faces with neutral objects in two-cue presentations, but instead measured manual responses. They found consistently facilitated manual responses to targets cued by uninformative faces (vs. neutral objects) across a range of cue-target stimulus onset asynchronies (SOAs; from 100–1,000 ms). However, as the focus of their research was primarily concerned with whether explicit

top-down task strategies can overturn an existing attentional bias for faces, several features of their paradigm limit the applicability of their findings to the present focus. For example, there was no control for eye movements and cue duration was identical to the SOA length, such that longer SOA conditions also had longer cue presentations. Consequently, no distinction could be made between whether overt or covert attentional resources were allocated to process cues. Similar concerns apply to distinguishing endogenous and reflexive orienting effects, particularly at longer SOAs, when attention orienting and residing at face stimuli is more likely to reflect volitional preferences rather than a superior ability of faces to reflexively capture attention (see Theeuwes & Van der Stigchel, 2006, for a similar argument). This presumably contributed to the lack of an IOR effect for faces observed at the 1,000 ms SOA.

The present study used a spatial cuing paradigm to measure how the semantic manipulation of a cue's sociobiological significance influenced covert attentional mechanisms in a manual motor discrimination task. Cues could either be of high (i.e., faces) or low (e.g., appliances) sociobiological significance. On a subset of trials, two cues (always a face and a neutral object) were presented, one on either side of fixation, to assess what role semantics play in the competition for attention. Participants indicated the identity of a subsequent target symbol by pressing the appropriate button using their index finger.

A discrimination task was used to maximise the point of difference from saccadic responses, that is, the involvement of the underlying oculomotor neural circuitry. Because certain types of manual responding require a high level of visuospatial

information for their successful execution, aspects of oculomotor circuitry are often utilised. For instance, specific neurons in the SC, alongside those responsible for generating saccades, have been implicated in manual reaching tasks (Werner, Dannenberg, & Hoffman, 1997). Research has also shown SC neurons plan reaching movements to targets in terms of eye-centred coordinates (Batista, Buneo, Snyder, & Anderson, 1999; Stuphorn, Bauswein, & Hoffman, 2000). In contrast, discrimination responses are based on nonspatial target characteristics and so should require minimal SC involvement. A further reason for using a discrimination task was to avoid preparatory motor response biases induced by the cue, which have been shown to occur with manual responses in a spatial cuing paradigm (Wilson & Pratt, 2007). Because, in the discrimination task, the location (or any other feature) of the cue could not prime the required response, the contribution of response-preparatory mechanisms can be discounted, allowing any influence from the cue to be attributed to the involvement of attentional mechanisms (see Fox et al., 2001; Fox et al., 2002, for a similar argument). A final important aspect of the current paradigm was the use of strict eye-control to ensure only covert attention could be oriented in response to the cue.

Previous research finding IOR effects for manual discrimination responses (e.g., Fox et al., 2002; Kingstone & Pratt, 1999; Lupiáñez, Milan, Tornay, Madrid, & Tudela, 1997; Lupiáñez & Milliken, 1999; Pratt & Abrams 1999; Pratt, Kingstone, & Khoe, 1997) tended to show a later transition from facilitatory to inhibitory processing at the cued location, compared to simple localisation or detection tasks. This has been attributed to task difficulty factors (e.g., Klein, 2000). Because the present task was discriminatory

and involved manual responses, the cue-target SOAs of 200 ms and 700 ms used were expected to produce positive and negative spatial cuing effects, respectively.

Based on the expected biphasic nature of attentional cuing in the manual discrimination task, evidence of superior capture and hold of attention by face cues should be expressed differently depending on the SOA length. Because the 200 ms SOA was expected to tap into facilitative processing of the target at the cued location, faster reaction times (RTs) for faces following single valid cues would indicate superior capture of attention, while slower RTs for faces following single invalid cues would indicate superior hold (as attention is slower to disengage and shift away from the invalidly cued location to process the target). Faster RTs following valid face (vs. valid neutral) cues in competition, would indicate faces preferentially captured attention over neutral objects. In the 700 ms SOA conditions, expected to generate IOR (i.e., slower valid compared to invalid single-cue RTs), a smaller IOR for face cues would reflect superior hold due to attention taking longer to withdraw from the cue, resulting in a less developed IOR at the time of target appearance (Fox et al., 2002). Slower RTs for valid face cues in the competition trials would imply that they generated more IOR from receiving preferential reflexive attention, indicating evidence of superior attentional capture when in competition for attention.

Method

Participants

Participants were 35 Victoria University of Wellington students, all with normal or corrected-to-normal vision, who completed the experiment in exchange for course

credit. The School of Psychology Human Ethics Committee approved all procedures. Ten participants were excluded due to each having more than 20% of trials rejected because of errors (see trial rejection criteria below). The remaining 25 participants (15 female, all right-handed) had a mean age of 20.00 years. Participants were naïve as to the purpose of the experiment.

Stimuli and Apparatus

The SR Research Experiment Builder (version 1.4.128 RC) was used to program the experiment, which was then run on a 3-GHz Pentium D computer. Stimuli were presented on a 21" monitor with a 1,024 × 768 pixels resolution and a 60-Hz refresh rate. Participants were seated at a viewing distance of 57 cm, maintain by forehead and chin rests. Using the EyeLink® 1000 video-based Tower Mount Head Supported System (SR Research Ltd., Ontario, Canada), the left-eye position was tracked with a spatial resolution of 0.01°, and the signal was sampled and stored at 1000 Hz.

A black fixation dot, with a diameter of 0.5°, was presented at the centre of the screen. Cue stimuli were taken from Ro et al. (2001), and consisted of six greyscale photographs within each of four categories (faces, appliances, musical instruments and clothing). Cues subtended 2.9° × 2.9° and were presented with their inner edge either left or right of fixation at an eccentricity of 9.7°. Targets were either an "&" or "%" symbol displayed in black 36-point Arial font, vertically subtending 1.4° and presented at the centre of the same location as the cue stimuli. All stimuli were presented on a white background. Participants used an EyeLink© button box to respond to the target stimuli by using their left and right index fingers to press the shoulder buttons.

Procedure

Each participant was individually tested over a 40-minute session. Trials were initiated either by a button-press or following an inter-trial interval of 5,000 ms. Every trial began with participants fixating a centrally presented dot for 500 ms. One or two cues were then presented for a duration of 100 ms to either the left, right or both (in the two-cue condition) sides of fixation. After a cue-target SOA of 200 or 700 ms, the fixation point disappeared and a target (“%” or “&”) was displayed either to the left or right of fixation. Participants were asked to identify the target as quickly and as accurately as possible by pressing the appropriate button (e.g., the left shoulder button with the left-hand index finger to indicate presence of a “%” target symbol; right shoulder button with the right-hand index finger to indicate an “&” target symbol). The target remained onscreen for 200 ms following a response or 8,000 ms in the absence of a response. Participants were instructed to ignore the cues and maintain fixation until the target appeared. If fixation was broken before the target appeared, the trial aborted and a reminder to maintain fixation was given. The trial would then restart following a button-press, a 2,000 ms delay and re-initiation of fixation for 500 ms.

Visual and verbal feedback was given for the 12 initial practice trials. Six blocks of 40 experimental trials followed, providing 240 analysable trials. Calibration and validation of eye position was performed before practice and each block of experimental trials. A visual reminder of the stimulus-response map to be used was also provided at the commencement of each block of trials.

Design

The dependent variable, button-press RT, was defined as the time taken to make an appropriate button-press after the target had appeared. Within-participant factors included two cue-target SOAs (200 ms and 700 ms) \times three cuing conditions (single-cue valid, single-cue invalid, and two-cue competition) \times two semantic cue values (face and neutral) making up 12 conditions, intermixed within each trial block.

The single-cue conditions contributed 192 experimental trials, where the cue could either validly (i.e., single-cue valid) or invalidly (i.e., single cue-invalid) predict the location of the target with equal probability. On these trials, the sociobiological significance of the cue could either be high (i.e., a face cue, 25% of single-cue trials) or low (i.e., neutral; either an appliance, musical instrument, or clothing cue, with equal probability, contributing to 75% of single-cue trials). In the two-cue competition condition, contributing 48 trials, a face cue was always presented along with a neutral object cue (any of the three neutral categories with equal probability). In these trials, the target was equally likely to appear at either the same location as the face or the neutral cue. The semantic cue value in the competition cuing trials refers to which of the two (face or neutral) cues were valid in indicating the subsequent target location. The cue-target SOA had an equal likelihood of being either 200 ms or 700 ms across all cuing conditions. No cue features were predictive of the target symbol or location.

The two target symbols and two cue (or the face cue in the two-cue trials) and target locations, both equally likely to appear in either hemifield, were counterbalanced across all 12 conditions. The trial order was pseudo-random, limited by having no more than three successive presentations of a face cue, or four of any specific neutral cue

category, cuing condition, SOA, cue location or target location. Two trial orders (one reversed) \times two stimulus-response maps were counterbalanced across participants.

Data Analysis

Fixation initiation and maintenance was defined as a lack of shifting in eye position greater than 0.1° per 100 ms anywhere within 3.7° of the central fixation point. An eye-blink was recorded if the pupil became occluded by the eyelid for at least 12 ms.

Trials were rejected for any of the following reasons: a) fixation was not maintained until the target appeared (the following restarted trial was also rejected), b) an eye-blink was recorded anytime from the presentation of the cue until the appearance of the target, c) a button-press was initiated within 100 ms of the target onset (i.e., considered an anticipative response) or after three standard deviations above mean RT (i.e., considered a late response), d) an incorrect button-press was made to indicate the identity of a target.

Ten participants who had more than 20% of their trials excluded based on these rejection criteria were excluded from further analyses. Of the remaining 25 participants, data from a total of 9.13% trials were not subsequently used in RT analyses. Button errors (i.e., incorrect target identifications), which contributed to 4.01% of these excluded trials, were further examined separately to investigate the possibility of speed-accuracy trade-offs. Each remaining participant's mean RTs and error rates were calculated for each of the 12 conditions. Data were collapsed across trial order, stimulus-response map, target symbol, and presentation hemifield of the cue and target.

Data were analysed for the single cue conditions by conducting a three-way repeated measures analysis of variance (ANOVA) on mean RTs and error rates. Within-participants factors were SOA (200 ms vs. 700 ms), cuing condition (valid vs. invalid) and semantic cue value (face vs. neutral). If a significant interaction between SOA and cuing condition was revealed, two-way repeated measures ANOVAs were to be run separately for each SOA, using cuing condition and semantic cue value as within-participants factors. For the competition cuing condition, RTs and error rates were submitted to a two-way repeated measures ANOVA, using SOA (200 ms vs. 700 ms) and semantic cue value (face vs. neutral) as within-participants factors.

All *t* tests were two-tailed and all inferential statistical tests used an alpha level of .05. Because each condition did not consist of an equal number of trials, reported means collapsed across other factors were weighted based on trial proportions for each collapsed condition.

Results

The mean correct button-press RTs and standard errors as a function of semantic cue value and cuing condition are presented in Figure 2.1, separately for the 200 ms and 700 ms SOA conditions. While RTs appeared faster overall at the 700 ms SOA condition, they did not appear to differ as a function of single-cue validity (or semantic cue value) at either SOA, suggesting no attentional cuing effects. However, in the competition cuing condition, RTs looked to be a lot faster following valid face versus neutral cues across both SOAs.

Figure 2.1 Mean button-press reaction times (ms) and standard errors for face and neutral cue trials as a function of cuing condition and stimulus onset asynchrony (SOA; ms). Each SOA condition is presented in a separate panel. The cue category in the competition cuing condition represents the valid cue.

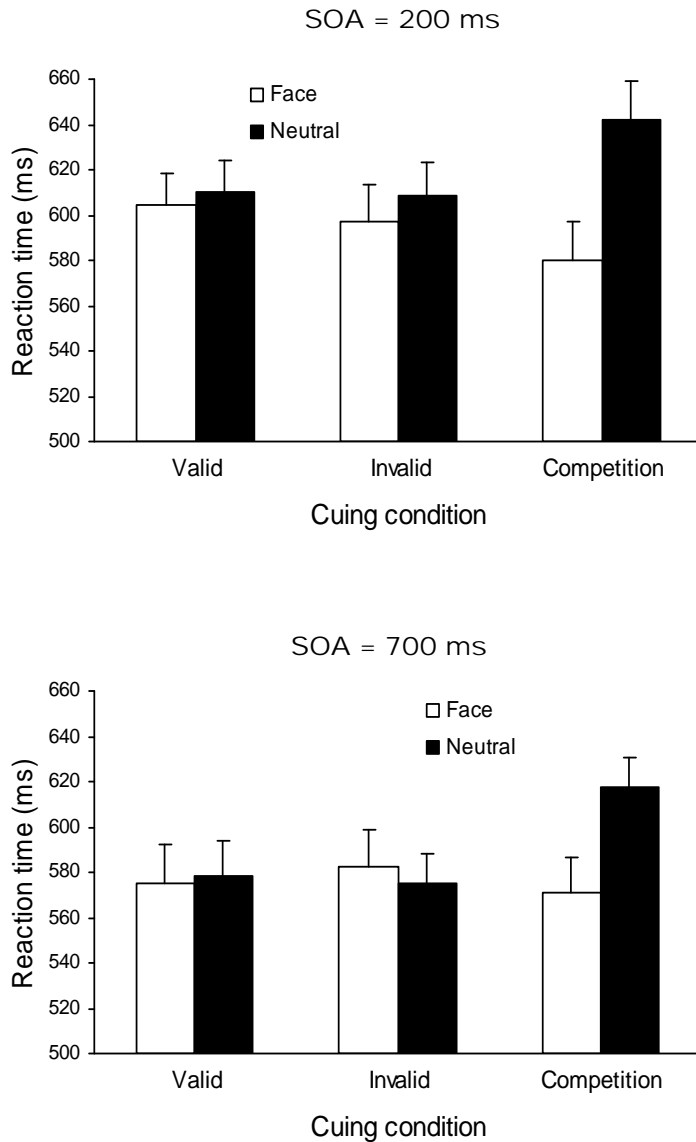


Table 2.1 presents the mean error rates (percentage of incorrect button-responses) and associated standard errors as a function of SOA, semantic cue value and cuing condition. Error rates were generally low overall and the ANOVAs conducted on button errors found no reliable effects for either the single or competition cuing

conditions (F values < 2.4). Because no evidence of a speed-accuracy trade-off was indicated, button-press RTs became the measure of focus.

Table 2.1 *Mean error rates and standard errors as a function of stimulus onset asynchrony (SOA), cuing condition, and semantic cue value*

Semantic Cue Value	Valid		Invalid		Competition	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
SOA = 200 ms						
Face	4.00	1.19	5.33	1.35	3.33	1.18
Neutral	3.22	0.65	3.89	0.66	5.00	1.27
SOA = 700 ms						
Face	2.33	0.90	5.33	1.17	4.67	1.67
Neutral	4.11	0.77	3.11	0.82	4.00	1.28

Note: Mean error rate as a percentage.

Single Cuing Condition

The three-way repeated measures ANOVA on RTs from the single cuing conditions revealed a main effect of SOA, $F(1, 24) = 44.98$, $MSE = 824.39$, $p < .001$, $\eta^2 = .65$, showing RTs to be, on average, 27 ms faster for the 700 (vs. 200) ms SOA condition. No significant main effect of cuing condition, or an interaction between cuing condition and SOA was observed (F values < 0.9), indicating an absence of either facilitative or IOR cuing effects.

Competition Cuing Condition

Analyses showed a significant main effect of semantic cue value, $F(1, 24) = 76.31$, $MSE = 953.14$, $p < .001$, $\eta^2 = .76$, whereby targets were identified 54 ms faster when validly cued by a face cue rather than a neutral cue in the two-cue competition condition. A significant main effect of SOA was also observed, $F(1, 24) = 5.66$, $MSE =$

1,189.51, $p < .05$, $\eta^2 = .19$, showing RTs to be, on average, 16 ms faster in the longer (vs. shorter) SOA condition. No significant interaction between semantic cue value and SOA was observed ($F < 0.9$).

Discussion

The results indicate a striking effect of semantic information on manual motor RTs under conditions of competition. A prominent main effect of semantic cue value was found, indicating that when a sociobiologically salient cue (i.e., a face) was in competition with a neutral cue for attention, participants were faster to respond when the target was presented in the same location as the face cue compared to the neutral cue, regardless of the SOA length. The lack of a semantic effect in the single-cue conditions suggests that it may be limited to situations of competition between objects. Results also showed a general absence of typical attentional cuing effects for single cues. No main effect of cuing, nor an interaction between single cuing condition and SOA was evident for RTs. As such, the predictions regarding the biphasic nature of cuing effects observable using the short and long SOAs were not borne out in the data.

It is argued that the results reflect a better capture of attention by faces when in competition for attention, which then facilitates manual motor responses to targets presented in the same spatial location. That RTs at 200 ms SOAs were facilitated only for valid face (vs. neutral) cues in the two-cue condition, indicates preferential capture of attention by faces. The finding of this effect at the 700 ms condition (in the absence of evidence for IOR) suggests that such competition-dependent capture is temporally robust for at least several hundred milliseconds. An attentional bias rather than motor

response bias is implicated because the discrimination task was based on nonspatial target features, precluding any contribution from preparatory motor mechanisms. Thus, semantic information appeared to bias competition for attention towards those objects which were more sociobiologically relevant. Once attentional resources had oriented to the face cue location, a target subsequently presented at this location could be more readily identified by means of a manual motor response. Taken together, semantics appeared to interact with attentional orienting when expressed by manual motor responses, but only in competitive situations.

Our findings are consistent with other research showing sociobiologically significant stimuli preferentially receive attentional processing when in competition with other objects (Bindemann et al., 2007; Ro et al., 2001; Theeuwes & Van der Stigchel, 2006; Vuilleumier, 2000). It is curious that, despite the methodological differences, the current results bear a striking resemblance to those of Bindemann et al. (2007). They also found that when uninformative face cues competed with other stimuli, valid faces facilitated manual motor RTs across a range of SOAs (100–1,000 ms; none of which produced an IOR effect). It would be interesting to directly compare a broader range of two-cue combinations to further explore the nature of how semantic information operates to create this bias. By comparing face-neutral cue presentations with face-face or neutral-neutral cue presentations, it could be assessed how semantic salience differences between simultaneously presented cues, as well as overall sociobiological significance, affect competition for attention. Comparable assessments might also be

made by manipulating the semantic relationship between the two cue objects (along similar lines to Stolz, 1996).

In the current study, the influence of semantic information on attentional orienting and manual motor RTs depended on competition between objects. Similarly, Ro et al. (2001) found a change detection advantage for faces only when in competition. It may be that there is a trade-off between the influence of semantic information and low-level perceptual features on attention depending on whether objects are in competition. When an object appears in isolation, low-level physical properties (e.g., asymmetrical physical transients) appear to have a large role in determining where attention is allocated, while influence from semantic information is seemingly minimal. That is, attention reflexively orients towards the sudden appearance of a single object regardless of its semantic significance. However, in more complex visual environments where more than one object competes for attentional resources, semantic information appears to play more of a role in determining appropriate orienting to relevant objects, whereas low-level influences become reduced (e.g., the symmetrical physical transients effectively cancelled each other out in two-cue conditions). Such a trade-off may be analogous to the notion that semantics have a smaller role in purely exogenous attention (i.e., reflexive attentional orienting initiated in response to physical properties of an object) compared to more hybrid forms of attentional control (e.g., reflexive attentional orienting initiated in response to higher level factors, see Klein, 2004; Klein & Shore, 2000). Increasing the number of cues in competition with the face object would be a useful method to examine whether increasingly complex visual presentations

further modulate preference for sociobiological cues. Further research would also be important to establish that semantic effects remain absent for single-cue presentations even when attentional cuing effects are observed.

It is important to note that the lack of facilitative or IOR effects for single-cue conditions is not an indication that these cues did not capture or hold attention (orienting to such cues is reflexive after all), only that they did not produce observable effects on manual motor RTs. It is possible that both SOAs fell within the temporal crossover point between facilitative and inhibitory effects. The 200 ms SOA may have been too long to produce facilitative effects, and the 700 ms SOA too short to find the subsequent development of IOR, which occurs later for manual motor discrimination tasks (compared to saccade detection or localisation tasks). Samuel and Kat (2003), in their graphical meta-analyses of 166 attentional cuing effects on manual motor responses, observed that robust evidence for facilitation effects using SOAs of up to 100 ms becomes much more fragile when SOAs approach 200 ms. Fox et al. (2002) achieved IOR effects in a manual motor discrimination task, however they used a longer SOA of 960 ms. They also increased fixation luminance between cue and target onset, promoting the withdrawal of attention from the cued location, and thereby facilitating IOR development. Lupiáñez et al. (1997) reported unpublished findings from their research laboratory showing IOR effects in manual discrimination tasks at SOAs of 1,000 ms but not at 600 ms.

A number of other factors may have contributed to the lack of attentional cuing effects observed in the current study. For instance, valid cues might have masked

perception of the target stimulus, resulting in inflated RTs on valid single-cue trials and therefore obscuring potential facilitation effects at 200 ms SOAs. Pratt, Hillis, and Gold (2001) found that attentional cuing effects for manual RTs at SOAs of 100 and 200 ms became absent once valid cues and targets spatially overlapped. As previously mentioned, the magnitude of IOR also tends to be smaller for manual motor responses because IOR is suggested, in great part, to depend on activation of the oculomotor system (Li & Lin, 2002; Rafal et al., 1989). It is notable that several other studies have failed to find an IOR effect for manual discrimination (e.g., Tanaka & Shimojo, 1996; Terry, Valdes, & Neill, 1994; and see Klein & Taylor, 1994). Combined with other research (e.g., Danziger, Kingstone, & Snyder, 1998; Enns & Richards, 1997; Tassinari, Agliotti, Chelazzi, Peru, & Berlucchi, 1994; Tassinari & Berlucchi, 1993; but see Lupiáñez & Weaver, 1998; Maruff, Yucel, Dankert, Stuart, & Currie, 1999), it is apparent that attentional orienting in response to peripheral cues does not necessarily result in the often-touted biphasic nature of facilitatory and inhibitory effects (Pratt et al., 2001). Future research aiming to establish more typical attentional cuing effects from single cues on manual motor RTs might employ a broader range of SOA lengths, or use cues and targets that do not spatially overlap.

The brief general semantic priming effect (triggered by the sudden appearance of a single face cue) observed for saccadic responses in the previous chapter was not found for manual responses in the current study. The most likely explanation for this divergence lies in the differences between the underlying neural circuitry for each response type. In the current study it would not have been expected to find a general

semantic effect purported to act via influence on the SC, because the involvement of the SC was not required to make a manual motor discrimination response. An exciting alternative explanation could be that the absence of a general priming effect from face cues may have represented a reduction in social facilitation effects due to increased task and response complexity. Research has shown an inverse relationship between task complexity and social facilitation effects on performance (Zajonc, 1965). As task complexity or difficulty increases, facilitation of performance is first reduced, before becoming an impairment. The increased difficulty of a discrimination task and the requirement of a manual motor response (which may be considered to represent a more indirect and complex stimulus-response mapping than simple saccadic localisation responses; Khatoon et al., 2002) could account for a reduction in short-lived semantic priming effects for single-cues. Such a notion, however, would have to be reconciled with findings from the present study showing semantic effects in more complex visual environments (i.e., in the two-cue competition condition). These explanations (though not necessarily mutually exclusive) might be distinguished by examining manual motor detection and localisation responses. While both responses are similar in their complexity, the execution of a localisation response relies more on spatial information, and thus SC involvement.

In summary, these results indicate that the influence of semantic information expressed via a manual motor response system affects the capture mechanism of attentional orienting, but only in competitive situations. Such a role of semantics in competition was only obtained for manual responses.

What would be the functional advantage of having a semantically driven attentional bias expressed in manual motor rather than saccadic performance? The current study has shown that increasing competition for attention, by the appearance of more objects in a visual scene, appears to increase the need of top-down biases in order to resolve the competition. It might be that this increased role of semantic information is more pertinent when making appropriate motor manual responses. Compared to saccades, manual motor responses tend to be more complex, effortful and time-consuming to execute. When competition between visual objects which signal an upcoming manual (rather than oculomotor) response is required, selecting the most relevant object to which to respond may be more crucial to making an appropriate response, as the temporal cost of committing attention to a less relevant object is greater. The role of semantic information would represent a vital tool in suitably resolving such competition for attention and action. Contrasting the increased role for semantic information in competition for manual motor responses with the general semantic priming effects observed for saccades in the previous chapter, it could be argued that perhaps this represents the most efficient way of operating in a complex and dynamic visual environment where objects vie for attention and demand action. Such a system of operating may use semantic information differently in order to take optimal advantage of the relative benefits and shortcomings associated with each response system under different circumstances.

Relating back to the overall thesis scope and 2×2 matrix, the current study provides evidence of semantic influence on the capture of covert orienting of attention

when expressed in manual motor response performance, but only when objects were in direct competition for attention (see Figure 2.2). Taken together with a lack of observable attentional cuing effects, what is clear from the current findings is that saccades and manual motor movements represent very different response systems. Both semantic information and attentional orienting are expressed in a unique manner by each response system, suggesting a degree of independence exists between the systems. This emphasises the need to consider the impact different response systems may have when exploring semantics and visual attention.

Figure 2.2 Visual attention findings.

		Single Cue		Cue in Competition	
		Forms of orienting		Forms of orienting	
		Covert	Overt	Covert	Overt
Stages of orienting	Hold	no semantic effect		no semantic effect	
	Capture	no semantic effect		significant semantic effect	

Chapter 3

Semantic Influences from a Brief Peripheral Cue Depend on Task Set

Weaver, M. D., Phillips, J., & Lauwereyns, J. (2010). Semantic influences from a brief peripheral cue depend on task set. *The Quarterly Journal of Experimental Psychology*, 63(7), 1249-1255.

Semantic Influences from a Brief Peripheral Cue Depend on Task Set

One of the most fundamental issues in the study of human perception and action has been, and continues to be, the interaction between sensory processing, responsive to physical features in the environment, and higher-level cognitive processing, determined by internal factors such as experience and expectation. Continuing a long (predominately Russian) line of research on “the orienting response,” which had culminated in a classic book by Sokolov (1963), Posner (1980) introduced the spatial cuing paradigm to investigate the locus of control in visual information-processing (see also Posner, Snyder, & Davidson, 1980; and reviews, e.g., LaBerge, 1995; Lauwereyns, 1998; Van der Heijden, 1992). Central, symbolic cues such as arrows would invite top-down or voluntary control of orienting, whereas the sudden appearance of peripheral cues would elicit automatic or reflexive orienting. For example, in the case of peripheral cuing, participants may be asked to maintain fixation on a marker in the middle of a computer screen, and subsequently respond to a target stimulus that appears either to the left or right of the point of fixation. Just prior to the onset of the target, a peripheral cue might appear in the form of a small lighted circle either at the same location as the subsequent target (valid trial) or the alternative location (invalid trial).

Posner (1980) suggested that effects of cue validity on response time (RT) should be attributed to “orienting of attention,” whereby limited information-processing resources are spatially aligned with the cue location. The orienting, moreover, would constitute a covert process, unaccompanied by head or eye movements. The time it

takes for a peripheral cue to draw the optimal amount of spatial attention to a particular location can be determined by manipulation of the stimulus onset asynchrony (SOA) between the cue and the target. Cheal and Lyon (1991) reported that positive cuing effects, with faster RTs in valid trials than in invalid trials, peak at around 100 ms. Klein (2000) noted that the facilitation can disappear when the SOA is between 200 and 300 ms. Furthermore, when the SOA is increased to between 300 and 600 ms, validly cued targets may elicit even a slower RT compared to invalidly cued targets—a phenomenon termed *inhibition of return* (IOR).

Because such cuing effects have been shown to occur even when cues are uninformative or have been instructed to be ignored (Jonides, 1981), the processes involved in exogenous control of attention were initially thought to be influenced only by the physical, and not semantic, characteristics of the sudden-onset peripheral cue stimuli (e.g., Briand & Klein, 1987). This idea was later challenged by research showing that semantic interference can occur in exogenous spatial cuing (Stolz, 1996). A spatial cuing paradigm was employed that used words as abrupt-onset peripheral cues which could be either semantically related or unrelated to a context word presented at fixation. While there was no difference observed for valid cues, when cues were invalid, RTs to a subsequent target were slower when the word cue was semantically related to the context word. This finding was interpreted as evidence of semantic interference on the hold (or disengagement) processes of exogenous control of attention. The cues which were related to the context word could be considered as having an “intrinsic informativeness” to the participant who accordingly increases their allocation of

attentional resources to process these cues, thus resulting in prolonged hold and a relatively difficult disengagement of spatial attention when relocating to the invalidly cued target. As such, this intrinsic informativeness may elicit a form of cognitive distraction by directing attention away from a task at hand. Fox, Russo, Bowles, and Dutton (2001) similarly found semantic influences on hold processes for high state-anxious participants when threatening (vs. positive or neutral) words and faces were used as cues. For those participants who were highly state-anxious, the threatening cues could again be considered to have an intrinsic informativeness, relatively absent in the other cues. Comparable semantic influence effects in spatial cuing have since been found with a number of variations to the spatial cuing paradigm (e.g., Okon-Singer, Tzelgov, & Henik, 2007; Theeuwes & Van der Stigchel, 2006).

In the abovementioned studies (and in the previous chapters), the task consisted of simple symbol discrimination relying on a set of information properties that share no commonalities with the cue. Could the nature of the task set determine the extent of semantic influence from a brief peripheral cue? A recent study by Koivisto and Revonsuo (2007) using an inattention blindness paradigm suggests it might. Inattention blindness refers to an inability to perceive unexpected, salient stimuli when attention is directed elsewhere, even if such stimuli are foveated (Mack & Rock, 1998). An unexpected stimulus presented during a category recognition task was detected more often when it shared information properties with the attended target objects defined by the task set (e.g., the word “cat” when looking for pictures of animals). It appeared that

the degree of information overlap between the unexpected stimulus and task set was crucial in determining whether the irrelevant stimuli were perceived.

Such methodological logic can be translated to a spatial cuing paradigm in order to explore whether the semantic influence from a brief peripheral cue also depends on task set. By manipulating the task set and its consequent degree of information overlap with briefly presented task-irrelevant peripheral cues, a “context-dependent informativeness” can be created for the cue, where informativeness to the participant depends on whether the cues share information properties with the task set, even if such information is task-irrelevant. Evidence of semantic influence from cues might be assessed by manipulating the semantic congruency of their information properties with equivalent target information properties to determine whether this differentially impacts task performance. The present study thus aimed to further test the capture and hold cells of covert attentional orienting within the 2×2 matrix of visual attention processes (see Figure F2, left column) for evidence of semantic information under conditions of high overlap of cue-task information properties.

A spatial cuing paradigm was utilised in the present study, whereby individually tested participants were asked to ignore peripheral word cues and discriminate either the gender (gender task) or emotional expression (emotional task) of a subsequently presented face. The cues consisted of either male or female first names (gender category), or positively or negatively charged words (emotional category). Consequently, and depending on the task set, word cues could have context-dependent informativeness based on whether they shared (e.g., an emotional word presented

during an emotion task) or did not share (e.g., a first name presented during an emotion task) information properties with the task. Correct discrimination RTs were measured. To assess semantic influence, cues were used, that not only differed in their degree of information overlap with the task set, but also with respect to whether they were semantically congruent (e.g., a male first name followed by a male face) or incongruent (e.g., a positive word cue followed by a face with a negative expression) with the value of the equivalent face property. Cue features did not predict targets in any way and were presented for a 100 ms duration to maximise their semantic impact (for comparison, durations of between 50–250 ms have been used by Stolz, 1996; Fox et al., 2001; Theeuwes & Van der Stigchel, 2006). Eye tracking was used to carefully monitor eye position to allow measurement of purely covert attentional processes.

Experiment 1

In the first experiment, each participant was assigned to complete one of the two tasks. Cue-target SOAs of 200 ms and 700 ms were used respectively to examine positive and negative cuing effects (compared to 100–300 ms SOAs used by Stolz, 1996; Fox et al., 2001, for facilitation effects and 600–800 ms by Theeuwes & Van der Stigchel, 2006, when examining IOR effects).

Based on Koivisto and Revonsuo's (2007) findings, it was predicted that the semantic value of cues would differentially influence task performance when there was a high degree of information overlap between the word cue category and the task set (i.e., emotional cue with emotion task, or gender cue with gender task). Consistent with standard priming paradigm predictions (e.g., Kornblum, Hasbroucq, & Osman, 1990;

Posner & Snyder, 1975), this semantic influence was expected to be expressed by better performance (i.e., faster RTs or less errors) when the value of the cue stimuli was semantically congruent with the value of the equivalent face property, due to the cue value priming the correct response. Word cues which were incongruent with the equivalent face property (and thus the required response) were expected to prime the incorrect response, resulting in comparatively worse performance. No such differences were expected for the cues with a low degree of information overlap with the task set (i.e., gender cue with emotion task, or emotional cue with gender task). Based on findings by Stolz (1996) and Fox et al. (2001) it was expected that the semantic influences would interact with spatial orienting (specifically hold) processes by differentially influencing responses to validly compared to invalidly cued targets within each SOA.

Method

Participants

Fifty-seven Victoria University of Wellington students took part in the experiment for course credit. Participants had normal or corrected-to-normal vision, were naïve as to the specific hypotheses of the experiment and gave informed consent before taking part. Data from seven participants were not used in the primary analyses due to excessive error rates (see criteria below). The remaining 50 participants (27 female, 47 right-handed) had a mean age of 20.16 years. All procedures were approved by the School of Psychology Human Ethics Committee.

Stimuli and Apparatus

The experiment was programmed using SR Research Experiment Builder (version 1.4.128 RC), run on a 3-GHz Pentium D computer and displayed on a 21" monitor with a resolution of $1,024 \times 768$ pixels and a 60-Hz refresh rate. Eye position was tracked and recorded using the EyeLink® 1000 Tower Mount Head Supported System (SR Research Ltd., Ontario, Canada). The system had a spatial resolution of 0.01° , and sampled and stored the signal at 1000 Hz. Participants were seated at a viewing distance of approximately 57 cm, maintained by a chin and forehead rest.

A black fixation dot (diameter of 0.5°) was presented centrally on the screen. Cue and target stimuli were presented in either the upper or lower visual field. Cue stimuli were made up of 32 words including: eight each of male (e.g., jonathon) and female (e.g., michelle) first names, and eight each of positively (e.g., laughter) and negatively (e.g., murderer) charged words. First names were chosen from the AVSS unofficial list of baby girl and boy names in California (2006). The emotionally charged words were taken from the ANEW (Affective Norms for English Words) database (Bradley & Lang, 1999). Both emotional word lists were similarly matched for valence rating (relative to their respective extreme values), arousal rating and word frequency. All four word lists were matched for word length ($M = 6$ letters, range: 3–8 letters). Words were presented with the closest side 3.1° away from fixation in lowercase black Arial 15-point font, subtending a height of 0.5° .

Target stimuli consisted of 32 colour photographs of faces selected from the AR Face Database (Martinez & Benavente, 1998). They included eight male faces exhibiting a happy expression (i.e., smiling), eight (different) angry male faces, eight happy female

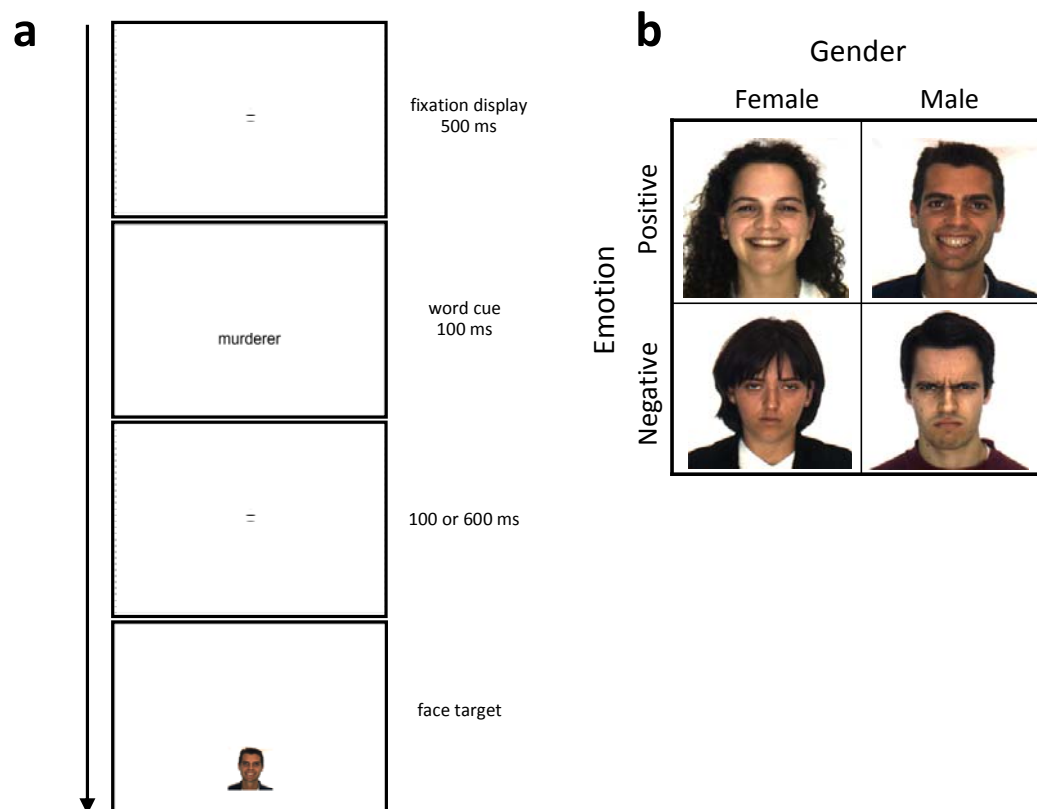
faces and eight (different) angry female faces. Face stimuli subtended $2.9^\circ \times 2.9^\circ$ and were presented with the closest edge 5.5° away from fixation. All stimuli were displayed on a white background.

Procedure

A typical trial sequence and face target examples are presented in Figure 3.1. Participants were tested individually over a 50-minute session. Each trial began with the participant fixating a centrally presented dot for 500 ms. A word cue would then appear for 100 ms above or below the fixation point. After a variable (200 ms or 700 ms) delay following cue onset, the fixation point was removed and a face target presented. Participants were asked to ignore the word cue and maintain central fixation until the face target appeared. They then discriminated between either the gender or emotional expression of the face by indicating as quickly and accurately as possible which feature was present using their left or right-hand index finger to press one of two shoulder buttons on an EyeLink© button box (e.g., left button-press for a male face; right button-press for a female face). The target remained onscreen until a response was made or 8,000 ms elapsed. Participants initiated the next trial with a button-press or by waiting 5,000 ms. If fixation was broken before the target appeared, the trial would stop immediately. The aborted trial would restart after a fixation reminder message, a button-press and a 2,000 ms interval.

The experiment commenced with a practice block of 12 trials where participants received verbal and visual feedback. Eight experimental blocks of 32 trials followed, giving a total of 256 analysable trials. Trials were self-paced.

Figure 3.1 a) A typical task sequence. Participants fixated the central point for 500 ms, after which a word cue was presented either above or below fixation for 100 ms. Following a variable delay of 100 or 600 ms a face target appeared either above or below fixation. Participants made a button-press to discriminate either the gender or the emotion of the face. Presented is an example of a word cue that is incongruent with the equivalent face property. Stimuli not drawn to scale. **b)** Examples of face stimuli used as targets, for each of the gender and emotion categories.



Design

Participants' RTs were measured as the time taken to make a correct button-press response after the target had been presented. The word cue position could validly or invalidly predict the location of the upcoming target, that is, appear in the same visual field as the target (valid cue), or appear in the opposite visual field (invalid cue), with equal probability. The word cue category was equally likely to have a high (e.g., emotionally charged word cue presented in an emotional task) or low (e.g., emotional word cue presented in a gender task) degree of information overlap with the task.

Additionally, the word cue value was either semantically congruent (e.g., a male first name preceding a male target face) or incongruent (e.g., a negative word cue preceding a happy target face) with the corresponding target feature, again with equal probability. There was no strategic advantage to attend to the word cue, as it was irrelevant to the task.

The discrimination task (gender, $N = 27$; emotional, $N = 23$) was a between-participants factor. Within-participants factors included two SOAs (200 ms and 700 ms) \times two cue validity conditions (valid and invalid) \times two cue-task information overlap conditions (high and low) \times two cue-target feature congruency conditions (congruent and incongruent) yielding a total of 16 conditions, each repeated 16 times. The 32 cue and target stimuli were each presented eight times during the experiment.

A pseudo-random trial order was employed, limited by allowing no more than four successive presentations of the same cue validity condition, cue value or task-relevant target value. Two trial orders (one reversed) \times two stimulus-response maps (i.e., index finger used to respond to a particular target) were balanced across participants.

Data Analysis

Central fixation was defined as having gaze or eye position remain within 1.65° of the fixation point. Trials were rejected from subsequent analyses if: a) an incorrect button-response was made, b) central fixation was broken before the target appeared (the restarted trial was also rejected), or c) RTs were less than 200 ms (i.e., considered

an anticipatory response) or more than three standard deviations above the mean for each task (i.e., considered a late response).

Seven participants' datasets were excluded from analyses because at least 20% of trials were rejected. Of the remaining 50 participants, a total of 9.28% of trials (8.12% and 10.27% for the emotional and gender tasks, respectively) were not included in the RT analyses. Button-response errors, which contributed to 3.05% of these rejected trials, were further analysed separately to examine the potential for speed-accuracy trade-offs.

Mean RTs were recalculated and response error rates determined for each of the 16 conditions for each participant. Two independent-samples *t* tests compared overall RTs and error rates between discrimination tasks.

A four-way repeated measures analysis of variance (ANOVA) was conducted on mean RTs and error rates using within-participants factors of SOA (200 ms vs. 700 ms), cue validity (valid vs. invalid), cue-task information overlap (high vs. low) and cue-target feature congruency (congruent vs. incongruent). If an ANOVA revealed a significant interaction between cue-task overlap and congruency for either mean RTs or error rates, four separate $2 \times 2 \times 2$ ANOVAs were to be conducted for each of the two (gender and emotional) discrimination tasks and two (gender and emotional) cue categories therein. The within-participants factors included SOA, cue validity, and cue-target feature congruency. If an ANOVA revealed a significant three-way interaction, four paired-samples *t* tests were planned to compare congruent with incongruent trials for each of the SOA \times cue validity conditions. Additional paired-samples *t* tests were

planned for two-way interactions in the absence of a three-way interaction. For an SOA \times congruency interaction, the two congruency conditions (collapsed across cue validity) were compared for each SOA; for a cue validity \times congruency interaction, the two congruency conditions were compared (collapsed across SOA) for each of the cue validity conditions; and for an SOA \times cue validity interaction, valid and invalid trials were compared (collapsed across congruency) for each SOA. An alpha level of .05 was used for all inferential statistical tests, and all t tests were two-tailed.

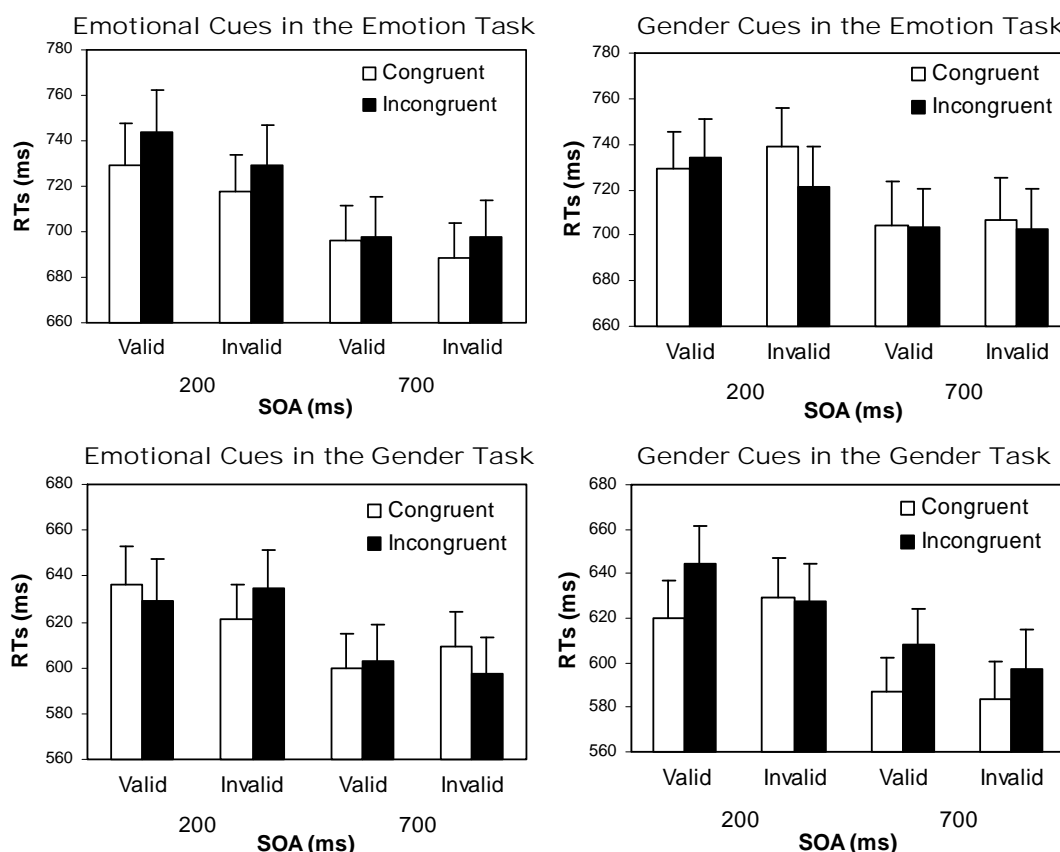
Results

Mean correct RTs and standard errors for each of the SOA \times cue validity \times congruency conditions are presented in Figure 3.2, separately for each cue category (emotion and gender) within each discrimination task (emotion and gender). No clear attentional cuing effects were apparent across either of the tasks, cue categories or SOAs, as would be characterised by differences between RTs as a function of cue validity. Faster RTs appeared to occur at the 700 (vs. 200) ms SOA. For emotional cues in the emotion task and gender cues in the gender task, RTs seemed to be generally faster when the cue was congruent, rather than incongruent, with the equivalent target feature. This did not appear to be evident for the other cue category \times task combinations.

Table 3.1 shows mean error rates (percentage of incorrect responses) and standard errors across each of the conditions for all four cue category \times discrimination task combinations. Error rates were low overall, with no difference between the emotional (2.62%) and gender tasks (3.43%), $t < 1.3$. When a particular condition

showed both RT and error rate effects, they were in the same direction, for example, if a condition had a higher error rate, it was never accompanied by faster RTs (and vice-versa). With no evidence of a speed-accuracy trade-off, the more sensitive measure of RT was concentrated on. Mean RTs for the gender task were 101 ms faster overall than for the emotional task, $t(48) = 4.55$, $SE = 22.26$, $p < .001$.

Figure 3.2 Mean reaction times (RTs; ms) and standard errors for congruent versus incongruent cue-target trials as a function of cue validity and stimulus onset asynchrony (SOA; ms) in the four different combinations of task and cue type in Experiment 1. Each panel represents one combination of task and cue type. White bars represent congruent cue-target trials; black bars represent incongruent cue-target trials.



The four-way ANOVA on RTs revealed a significant main effect of cue-task information overlap, $F(1, 49) = 4.11$, $MSE = 1,041.19$, $p < .05$, $\eta^2 = .08$; cue-target feature congruency, $F(1, 49) = 6.67$, $MSE = 718.06$, $p < .05$, $\eta^2 = .12$; and SOA, $F(1, 49) = 75.04$,

$MSE = 2,652.52$, $p < .001$, $\eta^2 = .61$. A significant interaction between cue-task overlap and congruency was found, $F(1, 49) = 12.20$, $MSE = 881.55$, $p < .01$, $\eta^2 = .20$, prompting a further four ANOVAs on RT to be conducted, of which the results of each are reported in separate paragraphs below.

Table 3.1 *Mean error rate and standard errors for congruent versus incongruent cue-target trials as a function of task, cue category, stimulus onset asynchrony (SOA), and cue validity in Experiment 1*

Cue Category and Cue-Target Congruency	SOA = 200 ms				SOA = 700 ms			
	Valid		Invalid		Valid		Invalid	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Emotional Task								
<i>Emotional Cue</i>								
Congruent	2.45	0.94	2.45	0.94	2.72	0.77	2.72	0.86
Incongruent	2.99	1.03	2.72	1.03	3.53	1.23	2.45	0.65
<i>Gender Cue</i>								
Congruent	2.17	0.93	3.26	1.10	2.45	0.94	2.45	0.86
Incongruent	4.35	1.21	2.72	1.03	2.99	0.87	1.36	0.55
Gender Task								
<i>Emotional Cue</i>								
Congruent	6.02	1.27	2.55	1.07	3.01	0.84	3.70	1.07
Incongruent	2.08	0.75	4.40	1.24	2.78	0.77	3.70	0.90
<i>Gender Cue</i>								
Congruent	1.62	0.54	3.24	0.70	1.62	0.54	4.86	1.07
Incongruent	6.25	1.16	5.32	1.32	3.70	1.02	3.24	0.91

Note: Mean error rate as a percentage.

Emotional Cues in the Emotional Task

The RT analyses for emotional cues in the emotional task revealed a significant main effect of congruency, $F(1, 22) = 5.63$, $MSE = 743.05$, $p < .05$, $\eta^2 = .20$, where cues congruent with the target emotion (708 ms) produced faster RTs than incongruent cues (717 ms). A significant main effect of SOA was also found, $F(1, 22) = 78.70$, $MSE = 714.97$, $p < .001$, $\eta^2 = .78$. The 700 ms (relative to the 200 ms) SOA condition produced

an RT benefit of 35 ms. There were no other significant main effects or interactions (all remaining F values < 3.2).

Gender Cues in the Emotional Task

A significant main effect of SOA on RT for gender cues, $F(1, 22) = 34.24$, $MSE = 950.08$, $p < .001$, $\eta^2 = .61$, found RTs following 700 ms SOAs were 27 ms faster than 200 ms SOAs. Analyses yielded no other significant main effects or interactions (all remaining F values < 1.7).

Emotional Cues in the Gender Task

A three-way interaction between SOA, validity and congruency was revealed in the RT analyses for emotional cues in the gender task, $F(1, 26) = 5.13$, $MSE = 833.61$, $p < .05$, $\eta^2 = .16$, of which further analyses showed no significant congruency differences for any of the SOA \times validity conditions (t values < 1.7). Another main effect of SOA, $F(1, 26) = 16.35$, $MSE = 2,619.36$, $p < .001$, $\eta^2 = .39$, showed 700 ms trials to be 27 ms faster than 200 ms trials. No other significant main effects or interactions were found (all remaining F values < 1.1).

Gender Cues in the Gender Task

A significant main effect of congruency on RT was evident, $F(1, 26) = 10.56$, $MSE = 1,078.16$, $p < .01$, $\eta^2 = .29$, as well as a significant interaction between validity and congruency, $F(1, 26) = 8.01$, $MSE = 491.43$, $p < .01$, $\eta^2 = .24$. When gender cues were valid in predicting the location of the upcoming target, RTs were 23 ms faster when the cue and target were congruent compared to incongruent. A significant main effect of SOA was also evident, $F(1, 26) = 26.57$, $MSE = 2,668.97$, $p < .001$, $\eta^2 = .51$. Compared to

the 200 ms condition, the 700 ms condition produced RTs which were 36 ms faster.

There were no other significant main effects or interactions (all remaining F values < 2.1).

Discussion

Our analyses found evidence supporting the hypothesis that semantic information from task-irrelevant peripheral cues differentially influences performance when sharing a high degree of information properties with the task set. When there was high cue-task information overlap for both tasks, cues which were semantically congruent, rather than incongruent with the target, facilitated task performance. This effect was observed across conditions for the emotional task, but was more pronounced in the valid cue conditions for the gender task. For the low cue-task information overlap conditions, gender cues did not interfere with the emotional task, whereas emotional cues interfered with performance on the gender task to some extent, as evidenced by a three-way interaction (with no significant differences revealed by planned contrasts). The finding that RTs were faster following a longer delay between cue and target onset was pervasive across conditions for both tasks and likely reflected easier anticipation of the target appearance at longer SOAs (see Gabay & Henik, 2008). Performance was faster overall for the gender task compared to the emotional task.

These data suggest that the task-dependent semantic effects likely resulted from the priming of an irrelevant response associated with the cue, comparatively facilitating task performance when it was congruent with the correct response. Contrary to predictions, however, the semantic effects appeared to occur independently of spatial

orienting. Main effects of congruency were found for emotional cues in the emotional task and for gender cues in the gender task, but no main effects of validity for either task. Thus, the semantic features of the cues were processed extensively enough to have a measurable impact on performance, even though these cues produced no spatial cuing effects with the current stimulus parameters. However, without a general validity effect, no firm conclusion can be made about the independence of spatial orienting processes from the observed semantic effects. The absence of a validity effect may have reflected the SOAs used, such that following a valid (vs. invalid) cue, any RT advantage was already lost by the time of the target appearance in the 200 ms condition, and that any subsequent RT disadvantage, or IOR effect, had yet to fully develop by the time of the target appearance in the 700 ms condition. Experiment 2 was designed to address this issue by replicating the findings of Experiment 1 utilising a shorter SOA time intended to produce positive spatial cuing effects.

Experiment 2

This second experiment was designed to replicate the semantic influence effects observed in Experiment 1, as evidenced by the cue-task information overlap and cue-target congruency interaction, and to test whether any such semantic effects were independent of an observed validity effect. To this end, Experiment 2 used a shorter and unchanging SOA time of 100 ms to induce spatial cuing effects.

Method

Participants

Thirty-six Victoria University of Wellington students (who had not taken part in Experiment 1) were selected as before. Data from four participants were not used in the primary analyses due to excessive trial errors. The remaining 32 participants (24 female, 28 right-handed) had a mean age of 19.56 years.

Stimuli, Apparatus, Procedure and Design

Only one unchanging SOA between cue and target onset of 100 ms was used for Experiment 2. The discrimination task became a within-participants factor, where each participant would first complete 10 practice trials followed by four experimental blocks of 32 trials for one task and then complete another 10 practice trials and a further four experimental blocks for the other task, altogether providing 256 analysable trials. Task order was counterbalanced across participants. In all other respects, the stimuli, apparatus, procedure and design were the same as in Experiment 1.

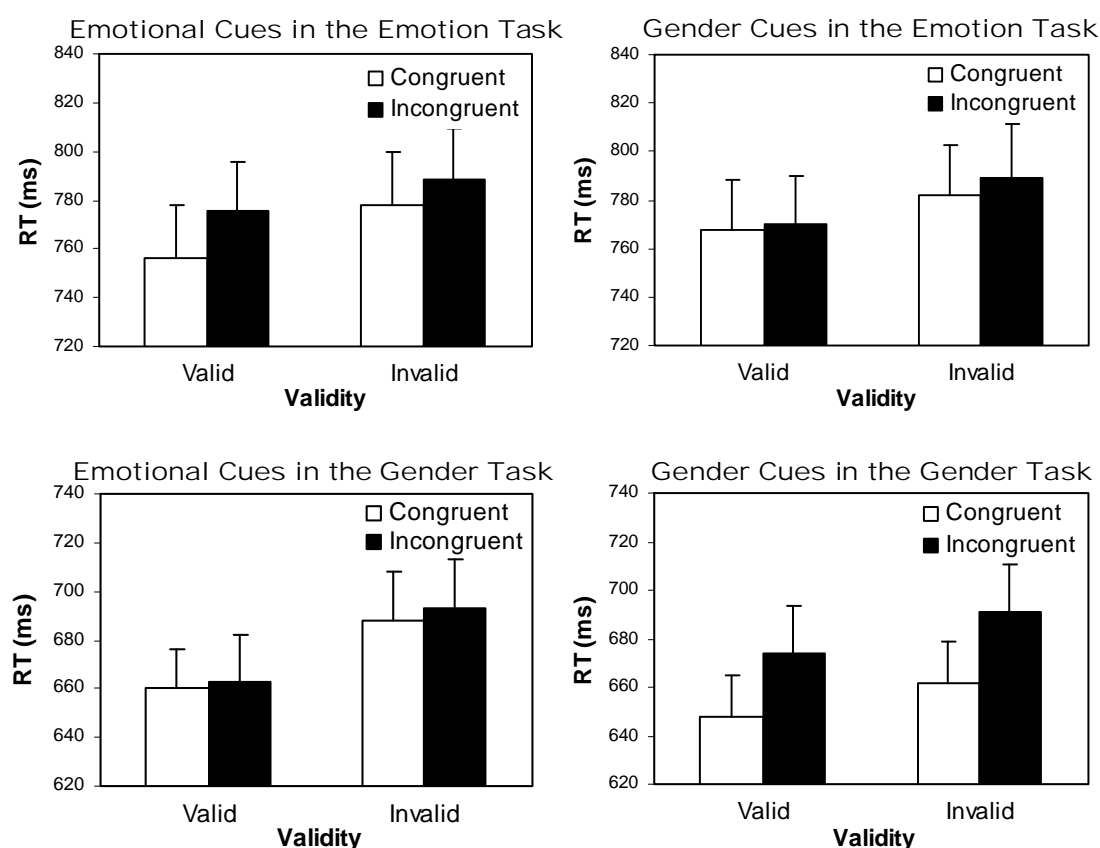
Data Analysis

Responses were again considered to late if RTs were more than three standard deviations above the mean for each task. One participant's dataset was excluded from analyses because more than 20% of trials were rejected. Of the remaining 32 participants, a total of 6.25% of trials (6.42% and 6.01% for the emotional and gender tasks, respectively) were not included in the RT analyses. Button-response errors, contributing to 3.66% of these rejected trials, were further analysed separately to examine for evidence of speed-accuracy trade-offs.

Data analyses were the same as for Experiment 1, but with the following exceptions. Because SOA was now fixed, a three-way ANOVA was conducted on mean

RTs and error rates using cue validity (valid vs. invalid), cue-task information overlap (high vs. low) and cue-target feature congruency (congruent vs. incongruent) as within-participants factors. If an ANOVA revealed a significant interaction between cue-task information overlap and congruency, four separate 2×2 ANOVAs were to be conducted for each of the two (gender and emotional) discrimination tasks and two (gender and emotional) cue categories therein. The within-participants factors for these two-way ANOVAs included cue validity and cue-target feature congruency.

Figure 3.3 Mean reaction times (RTs; ms) and standard errors for congruent versus incongruent cue-target trials as a function of cue validity in the four different combinations of task and cue type in Experiment 2. Each panel represents one combination of task and cue type. White bars represent congruent cue-target trials; black bars represent incongruent cue-target trials.



Results

Mean correct RTs and standard errors for each of the cue validity \times congruency conditions are presented in Figure 3.3, separately for each cue category (emotion and gender) within each discrimination task (emotion and gender). Again, RTs appeared faster following cues congruent (vs. incongruent) with the equivalent target feature, but only for the emotional cues in the emotion task and the gender cues in the gender task. A clear cue validity effect is suggested across all cue category \times task combinations, as characterised by faster RTs for validly (vs. invalidly) cued trials.

Table 3.2 shows mean error rates (percentage of incorrect responses) and standard errors across each condition for all four cue category \times discrimination task combinations. Error rates were again low, with no difference between task (emotional, 3.54%; gender, 3.78%), $t < 0.5$, or any evidence of a speed-accuracy trade-off. Accordingly, RTs again became the primary measure of focus. Mean RTs for the gender task (672 ms) were faster overall than for the emotional task (776 ms), $t(31) = 10.01$, $SE = 10.29$, $p < .001$.

The three-way ANOVA on RTs yielded significant main effects of validity, $F(1, 31) = 23.27$, $MSE = 1,036.98$, $p < .001$, $\eta^2 = .43$, and congruency, $F(1, 31) = 16.23$, $MSE = 689.74$, $p < .001$, $\eta^2 = .34$. A significant interaction was observed between cue-task overlap and congruency, $F(1, 31) = 4.35$, $MSE = 1,087.24$, $p < .05$, $\eta^2 = .12$. No interactions with validity were apparent (F values < 1.1). Consequently, the four ANOVAs on RT are again reported in separate paragraphs below.

Emotional Cues in the Emotional Task

For emotional cues in the emotional task a significant main effect of validity, $F(1, 31) = 6.42$, $MSE = 1,481.75$, $p < .05$, $\eta^2 = .17$, showed RTs to be 17 ms faster following valid (relative to invalid) cues. A significant main effect of congruency was also revealed, $F(1, 31) = 5.35$, $MSE = 1,347.25$, $p < .05$, $\eta^2 = .15$, where RTs were 15 ms faster when the emotion of the cue was congruent with that of the target compared to when it was incongruent. No significant interaction was observed between validity and congruency ($F < 0.4$).

Gender Cues in the Emotional Task

A significant main effect of validity was found for RTs following gender cues in the emotional task, $F(1, 31) = 7.24$, $MSE = 1,226.88$, $p < .05$, $\eta^2 = .19$. Valid cues produced RTs that were 16 ms faster overall compared to invalid cues. There was no main effect of congruency, nor any interaction between validity and congruency (remaining F values < 0.5).

Emotional Cues in the Gender Task

For the gender task, RTs were 29 ms faster overall when following a valid (compared to invalid) cue, $F(1, 31) = 21.47$, $MSE = 1,243.70$, $p < .001$, $\eta^2 = .41$. There was no main effect of congruency, nor any interaction between validity and congruency (remaining F values < 0.4).

Gender Cues in the Gender Task

For gender cues in the gender task, a significant main effect of validity was found, $F(1, 31) = 5.73$, $MSE = 1,334.98$, $p < .05$, $\eta^2 = .16$, with faster RTs (15 ms) following valid cues compared to invalid cues. A significant main effect of congruency, $F(1, 31) =$

14.05, $MSE = 1,768.99$, $p < .001$, $\eta^2 = .31$, showed cues of a gender congruent with that of the target produced RTs which were 28 ms faster than when incongruent.

Congruency did not significantly interact with validity ($F < 0.4$).

Table 3.2 Mean error rate and standard errors for congruent versus incongruent cue-target trials as a function of task, cue category, and cue validity in Experiment 2

Cue Category and Cue-Target Congruency	Valid		Invalid	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Emotional Task				
<i>Emotional Cue</i>				
Congruent	2.34	0.78	3.52	0.79
Incongruent	3.91	0.83	5.08	1.21
<i>Gender Cue</i>				
Congruent	3.52	1.05	3.91	0.92
Incongruent	3.13	0.84	4.88	0.92
Gender Task				
<i>Emotional Cue</i>				
Congruent	2.34	0.83	1.37	0.46
Incongruent	3.13	0.89	4.30	1.14
<i>Gender Cue</i>				
Congruent	2.15	0.66	3.91	1.42
Incongruent	4.88	1.28	6.25	1.51

Note: Mean error rate as a percentage.

Discussion

The findings from Experiment 1 were replicated, showing the extent of processing semantic information from task-irrelevant peripheral cues depended on the degree of information overlap between cue and task set. Across both tasks, when the cues had a high degree of overlap with the task set they facilitated task performance when congruent, compared to incongruent, with the equivalent target property. Unlike Experiment 1, however, a validity effect was found across all cue categories and discrimination tasks, where RTs were faster following cues which were valid compared

to invalid. Furthermore, there were no significant interactions evident between cue congruency and validity for any cue category \times discrimination task combination. Thus, the results demonstrate that the semantic influences were independent of an observed and robust validity effect. This provides more convincing evidence that the processing of semantic information from exogenous cues in the current paradigm is independent of, and utilises different mechanisms from, spatial attentional orienting.

General Discussion

The present study found evidence of task set-dependent semantic influence, where semantic information from peripheral cues was processed extensively enough to impact task performance. In the current paradigm, all experiments (and task sets therein) had faces as target stimuli, each with both gender and emotional expression features. When having to judge emotional expression, attending to emotional features of the face was prioritised, and the congruency of the gender cues to the gender features of the face did not influence task performance. Conversely, having to judge gender required attentional priority be given to the gender features of the face, where the congruency of the emotion cues to emotional expression features of the face had little impact on task performance.

These findings are consistent with those of Koivisto and Revonsuo's (2007), in that task set differentially influenced the level of processing for irrelevant stimuli, depending on whether they shared information properties with targets as defined by the task set. The present study thus provides converging evidence by effectively replicating and extending the findings of Koivisto and Revonsuo's (2007), via translation

of their methodology to an entirely different paradigm. The use of the spatial cuing paradigm afforded tighter experimental control, whereby individually tested participants each completed 256 critical trials allowing within-participants comparisons to be made (compared to one critical trial completed by group-tested participants in the inattentional blindness paradigm). It also allowed the use of the eye-tracking technique which confirmed participants' eyes remained fixated during cue presentation, showing that such differential processing of cues could be achieved when only covert exogenous attentional resources were available.

The current data suggest that the occurrence of semantic congruency effects for high cue-task information overlap conditions likely resulted from the priming of an irrelevant response associated with the cue, comparatively facilitating task performance when it was congruent with the correct response. These findings can best be interpreted using Kornblum et al.'s (1990) dimensional overlap model. When cues and task set shared a high degree of information properties, this also created a high degree of dimensional overlap between the response representations associated with the cue versus the target. According to the model, a task-irrelevant cue, containing a set of information properties which the discrimination task relied on, would have primed a response, so that when the target appeared, the computation of the correct response was facilitated or inhibited as a function of the already-activated response representation. Congruent activated responses would lead to relatively faster RTs than incongruent activated responses. When cues did not share information properties with

the task set, cue-target congruency had little impact on RTs given the lack of overlap between response representations associated with the cue versus the target.

Across both experiments, semantic effects were obtained independent of spatial orienting. This observation strongly suggests that the effects of response priming pertain to levels of processing other than those associated with the operation of selective attention. In this sense, the current data are consistent with those of Shalev and Algom (2000), who, using a Stroop task adapted for a spatial cuing paradigm, found semantic influences affected performance equally at both validly and invalidly cued locations. The current data do contrast, however, with the semantic effects obtained by Stolz (1996) and Fox et al. (2001) for invalidly cued locations only. It is also noteworthy that in the current paradigm, semantic response-congruent priming from cues consistently *facilitated* responses, whereas Stolz (1996) found semantically related invalid cues *slowed* RTs. A clue as to the cause of these differing results may reside in key differences between Stolz's paradigm, where cues shared information properties only with the context word and not with the task (i.e., intrinsic informativeness), and the present study, where cues shared information properties with the task (i.e., context-dependent informativeness).

The intrinsic informativeness that Stolz's (1996) cues possessed appeared to hold attentional resources for longer. Could it be that participants became aware of the semantic relation between context word and peripheral word cue? In this case, the extra allocation of attention to the peripheral cue would imply an explicit effort to integrate contextual information with the new information arriving in the visual field—

an exercise aimed at creating new information, or establishing a new context. Attention then would be locked onto the new information until the oddity is resolved, integrated, or otherwise satisfactorily processed.

In contrast, the context-dependent informativeness that the cues in the present study possessed elicited priming processes which appeared to occur autonomously, and indeed, regardless of the operation of selective attention. Such a nonspatial prioritisation of information should be regarded as a form of controllable goal-dependent automaticity (Bargh, 1992), in that it depends on a context which requires not only the presence of the cue stimulus, but also the specific processing goal (on part of the participant) derived from having to make a judgement relying on information properties which are shared by the cue. The resultant semantic activation could be argued to be automatic in the sense that it did not require spatial attentional resources, occurred involuntarily (i.e., cues were instructed to be ignored), and was autonomous once initiated upon presentation of the cue in the context of an appropriate goal. Although not examined in the present study, there is a considerable body of literature that would also suggest such semantic priming of responses can also occur without awareness (e.g., Balota, 1983; Damian, 2001; Dehaene et al., 1998; Fischler & Goodman, 1978; Fowler, Wolford, Slade, & Tassinari, 1981; Marcel, 1983, but see Daza, Ortells, & Noguera, 2007; Ortells, Vellido, Daza, & Noguera, 2006, for evidence that unawareness might change the nature of the priming).

The current findings indicate that once the semantic representation of the cue word primed the response representation, its subsequent impact on RTs was

independent of where attention resources were allocated when the target appeared. It is however suggested (e.g., Vivas & Fuentes, 2001) that attention *is* required to process the cue in order to activate the semantic, and thus response, representation in the first place. Their study explored the influence of IOR on Stroop interference, and observed an elimination of Stroop interference when presenting task-irrelevant incongruent cues in inhibited (i.e., validly cued) versus uninhibited (i.e., invalidly cued) locations. This was interpreted as inhibitory tagging, occurring in IOR, disconnecting the link between semantic and response representations. Importantly, their results showed that attentional processes (as measured by IOR) play a crucial role in how semantic information from cues primed associated responses (see also Choi, Cho, & Proctor, 2009).

The discrepancy between the current data and those of Shalev and Algom (2000) on the one hand, and those of Stolz (1996) on the other, does call for a re-evaluation of the blank notion that semantics interact with spatial orienting. Semantic influence does not necessarily impact on the spatial orienting system, even when irrelevant information clearly manages to infiltrate into the covert layers of the cognitive system, all the way up to the level of response preparation.

Intriguingly, in Experiment 1 a weak three-way interaction (which included validity) was observed for emotional cues on the gender task. Could this interaction reflect the intrinsic informative nature of emotional stimuli and its potential to impact on the process of spatial orienting regardless of the task? This would be consistent with Okon-Singer et al.'s (2007) proposal that emotional cues can be strong enough to

impede on task processing when they are entirely task-irrelevant (i.e., are irrelevant to the task and have a low degree of information overlap with the task set). The complexity of the effect, however, and the fact that it did not occur in Experiment 2, precludes any firm interpretation of the mechanisms through which this emotional influence might have operated.

The only difference between the Experiment 1 and 2 methodologies (apart from task set changing from a between- to within-participants factor) was the timing of the target presentation relative to that of the cue (i.e., the temporal profile of spatial orienting). Looking for solid evidence of semantic influence, in Experiment 1 it was opted to present the peripheral cues for an exposure duration of 100 ms, at a cue-target SOA of 200 ms or 700 ms. While finding evidence of semantic effects with this procedure, there was a failure to obtain main effects of spatial validity. Most likely, any facilitative effect of spatial orienting had already been lost by 200 ms, whereas the phenomenon of IOR had not yet fully developed by 700 ms. For Experiment 2, a cue-target SOA of 100 ms was used in a further attempt to observe reliable validity effects in spatial orienting. Using this SOA, a facilitative effect of spatial orienting was in fact observed. Importantly, semantic influences that depended on task set and did not interact with spatial orienting were again observed. Thus, even under conditions of high cue-task informational overlap, no evidence of semantic influence was observed on the capture and hold stages of covert attentional orienting (see Figure 3.4).

In conclusion, the present study showed a robust influence of semantic information carried by irrelevant peripheral cues which was dependent on task set. This

influence appeared to reflect semantic priming of response representations shared between the cue and target (as defined by the task), affecting task performance and occurring independently from spatial attentional processes. As such, it is suggested that an automatic nonspatial prioritisation of information occurs under certain contexts (as defined by task set) which render a context-dependent informativeness for the cue.

Figure 3.4 Visual attention findings.

		Forms of orienting	
		Covert	Overt
Stages of orienting	Hold	no semantic effect	
	Capture	no semantic effect	

Chapter 4

Attentional Capture and Hold: The Oculomotor Correlates of the Change Detection Advantage for Faces

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Attentional Capture and Hold: The Oculomotor Correlates of the Change Detection Advantage for Faces

The previous chapters have highlighted a degree of automatic semantic priming that occurs apparently independent of the capture and hold processes of covert attentional orienting. All experiments documented in the previous chapters utilised Posner's (1980) relatively constrained spatial cuing paradigm along with eye-tracking techniques to isolate covert allocation of spatial attention to semantic information. What would occur in more naturalistic, free-viewing situations where overt shifts of attention take place? The present study investigated whether semantic information influenced capture, hold, or both, processes of *overt* attention (see Figure F2, the two cells in the right column).

Exploring this issue requires re-examination of how capture and hold of visual attention was originally conceptualised and measured by Stolz (1996) within the spatial cuing paradigm. These processes then need to be re-operationalised within the framework of a suitable experimental paradigm and design to allow for their effective measure in a free-viewing context that utilises overt attention.

Within the spatial cuing paradigm, Stolz (1996) conceptualised the capture of covert attention as the shift towards, and engagement of attention at, a location in space. It was measured at short cue-target stimulus onset asynchronies by reaction time (RT) following valid cues, reflecting the shifting and engagement of covert attention at the cue location, near the subsequent target location. Conversely, covert attentional hold processes were measured by RT following invalid cues, where, after covert

attention has shifted and engaged at a cued location, it is held there until disengaging and shifting towards the subsequently appearing target at a relatively distant alternative location.

The key to an appropriate re-operationalising of capture and hold processes to enable their measurement in a free-viewing paradigm may lie in the tracking and measurement of eye movements. Eye movements determine the quality of early visual information processing, representing a form of behaviour more implicit and sensitive than manual button-press responses. This is because the anatomy of our eyes is such that our visual acuity is highest at the centre of our visual field, that is, when light falls on a small part of the retina called the fovea. The foveal size allows us to see only a 2° area of vision in sharp detail at any one time (approximately the size of a thumbnail held at arms length). Away from this centre of gaze, acuity quickly declines, forming our poorly detailed visual periphery. It is this high visual acuity that is needed to acquire the quality of visual information necessary to complete everyday actions and tasks (e.g., reading and driving). Because of its small size, the foveal area requires direction by the visual attention system in order to select that information which is behaviourally relevant for our goals, thus allowing us to utilise our limited visual information-processing resources to negotiate our daily environment effectively. Our fovea is reoriented, approximately three times per second, to various locations in our visual environment via rapid and ballistic eye movements (i.e., saccades), which reach velocities of up to 900°/s (Carpenter, 1998; Henderson & Hollingworth, 1999a). Once at a fixed location, a relatively stable gaze is maintained (i.e., a fixation) in order to acquire

perceptual and semantic information from that region. In this way, eye movements reflect a real-time measure of the overt allocation of visual attention.

Early research on eye movements has shown them to be responsive to informative regions (Buswell, 1935; Yarbush, 1967) in both simple (Mackworth & Morandi, 1967) and complex (Antes, 1974) scenes. More recent lines of research have explored how eye movements are influenced by semantic information (e.g., De Graef, Christiaens, & d'Ydewalle, 1990; Henderson, Weeks, & Hollingworth, 1999; Loftus & Mackworth, 1978), indicating the importance of both fixation location and fixation duration as sensitive and dynamic measures that reflect perceptual and cognitive processing during free-viewing conditions. Based on this rich history of eye-movement research, for the present study, capture processes were re-operationalised as being reflected by the speed and likelihood of initial fixations on objects in the visual environment, while those eye-movement variables measuring duration and number of fixations and re-fixations on an object were defined as reflecting hold processes. With this in mind, the focus then shifted towards finding a free-viewing paradigm and experimental design that allowed measurement of how such processes were influenced by semantic information.

People are surprisingly poor at detecting changes in their visual environment if the changes follow a large transient; a phenomenon referred to as change blindness (for a review, see Rensink, 2002). Change blindness occurs when local transient motion signals on the retinal image, caused by an image change (which would typically capture attention exogenously; e.g., Klein, Kingstone, & Pontefract, 1992; Posner, 1980), are

swamped by a global transient such as that caused by a saccade (Carlson-Radvansky & Irwin, 1995; Grimes, 1996; Henderson, 1997; Henderson & Hollingworth, 1999b; Irwin, 1991; McConkie & Currie, 1996), eye-blink (O'Regan, Deubel, Clark, & Rensink, 2000), intervening interval (Luck & Vogel, 1997; Pashler, 1988; Phillips, 1974; Rensink, O'Regan, & Clark, 1997; Simons, 1996), cut between camera positions during a movie sequence (Levin & Simons, 1997, 2000), or real-world occlusion (Simons & Levin, 1998; Wang & Simons, 1999). Based on the findings that such changes are more rapidly detected at "centres of interest" (e.g., Rensink et al., 1997) and exogenously cued locations (Scholl, 2000) it has been proposed that focused attention is necessary (but not sufficient; e.g., Ballard, Hayhoe, & Pelz, 1995; Levin & Simons, 1997; Simons, 1996; Simons & Levin, 1998) for the visual perception of change. As such, successful change detection requires attention be oriented to the location of change.

A useful paradigm was developed by Rensink et al. (1997) to measure change blindness. The "flicker" paradigm intersperses two continuously alternating displays (one original and one modified image) with a brief blank screen to create the appearance of a flicker. Participants freely view the alternating display, and when a change across images is perceived, respond with a manual button-press. Using this paradigm, Ro, Russell, and Lavie (2001) found that participants were both faster and more accurate at detecting changes in human faces than they were in other objects of less sociobiological significance, but only when faces were upright and in multiple-object displays. Their interpretation of this finding was that faces, due to their high biological

and social significance, received attentional priority when in competition with other objects.

The present study proposed to examine the oculomotor correlates of the change detection advantage for faces in the flicker paradigm, to explore which overt attentional processes in a free-viewing paradigm are influenced by the semantic manipulation of sociobiological significance. Recent research by Ro, Friggel, and Lavie (2007) and Bindemann, Burton, Hooge, Jenkins, and de Haan (2005) would suggest such a semantic manipulation to affect attentional hold processes, while other research (e.g., Devue, Laloyaux, Feyers, Theeuwes, & Brédart, 2009; Langton, Law, Burton, & Schweinberger, 2008; West, Anderson, & Pratt, 2009) would suggest capture processes to be differentially affected. By comparing the ability of a face versus a neutral object to capture and hold overt attention (as measured by eye movements), it can be determined how the semantic manipulation of biological and social significance influences the capture and hold mechanisms of attention, and thus how semantic information influences overt visual attention processes.

A further question the present study aimed to address was whether the preferential attentional processing afforded to faces was under the control of the participant. The face advantage as observed by Ro et al. (2001) may have been driven by the sociobiologically salient stimuli itself, where the face would have elicited mandatory (i.e., unintentional and uncontrollable) attentional processing from the participant when in competition for attention with other objects. Neuropsychological evidence has suggested that we may have a specialised module for processing human faces (Farah,

1995, 1996; Kanwisher, McDermott, & Chun, 1997), in that the mere appearance of a face in our visual field would prompt its own processing via the mandatory engagement of attentional resources (Fodor, 1983). This idea is also supported by behavioural evidence (Lavie, Ro, & Russell, 2003).

An alternative explanation for the face advantage, however, may be that participants, when faced with a change detection task, employed an idiosyncratic strategy of giving attentional priority to faces over the other object categories. Ro et al. (2001) argued against the idea that the face advantage was strategic, based on the probability of a face change being low (8% of trials) and equal to that of the other five (less sociobiologically salient) object categories. However, the literature is rife with examples across a diverse range of paradigms where participants employ strategies that are not advantageous with respect to the task (e.g., Kahneman, Slovic, & Tversky, 1982; Plous, 1993; see also Collier, Johnson, & Berman, 1998, for evidence in rats). Therefore, it is not unfeasible that participants in Ro et al.'s (2001) study engaged in a strategy of attending to faces at the expense of the less sociobiologically significant stimuli. Whether the face advantage was due to mandatory processing or an idiosyncratic strategy has important implications for the extent to which semantic information associated with biological and social significance can be processed automatically (Bargh, 1992).

This question was investigated in the present study by manipulating whether participants had preknowledge of the object category in which to expect a change. In the preknowledge condition, participants were informed, immediately prior to a trial, of

the category of change. This information was completely valid in that, *if* a change occurred, it would always occur in the identified object category. This effectively narrowed a participant's focus by guiding their search for change detection toward a single category of objects. Consequently, if the face advantage in the flicker paradigm was solely due to strategic search, it would disappear when the more explicit and efficient strategy of utilising preknowledge of the object category to detect changes was available. However, if giving attentional priority to faces was not based on strategic search, then the face advantage should still remain even when the category of change had been made explicit to the participant. This would then provide evidence of the mandatory processing of biologically and socially significant stimuli.

Based on past research, preknowledge of the object category of change was predicted to decrease overall RTs in the change detection task (Austen & Enns, 2003; Rensink et al., 1997), and that this would not eliminate the face advantage (Bindemann, Burton, Langton, Schweinberger, & Doherty, 2007). With respect to overt attentional processes, the face category was expected to both capture attention faster and hold it longer, compared to the less sociobiologically significant object categories. This would be reflected by faces, compared to the other objects, in the changing display being fixated faster and proportionally more often (superior capture), and by receiving longer, as well as more, fixations and re-fixations within a particular trial (superior hold).

Method

Participants

Participants were 34 Victoria University of Wellington students. Each was tested individually over a one-hour session for which they received course credit. All procedures were approved by the School of Psychology Human Ethics Committee, participation was voluntary and informed consent was given by all participants. Data from four of the participants were eliminated from analyses due to poor eye-tracking calibration ($N = 3$) and a computer malfunction ($N = 1$). The remaining 30 participants (19 female, 26 right-handed) had a mean age of 20.80 years and all had normal or corrected-to-normal vision. Participants were naïve as to the specific experimental hypotheses and debriefed following the experiment.

Stimuli and Apparatus

SR Research Experiment Builder (version 1.4.128 RC) was used to program the experiment, which was then run on a 3-GHz Pentium D computer and displayed on a 21" monitor, with a resolution of $1,024 \times 768$ pixels and refresh rate of 60 Hz. Participants placed their chin and forehead on a rest approximately 57 cm from the display screen. Eye position was determined and recorded using the EyeLink® 1000 Tower Mount Head Supported System (SR Research Ltd., Ontario, Canada). The system has a spatial resolution of 0.01° and the signal was sampled and stored at a rate of 1000 Hz.

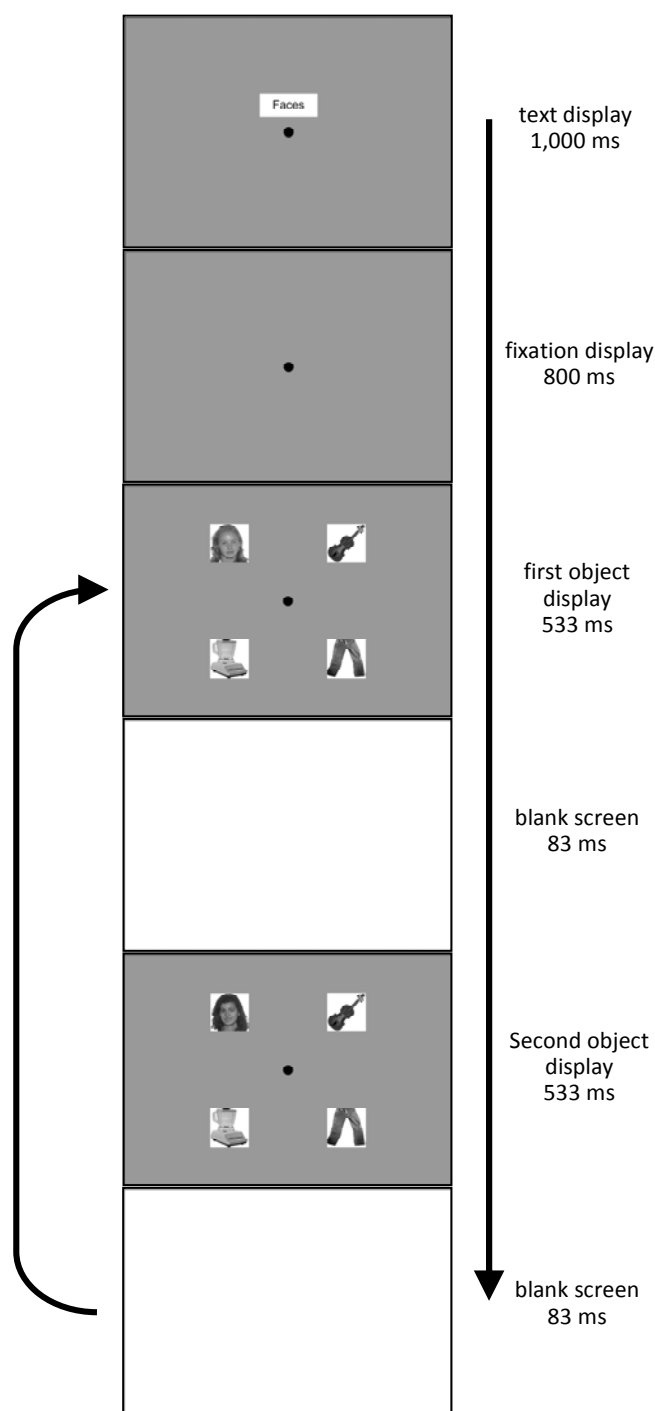
A black fixation dot (with a diameter of 0.5° of visual angle) was presented in the centre of the display screen. Object stimuli were taken from Ro et al.'s (2001) study and consisted of six greyscale photographs for each of four object categories: female faces, musical instruments, appliances and clothes. Each of the 24 objects subtended $2.9^\circ \times 2.9^\circ$ and was presented with its centre 8.5° from fixation. An eccentricity greater than

that used by Ro et al. was employed to decrease possibility of participants using only peripheral vision to process the objects. An object display was made up of four objects (one from each category) presented on a grey background, one in each visual quadrant at right angles to fixation. Five word stimuli were used, consisting of the four object categories names and the word “Any”. All text was displayed in 12-point black Arial font with the first letter of each word capitalised. The word cues subtended a height of 0.5° and were enclosed within a white box which (depending on the cue category) had a height between 0.8° and 1.5° , a width between 1.2° and 3.0° , and was positioned with its lower edge 0.5° above central fixation.

Procedure

The trial sequence is presented in Figure 4.1. Each trial began with a screen with text displaying “READY” for 2,000 ms, before a central fixation dot appeared. After 1,200 ms, or a 500 ms fixation by the participant anywhere within the fixation point area, text was displayed for 1,000 ms just above the fixation point. This text either identified the object category in which a participant could expect a potential upcoming change (i.e., category known) or else indicated that a change could occur in any category (i.e., category unknown). An 800 ms delay followed (where only the fixation point remained), after which two continuously alternating object displays were presented. Object displays were presented for 533 ms apiece, and separated from each other by a blank white screen presented for 83 ms, creating a flicker effect between consecutive object displays. Object displays consisted of four objects (one from each of the four categories) occupying different visual quadrants. On two-thirds of trials, the two object displays

Figure 4.1 A typical task sequence. Participants were presented with text for 1,000 ms above fixation which identified the object category of change. After 800 ms where only the fixation point was displayed, two object displays, each presented for 533 ms, alternated continuously, separated by an 83 ms blank white screen. Object displays consisted of four objects (one from each category) occupying separate visual quadrants. One object differed between object displays in the change-present condition (pictured), while both displays were identical in the change-absent condition. Participants made a button-press to indicate whether a change was present or absent.



differed from each other by using a different image within one object category. On the remaining trials both object displays were identical. Participants were asked to indicate as quickly and as accurately as possible whether an object image was changing between object displays by pressing either the left or right shoulder button on an EyeLink© button box with their equivalent index finger (e.g., left button-press to indicate change-present; right button-press to indicate change-absent). If a change was indicated in the category unknown condition, participants were subsequently asked to identify the changing object category by using the right thumb to press the corresponding button on the button box in response to a spatially altered object array containing four objects representing each category (not necessarily the same image shown in the particular trial). Accuracy rather than speed was emphasised for this category selection. The next trial would immediately begin after the relevant response was made or 20 seconds of alternating object displays had elapsed.

At the beginning of the experiment, participants were shown the six objects for each of the four categories used. They completed a block of 12 practice trials where they were given visual and verbal feedback. Participants then completed five experimental blocks of 36 trials giving a total of 180 analysable trials. Rests were encouraged between blocks.

Design

Dependent variables were separated into button-presses (RTs and error rates) and oculomotor correlates (categorised based on whether they purport to measure

capture or hold processes). Precise operational definitions of these variables are provided in the data analysis section (below).

Within-participants factors included two preknowledge conditions (category known and category unknown), two change conditions (change-present and change-absent) and two semantic values of the changing object category (face and neutral).

Preknowledge of category object was available on 80% of the trials (i.e., 36 trials for each of the four object categories) and always correctly predicted the category of change. On the category unknown condition (made up of 36 trials), the word “Any” was used in place of an object category name, indicating that a change could occur in any of the four object categories. Overall, changes were made on two-thirds of (i.e., 120) trials, equally across both category known (and for each of the four object categories within) and unknown conditions. All four object categories changed with equal probability (i.e., faces on 30 trials; combined neutral objects on 90 trials overall) for both preknowledge conditions.

The Latin-square method was used to counterbalance which image within each of the four object categories was presented on any one trial. For the category selection screen, the objects, and consequently the corresponding button required to indicate a category, substituted spatial positions in successive trials (four object category layouts were used).

Two trial orders (forward, $N = 15$; reversed, $N = 15$) \times two stimulus-response maps (i.e., index finger used to indicate change presence; right button, $N = 14$; left button, $N = 16$, vs. change absence) were balanced across participants. The order of

trials was pseudo-random, where no more than four consecutive trials within a block were of the same change condition, and no more than three successive change-present trials involved the same object category changing.

Results

Data Analysis

An alpha level of .05 was used for all inferential statistical tests, and all *t* tests were two-tailed.

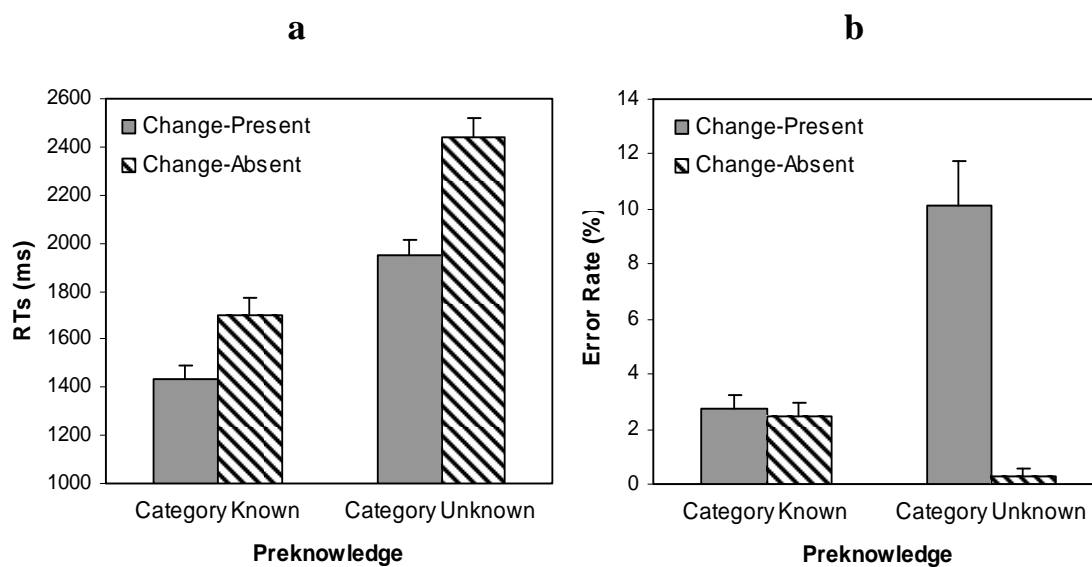
Button-press analyses. Change detection RT was measured as the time taken from initial presentation of the first object display to the time of a correct button-press. A button-press was considered correct if it accurately indicated the presence (and, if relevant, the subsequent identity of the change category) or absence of a change between object displays.

Those RTs which were made within 200 ms of the second object display presentation (i.e., where a potential change can first be detected; considered anticipatory responses) or were more than three standard deviations above the mean (i.e., considered late responses) were removed from subsequent RT analyses (a total of 1.20% of trials).

Three types of errors were possible: misses (incorrectly indicating absence of change), false alarms (incorrectly indicating presence of change), and category identification errors (incorrectly identifying which category of objects changed when category was unknown). Error trials, contributing to a total of 3.48% of all trials, were

not included in the RT analyses, but submitted to their own error rate analyses to determine response accuracy.

Figure 4.2 **a)** Mean reaction times (RTs; ms) and standard errors, and **b)** mean error rates (percentage) and standard errors, for change-present versus change-absent trials as a function of preknowledge. Grey bars represent trials where a change was present; striped bars represent trials where a change was absent.



Preknowledge and change conditions. For each participant, mean RTs and error rates (percentage of incorrect responses) were determined for each of the two preknowledge \times two change conditions. Mean RTs, error rates and associated standard errors for each of the two preknowledge \times two change conditions are presented in Figure 4.2. Participant RTs appeared to be faster when detecting a change was present (vs. absent) and when category of change was known (vs. unknown). Error rates looked to reduce for change-present trials, but increase (albeit not by as much) for change-absent trials when category of change became known. Error rates seemed similar for both change-present and change absent trials when category was known.

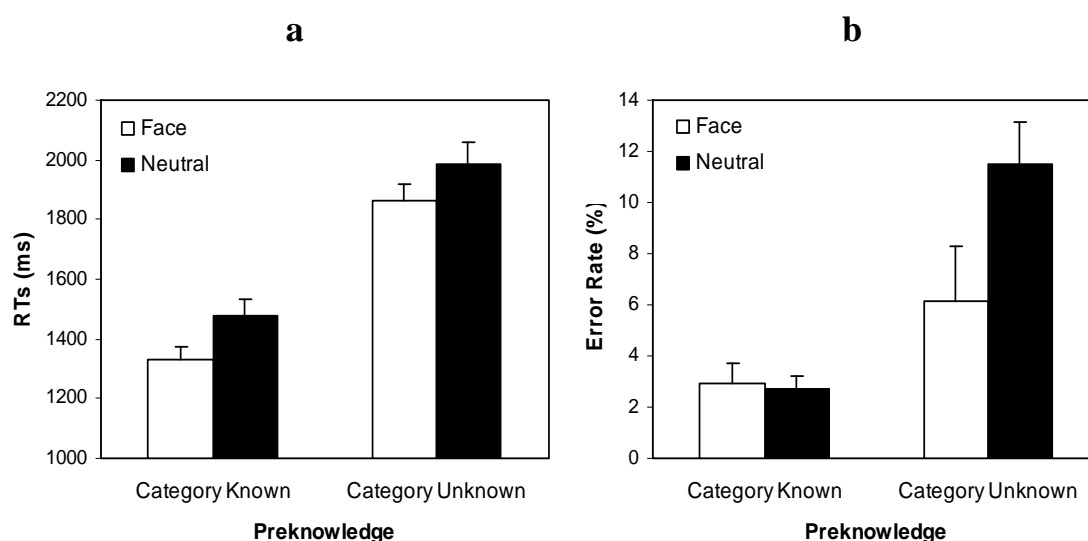
Separate 2×2 repeated measures analyses of variance (ANOVAs) were conducted on mean RTs and error rates, using within-participants factors of preknowledge (category known vs. category unknown) and change (present vs. absent). Two paired-samples t tests were planned if an interaction was evident, comparing the two preknowledge conditions within each of change-present and change-absent conditions.

Reaction time. The ANOVA conducted on RTs revealed a significant main effect of preknowledge, $F(1, 29) = 173.90$, $MSE = 67,098.48$, $p < .001$, $\eta^2 = .86$, indicating participants were on average 592 ms faster to indicate the presence or absence of a change when they had preknowledge of which category of objects could be expected to change. Participants were also significantly faster to indicate a change was present ($M = 1,532$ ms) rather than absent ($M = 1,847$ ms), $F(1, 29) = 167.48$, $MSE = 25,483.77$, $p < .001$, $\eta^2 = .85$. A significant interaction was present, $F(1, 29) = 20.02$, $MSE = 18,869.53$, $p < .001$, $\eta^2 = .41$, revealing a larger benefit of preknowledge on RTs for change-absent (735 ms), $t(29) = -11.40$, $SE = 64.58$, $p < .001$, versus change-present (511 ms) trials, $t(29) = -12.95$, $SE = 39.51$, $p < .001$.

Error rates. The ANOVA on error rates showed significant main effects of preknowledge, $F(1, 29) = 17.37$, $MSE = 11.87$, $p < .001$, $\eta^2 = .37$, and change condition, $F(1, 29) = 28.12$, $MSE = 27.61$, $p < .001$, $\eta^2 = .49$, whereby participants made less errors (i.e., were more accurate) when category of change was known (2.64%) versus unknown (6.85%) and when a change was absent (2.00%) rather than present (4.22%). There was also a significant interaction, $F(1, 29) = 37.84$, $MSE = 18.07$, $p < .001$, $\eta^2 = .57$, showing

that when category was known (vs. unknown), 7.40% fewer errors were made in change-present trials, $t(29) = -5.57$, $SE = 1.33$, $p < .001$, but 2.15% more errors were made in change-absent trials, $t(29) = 4.45$, $SE = 0.48$, $p < .001$.

Figure 4.3 a) Mean reaction times (RTs; ms) and standard errors, and *b)* mean error rates (percentage) and standard errors, for faces versus neutral objects in change-present trials as a function of preknowledge. White bars represent trials where a change occurred in the face category; black bars represent trials where a change occurred in a neutral object category.



Preknowledge and semantic value conditions. For each participant, mean RTs and error rates were determined for each of the two semantic value \times two preknowledge conditions for change-present trials only. The change-absent trials were not examined as these could not be broken down by semantic value. Mean RTs, error rates and associated standard errors for each of the four change-present conditions (two preknowledge \times two semantic value conditions) are presented in Figure 4.3. Participants' RTs seemed to be faster when detecting changes in faces and similarly so for both preknowledge conditions. Reaction times appeared a lot faster when category of change was known versus unknown. Error rates were also low when changing category was known (vs. unknown), where they appeared undifferentiated as a function

of the semantic value of the changing object category. However, error rates looked a lot lower for face (vs. neutral) changing objects when category was unknown.

Separate 2×2 ANOVAs were conducted on mean RTs and error rates for change-present trials, using within-participants factors of preknowledge (category known vs. category unknown) and semantic value of the changing object (face vs. neutral). If an interaction was evident, two paired-samples t tests were planned to compare the two semantic values of the changing object for each preknowledge condition.

Reaction time. The ANOVA on RTs showed significant main effects of semantic value, $F(1, 29) = 10.72$, $MSE = 49,615.55$, $p < .01$, $\eta^2 = .27$, and preknowledge, $F(1, 29) = 156.45$, $MSE = 52,181.33$, $p < .001$, $\eta^2 = .84$. This showed that participants were faster, on average, to indicate a change in a face (1,432 ms) compared to a neutral object (1,568 ms) category, and when the category of change was known (1,438 ms) versus unknown (1,949 ms). No interaction was evident ($F < 0.4$).

Error rates. The ANOVA on error rates revealed main effects of semantic value, $F(1, 29) = 5.49$, $MSE = 36.09$, $p < .05$, $\eta^2 = .16$, and preknowledge, $F(1, 29) = 18.50$, $MSE = 58.29$, $p < .001$, $\eta^2 = .39$. Participants were more accurate in detecting that a change was present when the changing object was a face rather than neutral, or when category was known versus unknown (as indicated in the above planned t test for the first ANOVA). A significant interaction, $F(1, 29) = 10.55$, $MSE = 22.30$, $p < .01$, $\eta^2 = .27$, showed participants to be significantly more accurate in detecting changes in faces compared to neutral objects, but only when they had no preknowledge of the changing category, $t(29) = -2.93$, $SE = 1.84$, $p < .01$ (vs. category known, $t < 0.4$).

Oculomotor correlates. Many of the eye-movement variables used in the present study were taken from Henderson et al. (1999) who, in turn, translated them from the reading literature (e.g., Rayner, Sereno, Morris, Schmauder, & Clifton, 1989) to a free-viewing paradigm. Several of the eye-movement dependent variables are highly correlated with each other. Multiple measures have been included to give a more comprehensive understanding of the attentional processes involved. They have been separated into whether they purport to measure capture or hold processes.

For the purpose of operationalising and analysing the eye-movement dependent variables, the changing object category is referred to as the target object. Early fixations refer to any fixation occurring within 100 ms of the onset of the first object display (i.e., before the change), including those fixations which began before the onset of this display.

A fixation was defined as the time between saccades, where gaze moved no more than 0.1° per 100 ms. A saccade was defined as an eye movement of a velocity greater than $30^\circ/\text{s}$ or acceleration greater than $8,000^\circ/\text{s}^2$.

Eye-movement analyses were conducted using an interest area, constructed around the target object, of $2.9^\circ \times 2.9^\circ$ (i.e., the exact size of the target object). Means of each eye-movement variable were calculated for each of the four change-present conditions (two preknowledge \times two semantic value conditions) for each participant.

Separate 2×2 repeated measures analyses of variance (ANOVAs) were conducted on each of the eye-movement dependent variables for the change-present trials only. Within-participants factors included the semantic value of the changing

object (face vs. neutral) and preknowledge (known vs. unknown). If any interactions were evident, additional paired-samples *t* tests were planned to compare the two semantic values of the changing object for each of the preknowledge conditions.

Table 4.1 *Oculomotor measures of capture and hold processes for the target object on change-present trials as a function of preknowledge and semantic value of object*

Measure	Category Known				Category Unknown			
	Face		Neutral		Face		Neutral	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
<i>Capture</i>								
Time taken till first fixation (ms)	425	22	626	21	878	52	1044	33
Initial saccade amplitude to target	8.60	0.22	9.02	0.18	9.05	0.42	9.55	0.26
Proportion fixated after first saccade	0.30	0.03	0.17	0.01	0.25	0.04	0.15	0.02
No. of fixations till target object	2.02	0.06	2.62	0.06	2.91	0.14	3.19	0.10
Proportion fixated before other objects	0.61	0.03	0.39	0.02	0.39	0.04	0.27	0.02
Rank order of target object fixation	1.42	0.04	1.77	0.04	2.01	0.10	2.16	0.06
Proportion fixated	0.96	0.01	0.92	0.02	0.93	0.03	0.90	0.02
<i>Hold</i>								
First fixation duration (ms)	430	22	510	16	473	26	515	25
First-pass gaze duration (ms)	832	32	716	30	750	47	681	41
Second-pass gaze duration (ms)	572	81	596	44	510	59	477	42
Total gaze duration (ms)	850	32	767	36	834	48	788	46
First-pass fixation count	1.70	0.07	1.36	0.06	1.52	0.09	1.21	0.05
Second-pass fixation count	0.04	0.01	0.11	0.03	0.20	0.06	0.23	0.04
Total fixation count	1.74	0.07	1.47	0.07	1.73	0.11	1.47	0.08
Number of entries	0.99	0.01	1.01	0.03	1.08	0.05	1.11	0.05

Mean and standard errors of the eye-movement variables for each of the preknowledge × semantic values within change-present trials are presented in Table 4.1.

Capture. *Time taken till first fixation.* This was measured as the time elapsed between the onset of the first object display and the first fixation within the target object area. Early fixations within the target object area were removed from analyses, as were trials in which target objects were not fixated.

A significant main effect of semantic value was found, $F(1, 29) = 37.55$, $MSE = 26,978.89$, $p < .001$, $\eta^2 = .56$, whereby the first fixation was made, on average, 190 ms

earlier when target objects were faces rather than neutral. A significant main effect of preknowledge was also evident, $F(1, 29) = 157.63$, $MSE = 36,156.88$, $p < .001$, $\eta^2 = .84$. When participants had preknowledge as to the object category in which to expect a change, they fixated the target object 425 ms earlier than when the category was unknown. No interaction was evident ($F < 0.5$).

Amplitude of initial saccade to target. This is the amplitude (in degrees) of the first saccade which landed inside the target object area following the onset of the initial object array. For early saccades (completed within 100 ms of object display onset) into the target object area, the next saccade that landed within (though not necessarily beginning from outside) the target object area was used.

There were no significant main effects, nor was there an interaction among semantic value and preknowledge factors on the amplitude of the first saccade made to the target object (F values < 3.9).

Proportion of trials in which the target object was fixated after the first saccade. This measures the proportion of correct RT trials in which the target object was fixated following the first saccade subsequent to the presentation of the initial object display (not taking early fixations into account). It was calculated by dividing the number of trials in which only one fixation was made to reach the target object (see “Number of fixations before reaching the target object” variable, below) by the total number of correct trials (including those in which the target object was not fixated or only fixated early).

A significant main effect of semantic value was found, $F(1, 29) = 21.96$, $MSE = 0.02$, $p < .001$, $\eta^2 = .43$, indicating that a higher proportion of face (0.29) versus neutral (0.16) target objects were fixated after the first saccade following presentation of the first object display. There was no main effect of preknowledge, nor any interaction between semantic value and preknowledge (remaining F values < 2.0).

Number of fixations before reaching the target object. This measures the number of fixations that were made from the first fixation commencing after the onset of the object display to the first fixation within the target object area (inclusive). Trials were only included in the analyses if the target object area was fixated. Early fixations within the target object area were excluded from the calculation, but further fixations in the same trial were included in the analysis (i.e., the subsequent target fixation was used as the end point).

A significant main effect of semantic value was found, $F(1, 29) = 25.23$, $MSE = 0.24$, $p < .001$, $\eta^2 = .47$, whereby less fixations were made before reaching a face (2.18) versus a neutral (2.73) target object for the first time. A significant main effect of preknowledge, $F(1, 29) = 59.82$, $MSE = 0.27$, $p < .001$, $\eta^2 = .67$, revealed that preknowledge of the changing category reduced the number of fixations made to first reach the target object by 0.65. No interaction was evident ($F < 4.2$).

Proportion of trials in which the target was the first object fixated. This measures the proportion of correct trials in which the target object was the first object fixated. It was calculated by dividing the number of trials in which the target object was the first object fixated (see “Rank order in which the target object was fixated” variable, below)

by the total number of correct trials (including those where the target object was not fixated or only fixated early).

Significant main effects of semantic value, $F(1, 29) = 58.95$, $MSE = 0.01$, $p < .001$, $\eta^2 = .67$, and preknowledge, $F(1, 29) = 37.09$, $MSE = 0.02$, $p < .001$, $\eta^2 = .56$, were evident, showing that a higher proportion of face (0.56) versus neutral (0.37) target objects were fixated first, as too were target objects when participants had preknowledge of the changing category (0.44) versus category unknown (0.30). These effects were complicated by an interaction between semantic value and preknowledge, $F(1, 29) = 4.33$, $MSE = 0.02$, $p < .05$, $\eta^2 = .13$, where the face advantage was shown to be significantly more pronounced (0.22 vs. 0.11) when category of change was known, $t(29) = 11.40$, $SE = 0.02$, $p < .001$, rather than unknown, $t(29) = 2.67$, $SE = 0.04$, $p < .05$.

Rank order in which the target object was fixated. This variable measures, upon the presentation of the object display, the rank order of the first fixation to the target object compared to the first fixation to the other three objects in a given trial. Values ranging from 1 to 4 were assigned depending on whether the target object was the first, second, third, or last object to be fixated. Trials were only included in the analyses if the target object area was fixated. Early fixations within the target object area were excluded from the calculation, but further fixations in the same trial were included in the analysis (i.e., the subsequent fixation was used as the starting point).

Significant main effects of semantic value, $F(1, 29) = 26.33$, $MSE = 0.07$, $p < .001$, $\eta^2 = .48$, and preknowledge, $F(1, 29) = 57.44$, $MSE = 0.12$, $p < .001$, $\eta^2 = .66$, were evident, showing that a face versus a neutral target object was fixated earlier when

compared to other nontarget objects in a display, as too were target objects when participants had preknowledge of the changing category. There was also a significant interaction between semantic value and preknowledge, $F(1, 29) = 4.72$, $MSE = 0.07$, $p < .05$, $\eta^2 = .14$. Planned analyses revealed face target objects (1.42) were fixated significantly earlier than neutral target objects (1.77) when compared with other objects in the display, but only when category of change was known, $t(29) = -12.66$, $SE = 0.03$, $p < .001$. There was no significant difference when category was unknown ($t < 1.7$).

Proportion of trials in which the target object was fixated. This measures the proportion of correct trials in which the target object was fixated. If a target only received an early fixation, then it was defined as not having been fixated.

A significant main effect of semantic value was found, $F(1, 29) = 4.73$, $MSE = 0.01$, $p < .05$, $\eta^2 = .14$, indicating that a higher proportion of face (0.95) versus neutral (0.92) target objects were fixated at least once during a trial. There was no main effect of preknowledge, nor any interaction between semantic value and preknowledge (remaining F values < 3.5).

Hold. *First fixation duration.* This was defined as the duration of the first fixation within the target object area until a button-press was made. Early fixations within the target object area were removed from analyses, as were trials in which target objects were not fixated.

A significant main effect of semantic value was found, $F(1, 29) = 12.48$, $MSE = 8,864.16$, $p < .01$, $\eta^2 = .30$, where the first target object fixation was longer in duration for neutral (511 ms) compared to face (438 ms) objects. There was no main effect of

preknowledge, nor any interaction between semantic value and preknowledge (remaining F values < 1.6).

First-pass gaze duration. This was defined as the sum of the individual fixation durations made, between the first entry and exit of gaze (or button-press if the gaze did not exit), on the target object area. If gaze did not enter the target object area before a response was made on a particular trial, the missing value was removed entirely from analyses.

A significant main effect of semantic value was found, $F(1, 29) = 9.78$, $MSE = 26,268.75$, $p < .01$, $\eta^2 = .25$, where face target objects (817 ms) received a longer first-pass gaze than did neutral objects (710 ms). A significant main effect of preknowledge was also evident, $F(1, 29) = 8.69$, $MSE = 11,829.49$, $p < .01$, $\eta^2 = .23$. When the change category was known, compared to unknown, the first-pass gaze on the target object was 46 ms longer. No interaction was evident ($F < 1.0$).

Second-pass gaze duration. This was defined as the sum of the individual fixation durations made, between the second entry and exit of gaze (or button-press if the gaze did not exit), on the target object area. If, on a particular trial, gaze did not return to the target object area for a second time before a response was made, the missing value was removed entirely from analyses.

Due to the low number of re-fixations made to the target object area on trials (see “Second-pass fixation count” and “Number of entries” variables, below) there were not enough participants with data points across the four semantic value \times preknowledge

conditions for change-present trials. As such, a decision, driven by the data, was made to not further analyse this variable.

Total gaze duration. This was defined as the total fixation duration on a target object area until a button-press was made. It is the sum of the durations of all the individual fixations made within the target object area for a given trial. If the target object was not fixated during a trial, the missing value was removed entirely from analyses.

A significant main effect of semantic value was found, $F(1, 29) = 9.29$, $MSE = 13,242.33$, $p < .01$, $\eta^2 = .24$. Face (vs. neutral) target objects received gaze that was, on average, 76 ms longer within a trial. There was no main effect of preknowledge, nor any interaction between semantic value and preknowledge (remaining F values < 1.2).

First-pass fixation count. This measure reflects the number of individual fixations made, between the first entry and exit of gaze, on the target object area. If the target object was not fixated before a response was made, a zero was given as the count for the trial. Early fixations within the target object area were not included in the fixation count (but further fixations in the same trial were still included in the analysis).

Analyses revealed a significant main effect of semantic value, $F(1, 29) = 36.10$, $MSE = 0.09$, $p < .001$, $\eta^2 = .55$, showing faces (1.66) were fixated more often than neutral (1.33) target objects during the first-pass of gaze. A significant main effect of preknowledge was also evident, $F(1, 29) = 17.77$, $MSE = 0.04$, $p < .001$, $\eta^2 = .38$, indicating that preknowledge of the changing category increased the number of first-

pass fixations for a target object by an average of 0.15 fixations per trial. No interaction was evident ($F < 0.2$).

Second-pass fixation count. This is the number of individual fixations made, between the second entry and the exit of gaze, on the target object area. If gaze did not enter the target object area a second time before a response was made, a zero was given as the count number.

A significant main effect of preknowledge was found, $F(1, 29) = 14.60$, $MSE = 0.04$, $p < .001$, $\eta^2 = .33$. More second-pass fixations were made on the target object when the changing category was unknown (0.22) versus known (0.09). There was no main effect of semantic value, nor any interaction between semantic value and preknowledge on the number of second-pass fixations (remaining F values < 2.2).

Total fixation count. This is the total number of individual fixations made on a target object within a trial, until a button-press was made. If gaze did not enter the target object area before a response was made, a zero was given as the count number. Early fixations within the target object area were not included in the fixation count (but further fixations in the same trial were still included in the analyses).

A significant main effect of semantic value was found, $F(1, 29) = 28.69$, $MSE = 0.07$, $p < .001$, $\eta^2 = .50$. More total fixations were made on face (1.73) versus neutral (1.47) target objects within a trial. There was no main effect of preknowledge, nor any interaction between semantic value and preknowledge (remaining F values < 0.1).

Number of entries. This was defined as the number of times a saccade landed from outside to inside the target object area within a trial. If the target object area was

not fixated before a response was made, a zero was given as the count for the trial.

Early saccades (completed within 100 ms of object display onset) were not included in the analyses. Entries which were *only* due to early fixations within the target object area were not included in the entry count (subsequent target fixations in the same trial were included, however).

A significant main effect of preknowledge was found, $F(1, 29) = 8.05$, $MSE = 0.04$, $p < .01$, $\eta^2 = .22$. Overall, participants moved their gaze to the target object, on average, more frequently when the changing category was unknown (1.10) than when known (1.00). There was no main effect of semantic value, nor any interaction between semantic value and preknowledge (remaining F values < 0.4).

Discussion

The results revealed a change detection face advantage, which was shown to be robust despite the presence of a considerable preknowledge effect. Changes in faces were detected, on average, 136 ms faster than in neutral objects, replicating Ro et al.'s (2001) face advantage effect. Furthermore, this effect was found to be independent of a large effect of preknowledge, whereby responses were, on average, 592 ms faster when participants had preknowledge of the changing category. Participants were faster to correctly respond when a change was present rather than absent, with the benefit of preknowledge enhanced when a change was absent.

Lower error rates were evident when participants had preknowledge and when a change was absent (vs. present). The higher accuracy for change-absent trials, however, was only observed when the category was unknown and not when it was known.

Keeping in mind the different types of errors possible across conditions, preknowledge appeared to cause a shift in participants' decision criterion response. A bias in responding "change-absent" when category was unknown was eliminated once participants had preknowledge of the category.

While there was an overall accuracy advantage for the change detection of faces when a change was present, it was only evident when category was unknown (as in Ro et al.'s, 2001 research) and not when category was known. It would be tempting to interpret this finding as evidence that preknowledge eliminated the face advantage with respect to accuracy. However, interpretative caution must be exercised, as error rates for both changing faces and neutral objects when category was known were very low (i.e., 2.92% and 2.69%, respectively). This may reflect a floor effect that could be potentially masking two independent main effects of preknowledge and semantic value on error rates when a change was present (as was seen for RTs).

In summary, a change detection face advantage was found which remained when preknowledge was provided to participants. To answer how this face advantage was expressed in terms of capture and hold processes, the focus now switches to the oculomotor correlates.

Faces were shown to preferentially capture attention over neutral objects on six of the seven measures of capture. For a face (compared to a neutral) target object, less time was taken before its first fixation, a lower number of fixations were made before being reached, and it was fixated earlier in relation to nontarget objects. As the target object, faces were also fixated after the first saccade, were the first object fixated, and

were fixated at least once during a trial, on a higher proportion of trials than compared to neutral target objects. On two measures of how early the target object was fixated compared to nontarget objects, the benefit for faces was greater when the category of change was known. For one measure, the amplitude of the initial saccade to target object, no significant main effects of, or an interaction between, semantic value or preknowledge were observed. This may have been a product of all objects being presented spatially equidistant from fixation in a task where a generally low number of fixations were made to reach the target object (i.e., 2.18 and 2.73, for faces and neutral objects, respectively). Nevertheless, for all other measures of capture, a clear advantage for faces was evident.

Preknowledge decreased the time and fixations necessary for gaze to first reach the target object. However, it had no effect on the overall likelihood that a target object was fixated.

The evidence for superior hold by faces was less clear than that for capture processes. Faces, compared to neutral objects, received more fixations and longer gaze duration both in the first-pass and overall. However, neutral target objects received a longer first fixation. The general lack of re-fixations necessary to perform the task likely contributed to the absence of an effect of semantic value on the number of second-pass fixations and target object entries. Thus, faces were shown to have greater attentional hold by four oculomotor measures, with one measure going against this trend; that of neutral, compared to face, target objects receiving longer first fixation durations. With respect to this latter measure, it should first be noted that a degree of controversy

exists over what the first fixation duration actually reflects (see Henderson & Ferreira, 2004, for a discussion), such that Henderson et al. (1999) explicitly did not report the measure in their research. Reservations aside, why would faces receive shorter first fixation durations while paradoxically receiving longer first-pass (and overall) gaze durations? These seemingly contradictory findings may be explained by the finding that faces received more fixations than neutral objects in the current study. Research by Hsiao and Cottrell (2008) found that a critical number of two fixations were optimal for face processing. This suggests that perhaps participants in the present study followed a fixed procedure of making approximately two ($M = 1.66$) fixations in order to optimally process faces. Consequently, when encountering a face (vs. a neutral object), observers may not have required as long an initial fixation, as more fixations were allocated overall.

Having preknowledge increased first-pass fixations and gaze duration, but decreased the number of re-fixations. The combined result likely produced the null effect of preknowledge observed on total fixation count and duration. Taken together, these results indicate that, without preknowledge, participants' gaze remained within a single target object area for a shorter duration, but was more likely to return. This might reflect a strategy employed in response to increased uncertainty, where it may have been more efficient to distribute gaze over all objects in an array rather than devoting attentional resources to just one object. A converse strategy, however, may have been more efficient when preknowledge of the changing category was available.

Taken together, these results replicate the change detection advantage for faces when in competition with other stimuli, as achieved by Ro et al. (2001), and show that such an advantage was expressed in terms of superior capture, and potentially hold, of overt visual attention. Because faces had high biological and social significance compared to the other objects used in the study, these findings are interpreted as strongly indicating that semantic information influences overt attentional capture processes. The findings also suggest that hold processes of overt attention were similarly influenced by semantic information.

Preknowledge did not eliminate the face advantage, despite influencing many of the same measures of attentional processes (even augmenting some capture aspects of the face advantage). This suggests that even when the more efficient strategy of utilising preknowledge was salient, faces still received attentional priority due to their sociobiological significance. With the current paradigm, it can only be surmised (based on suggestions from the data and using Sternberg's, 1969, additive factors logic) that independent underlying mechanisms were responsible for the separate influences of preknowledge and semantic value. Although both preknowledge and semantic value worked to prioritise attention via attentional capture and hold processes, they appeared to do so in a predominantly additive, rather than interacting, manner.

Our finding of a semantic influence on the capture processes of overt attention extends on recent research (e.g., Devue et al., 2009; Langton et al., 2008) by directly measuring the specific oculomotor correlates involved. Once a display was apparent, overt attention (by way of eye movements) was oriented more rapidly towards faces

compared to neutral objects. This suggests that participants were able to make decisions based on the semantic information acquired from their visual periphery in order to plan and execute saccades toward certain object areas. These results differ from those of Henderson et al. (1999), who found no evidence that semantic information in the visual periphery influenced attention via initial saccades. They used a different paradigm where participants viewed complex scenes in preparation for a memory test or to detect the presence of an object, while manipulating the semantic consistency of a target object within the gist of a scene. The difference in the present results may lie in the use of a stronger semantic manipulation of sociobiological significance (i.e., faces vs. neutral objects), not within complex natural scenes, but within relatively simple displays of only a small discrete number of isolated objects. This simpler type of display avoids the potential influence of other high-level factors such as meaningful scene composition (for a similar argument, see Scholl, 2000), and so may have been more sensitive to effects of capture.

A superior ability to capture attention is an extremely useful tool in a visual environment where many stimuli compete for further visual processing. There may be an adaptive benefit of having faces superiorly capture attention over other objects, as the social cues inherent in faces are important in our everyday environment and often require prompt responding.

The current evidence showing that faces better hold overt attention is consistent with similar findings by Bindemann et al. (2005) and Ro et al. (2007). The present study extends these findings by utilising oculomotor measures of hold processes that are

Figure 4.4 Correlation across participants between the overall oculomotor face advantage (ms) and mean reaction time (RT; ms) face advantage. The overall oculomotor face advantage was calculated by summing the mean face advantage (i.e., mean for faces subtracted from that of the neutral target objects) for time taken till first fixation (representing capture) and total gaze duration (representing hold). The mean RT face advantage was calculated by the subtracting the mean RT for faces from that of the neutral target objects (collapsed across preknowledge conditions) for change-present trials. Each point represents the data of an individual participant.

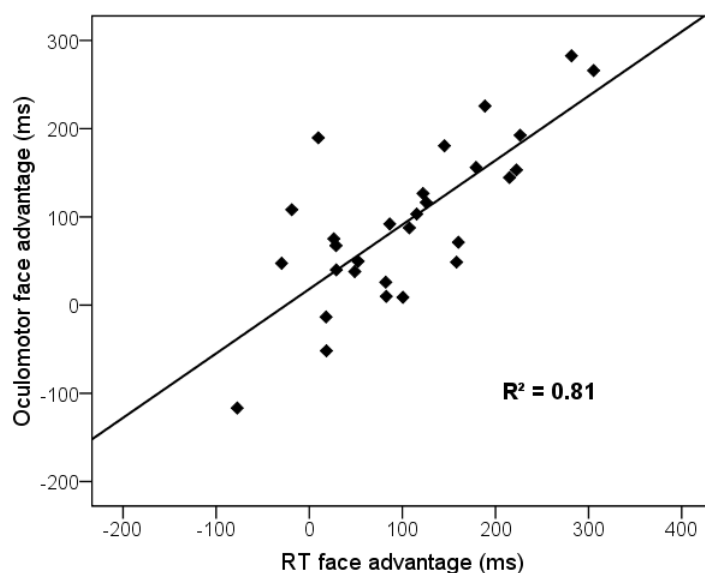
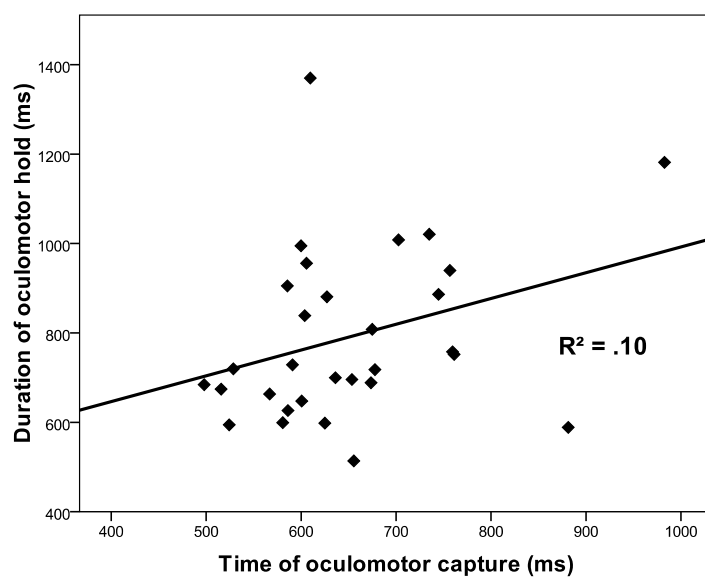


Figure 4.5 Correlation across participants between time of oculomotor capture (time taken till first fixation; ms) and duration of oculomotor hold (total gaze duration; ms) collapsed across semantic value. Each point represents the data of an individual participant.



more dynamic and sensitive than RTs, allowing for a more fine-grained understanding of how this mechanism may operate.

More generally, how do the oculomotor data map onto the button-press data? How are RTs faster in response to faces, as found both in the present study and by Ro et al. (2001), if faces capture attention faster, but also hold it longer? The RT benefit for faces compared to neutral target objects appears to be a composite of a faster attentional capture ($M = 190$ ms) and longer hold of attention ($M = 76$ ms for total gaze duration), where the former effect more than offsets the latter. The resulting difference (114 ms) approximately matches the average button-press RT advantage for faces of 136 ms. Conducting a one-tailed correlational analysis on the relationship between the overall oculomotor face advantage (computed by taking the difference between the capture and hold face advantage, as above) and mean RT face advantage for each participant revealed a strong positive correlation between the two (see Figure 4.4), $r(30) = .90$, $p < .001$. An alternative interpretation could be that the longer attentional hold does not reflect superior hold by faces, but rather is a consequence of earlier attentional capture within the current paradigm. Due to the nature of the change blindness paradigm, if gaze arrives at an object sooner, it might be expected to be then held longer in order to assess a potential change, irrespective of an object's semantic value. This proposal implies that an inverse relationship should be observed between time taken till first fixation (i.e., time of oculomotor capture) and total gaze duration (i.e., duration of oculomotor hold). This prediction was tested with the current data, collapsed across faces and neutral objects, comparing oculomotor capture and hold for

each participant (see Figure 4.5). A two-tailed correlational analysis revealed a trend ($p = .086$) towards a significant *positive* linear relationship, $r(30) = .32$. Thus, the alternative interpretation of an inverse relationship between oculomotor capture and hold appears incompatible with the current data. Instead, these analyses provide convincing evidence that the current oculomotor data map onto the button-press RT data, so that, for faces (vs. neutral objects), there is a faster attentional capture which outweighs the longer attentional hold to create an overall RT advantage.

Even if a face's ability to capture attention more than offsets the disadvantage (in terms of RT) from holding attention longer, what would be the functional benefit of holding attention longer on faces if it slows the speed of responding? Increased hold of attention might reflect a more extensive processing of information, which is the likely explanation of why an improvement in overall accuracy was observed for faces compared to neutral target objects. As such, it could be speculated that when faces are present in the visual environment, the function served by faster capture of attention is to elicit *prompt* responding, while greater hold elicits *appropriate* responding.

At a more general level, the present findings show an obvious attentional priority for faces when in competition with other objects of less social and biological significance. This priority is strongly indicated to be due to superior attentional capture and may also be due to superior attentional hold processes. Furthermore, utilising the more explicit strategy of preknowledge did not eliminate (or even reduce) observers priority for attending to faces, showing that such attentional priority was not due to strategic search. Rather, it indicates a mandatory processing of faces in the sense that

preferential attentional processing afforded to faces was unintentional and not under the control of the participant. Ro et al. (2001) showed (based on subjective ratings of difficulty) that participants were unaware of their face advantage, and Lavie et al. (2003) found evidence that face processing was unaffected by attentional load, suggesting that faces can be processed autonomously, without awareness and perhaps even attentional resources (but see Crist, Wu, Karp, & Woldorff, 2008). The present finding that faces were preferentially processed even when it was not advantageous to do so (faces did not change on 83% of trials in the present experiment), is consistent with Suzuki and Cavanagh (1995) and recent eye-movement research by Cerf, Frady, and Koch (2009). The latter also found faces presented in images of natural scenes received attentional priority independent of the task. Taken together, it is proposed that the mandatory processing for faces represents a form of preconscious automaticity (Bargh, 1992), in which the automatic processing of faces is solely triggered by their appearance, irrespective of observer intentions. However, further research should directly test the task-independent aspect of this claim in light of several visual search studies suggesting that task can mediate the necessity of attentional resources for preferential face processing (for a review, see Palermo & Rhodes, 2007). If mandatory processing was also revealed to be task-dependent, then this would implicate the involvement of goal-dependent automaticity in facial processing (Bargh, 1992).

Our focus was to investigate, given that Ro et al. (2001) showed faces to be treated differently when competing for attention, *how* faces are treated differently in terms of overt attentional mechanisms and mandatory processing. The purpose of the

present study was not to explain *why* faces in general are special or unique.

Nevertheless, when comparing face processing versus other object processing it is crucial to consider alternative accounts of exactly what it is about faces that causes them to be considered “special” or “different”. For example, it might be argued that the ability of faces to hold attention longer in the change detection task may have been because of their greater within-category visual similarity compared to the other neutral objects. Ro et al. (2001) intentionally used neutral objects within each category that were more visually different from each other in order to provide a conservative test for evidence of the face advantage when low-level conditions were unfavourable. Both for the present experiment and that of Ro et al.’s, this greater visual similarity was not reflected in the RTs and error rates, which instead favoured faces. When Ro et al. used inverted object displays (i.e., controlling for physical similarity while reducing the semantic influence for faces; see Yin, 1969), they found the RT and error rate advantage was eliminated. This suggests that such measures were more sensitive to the semantic manipulation rather than the low-level physical similarity of faces. For the present study, a choice to build on Ro et al.’s (2001) research was made, in part, because of the careful manner in which their stimuli were selected and controlled for differences in within-category visual similarity across experiments.

It also could be the case that with expertise, non-face stimuli may receive preferential processing in the same manner as faces in the change detection task (e.g., Archambault, O’Donnell, & Schyns, 1999; Werner & Thies, 2000). This is an issue which might be explored by measuring oculomotor correlates while manipulating expertise

with non-face stimuli. The conclusions from the present study, however, are unaffected by whether the increased biological and social significance associated with faces is hard-wired (e.g., Farah, Rabinowitz, Quinn, & Liu, 2000; Morton & Johnson, 1991) or learned through repeated experience, allowing us to become “face experts” (e.g., Gauthier & Tarr, 1997).

Figure 4.6 Visual attention findings.

		Forms of orienting	
		Covert	Overt
Stages of orienting	Hold		significant semantic effect
	Capture		significant semantic effect

To that effect, it is not proposed from the present study that faces are a unique stimulus in terms of how they are processed, but rather is posited that, due to their social and biological significance, faces receive mandatory processing when in competition with (and in comparison to) objects of less significance, in the form of greater capture and hold of overt attention. The larger attentional capture effect appears to overcompensate for that of the hold, to produce faster and more accurate manual responding. In reference to the 2×2 matrix of visual attention processes outlined in the Foreword, this chapter provided evidence that semantic information can influence the capture and hold stages of overt orienting of visual attention (see Figure 4.6).

Afterword

This thesis sought to explore how semantic information influences the allocation of visual attention. Previous research has found evidence of a semantic influence (e.g., Fox, Russo, Bowles, & Dutton, 2001; Fox, Russo, & Dutton, 2002; Okon-Singer, Tzelgov, & Henik, 2007; Ro, Russell, & Lavie, 2001; Stolz, 1996; Theeuwes & Van der Stigchel, 2006), but it is unclear as to what the extent of this influence is, or more specifically, which specific attentional processes are affected. This issue was examined by considering overt and covert forms of orienting separately and parsing the processes therein into the distinct mechanisms of capture and hold. Chapters 1 to 4 documented a variety of experiments designed to elicit and measure these separable elements of visual orienting to determine the extent of semantic influence on such processes, and thus the visual attention system. A summary of the main findings from each chapter is provided below.

Overview of Experiments and Chief Findings

Chapter 1 involved a five-experiment series exploring how the semantic manipulation of sociobiological significance of brief peripheral cues influenced covert attention within a spatial cuing paradigm. This was achieved by measuring subsequent saccade responses to a target probe under a variety of conditions. Clear attentional effects on saccadic reaction time (RT) in the form of inhibition of return (IOR) were established in response to the cues. The semantic value of the cue also influenced task

performance. Sociobiologically significant cues facilitated saccadic responses to a target presented shortly (200 ms) after cue onset. Importantly, this short-lived facilitation occurred regardless of the cues' validity in predicting target location, indicating that it operated independently from attentional capture and hold processes. Such semantic effects were reduced when eye-control criteria were relaxed, presumably because of additional noise from allowing a degree of overt orienting on otherwise purely covert attentional orienting processes. It was concluded that the sociobiologically salient stimuli created, what may be described as, a brief semantic priming or social facilitation effect on saccadic responses, which did not operate via covert attentional mechanisms of capture and hold to affect performance.

Chapter 2 followed on from the previous chapter by examining whether the expression of semantic influence on covert orienting might be modulated by the response system demanded by the task. Indeed, by requiring participants to make manual motor responses rather than saccades in a discrimination task, evidence of semantic influence on capture processes was found, but only when cues competed with each other for attention. It was concluded that a trade-off may have occurred between influences from low-level versus semantic information on orienting, such that when cues competed for attentional resources, semantic information became more influential in resolving the competition for attention. In making comparisons with Chapter 1, it is clear that underlying differences between the response systems employed represent an important factor in how semantic influence on covert visual attention is expressed.

The question of semantic information on covert attentional mechanisms was explored further in Chapter 3 by manipulating semantic congruency, and assessing whether the extent of consequent influence depended on the task set. Semantic influence on performance was found to rely on the degree of informational overlap between cue and task set. However, as in Chapter 1, this influence did not operate through attentional orienting processes. Semantic information from cues that shared a high degree of information properties with the task set appeared to influence performance by priming a response, resulting in facilitated performance when congruent (vs. incongruent) with the correct response required by the task. This shows that the independence of the semantic informational influence from attentional orienting mechanisms, first observed in Chapter 1, may not merely be limited to manipulations of sociobiological significance.

Chapter 4 examined semantic influence on overt orienting processes using the more naturalistic free-viewing paradigm. The oculomotor correlates of the face advantage in a change detection task were measured to determine whether capture and hold mechanisms were influenced by semantic manipulations of sociobiological significance. The face advantage found by Ro et al. (2001) was replicated. Evidence indicated that the preferential attention enjoyed by the sociobiologically significant stimuli was reflected both by the superior capture and hold of overt attention. The faster capture more than compensated for the longer hold of attention to create the face detection advantage as expressed in RT performance. This preferential capture and hold of overt attention by faces was robust, regardless of whether participants were

provided with preknowledge of the changing object category. This latter finding indicates that stimuli of such sociobiological importance may receive mandatory processing even when it is inefficient to do so.

Primary Conclusions

In the Foreword, the scope of the present thesis was outlined by constructing a 2 × 2 matrix which parsed the orienting of visual attention into the two separate and orthogonal distinctions of capture versus hold stages and covert versus overt forms. Using the matrix as a framework for the chapters that followed, semantic influence was investigated on a tractable set of processes by designing experiments to test each of the capture/hold and covert/overt combinations for evidence of semantic influence (see Figure A1). Chapters 1, 2, and 3 examined semantic influence on the capture and hold processes within covert forms of attentional orienting, using strict eye-control procedures in concert with a spatial cuing paradigm. Evidence for such an influence was only obtained in Chapter 2 for capture processes of covert attention, where it was observed under conditions of competition between cues of differing semantic value when manual motor responses were used to express the effects. For Chapters 2 and 3, while a semantic influence on RTs was observed, there was no evidence of influence on either capture or hold stages of covert attentional orienting across a range of exogenous (e.g., cue-target spatial overlap) and endogenous (e.g., task set) manipulations. Chapter 4 tested for, and observed, evidence of semantic influence on both the capture and hold stages of overt forms of attentional orienting.

Figure A1 Findings from Chapters 1 to 4 organised according to which of the visual attentional processes (as parsed in the 2×2 matrix) were influenced by semantic information.

		Forms of orienting	
		Covert	Overt
Stages of orienting	Hold	no semantic effect	significant semantic effect
	Capture	significant semantic effect* *only in competition with manual motor responses	significant semantic effect

When considering this body of research as a whole, several key conclusions are apparent regarding the nature of the influence from semantic information on visual attention. 1) Semantic information differentially influences covert and overt attentional orienting processes. 2) The capture and hold of covert attention is generally uninfluenced by semantic information. 3) Semantic information briefly encountered in the environment can facilitate or prime action independent of covert attentional orienting. 4) Overt attention can be both preferentially captured and held by semantically salient information encountered in visual environments. Each conclusion will now be examined in more detail. Limitations and suggestions for future research are offered to address emergent and unresolved questions.

Semantic Information Differentially Influences Covert and Overt Attentional Orienting Processes

Semantic information influenced attentional orienting processes differently depending on whether attention was oriented overtly or covertly. This dissociation lends further credence to the concept that covert and overt forms of attentional allocation, while related, represent functionally independent systems of orienting (e.g., Corbetta & Shulman, 2002; Fischer, 1999; Kingstone & Klein, 1993; Klein, 1980; Klein & Taylor, 1994; Stelmach, Campsall, & Herdman, 1997; Wright & Ward, 2008).

An important issue for future research will be the discovery of the underlying neural basis responsible for such differences between semantic influences on overt and covert forms of orienting. Or more specifically, determining what neural processes unique to overt orienting are affected by semantic information. However, perhaps the biggest unresolved question regarding this conclusion pertains to the extent to which differential semantic influence on overt and covert orienting may be explained by differences between endogenous and exogenous control of attention. The free-viewing flicker paradigm employed endogenous control of overt attention to process the objects, while the spatial cuing paradigm largely involved exogenous cuing of covert attention. However, it should be noted that an element of endogenous control was involved in covert attentional orienting when cues either side of fixation competed for attention. This thesis dealt with the issue of semantic influence on visual attention by considering capture and hold processes of overt and covert attention. It was beyond the scope of the current thesis to directly consider the additional impact of an exhaustive

range of factors which might have influenced the impact of semantic information on these processes. However, subsequent research may show type of control (exogenous or endogenous) to be another important factor in the expression of semantic influence on capture and hold of overt and covert orienting.

The knowledge produced by this thesis, regarding how semantics influence attentional processes, allows the opportunity for more in-depth investigations into how manipulation of specific types of semantic information (e.g., emotional valence) differentially impact attentional processes.

The Capture and Hold of Covert Attention is Generally Uninfluenced by Semantic Information

Covert orienting of attention, for the most part, was not preferentially captured or held by semantically salient information. Only when there was competition for attention and action required by the manual motor response system, was convincing evidence observed of selective capture of covert attention. Such findings (or lack thereof) do not necessarily rule out a semantic influence, but rather, combined with other research (e.g., Fox et al., 2001, Fox et al., 2002; Okon-Singer et al., 2007; Stolz, 1996; Theeuwes & Van der Stigchel, 2006), suggest that an influence on covert orienting mechanisms is modulated by a range of task factors. Such factors may include (but not necessarily be limited to): whether objects are in competition for attention, the response system required for action (e.g., manual motor vs. saccadic), the type of semantic information manipulated (e.g., sociobiological significance vs. congruency/relatedness vs. emotional valence), the event used to signal responses

(endogenous vs. exogenous), and the informative nature of the semantic stimuli (intrinsic vs. context-dependent informativeness).

Additional research will be required to determine which specific combinations of these task factors are necessary to observe semantic influence on covert attentional processes. Determining the necessary conditions will also function to elucidate the exact mechanisms involved and how they operate to alter the expression of semantic influence.

Based on findings from this thesis, conditions of competition and response system differences would most warrant further investigation in order to explore the nature of the semantic influence on capture of covert attention. It would be intriguing to determine whether the trade-off from low-level to semantic influence when in competitive situations becomes more pronounced when an increasing number of cues compete for attention with the face cue. Additionally, it would be of value to more extensively investigate the complexities of influence on selective orienting by making direct comparisons across a range of various object combinations in two-cue presentations, where relative and overall semantic saliency of information is manipulated.

Direct measures of attention such as event-related potentials (ERPs) might also prove useful in such investigations. The amplitude of the N170 component, considered to reflect face-specific neural processing, may be a useful indicator of the extent to which face cues are processed in the presence of increasing numbers of cues with less sociobiological significance. The N2pc component, considered to reflect evidence of

selective attention, would prove useful as a direct online measure of covert attentional selection for the various manipulations of semantic cue value amongst two-cue presentations.

The different findings obtained by using manual motor versus saccadic responses emphasises the need to consider the impact different response systems may have when researching attentional and semantic effects. Further research should explore what particular differences between the response systems were responsible for the differing expressions of semantic influence observed. The findings also attest to the need to consider alternative measures of attention, such as saccade trajectory deviations and ERPs (e.g., N2pc), as complementary measures to saccadic and manual motor RTs, to provide a more complete picture on the nature of semantic influence on visual attention.

Semantic Information Briefly Encountered in the Environment can Facilitate/Prime Action Independent of Covert Attentional Orienting

Surely the most interesting result to have emerged from this research was the repeated and unexpected finding that semantic information primed or facilitated action largely without requiring further attentional covert processing to do so. Semantic information was processed by covert attentional resources, but did not influence covert orienting processes (with the exception of manual responses following cues in competition). This semantic priming effect was observed across different semantic manipulations and to varying degrees of automaticity. Sociobiologically significant semantic information briefly facilitated all saccadic localisation responses, likely by way

of inducing a higher level of alertness or response readiness. This suggests a form of preconscious automaticity (Bargh, 1992), whereby the mere presence of the stimuli was sufficient for response facilitation. In situations of high informational overlap between cue and task set, cue information primed responses which facilitated congruent manual discrimination responses in a more durable and controllable, goal-dependent automatic manner (Bargh).

It is conceivable that such a phenomenon might prove useful in everyday visual environments, where it is not always possible or convenient to orient the fovea for purposes of finely detailed perceptual analyses. Under such circumstances, it might be more effective to bypass the visual attentional system in favour of priming or facilitating more immediate action. This could represent an efficient strategy in situations when it is more appropriate to sacrifice benefits from further processing for timely reacting. This concept shares similarities to the notion of a “threat-detector” route for facial processing, where it has been argued that finely detailed representations may be traded off for faster perception of basic arousal or emotion information (and thus action) in response to potentially threatening faces (Morris, de Gelder, Weiskrantz, & Dolan, 2001; Öhman, 2002).

This thesis has begun to discover features of this effect, such as its temporal properties, nature of priming, extent of automaticity, importance of context-dependent informativeness, and how these all can differ with changes to the type of semantic manipulation, response system and task. However, many questions still remain unanswered.

Possibly the most pertinent issue concerns whether the effects observed in Chapter 1 (involving sociobiological stimuli in a saccadic localisation task) and Chapter 3 (involving semantically congruent stimuli in a manual discrimination task) represent the same phenomenon. While they both indicate a semantic effect which can facilitate performance independent of covert processes of attention, there are differences in the nature of the priming (i.e., an increase in the general state of readiness vs. a particular response that is associated with the stimulus), the extent to which it occurs automatically, and its temporal profile. Currently, it is unclear as to which differences in the semantic effect properties can be attributed to differences in particular conditions between the experiments. Chapter 2 has already shown that such effects are no longer observed when changing the required response from saccades to manual motor responses and the task from a localisation to a discrimination. Chapter 3 then showed reinstated semantic effects independent of attention, once the semantic manipulation was changed to one of congruency between cue and target features under conditions of high cue-task set information overlap. Future research could address this issue more clearly by systematically altering type of semantic manipulation, response system and task, in order to bridge the gap between experiments in Chapter 1 and 3. Combined with attempts to find evidence beyond the spatial cuing paradigm, such investigations can be used to determine the robustness and particular expressions of this intriguing effect.

The use of alternative measures of attentional allocation will be vital in further establishing the validity of these results. They can be used to further confirm the

independence of the semantic effects from covert orienting processes and will assist in narrowing down the underlying neural basis. Comparing saccade trajectory deviations in an altered spatial cuing paradigm would provide an effective and complementary online measure of attentional allocation during saccadic response tasks. Additionally, comparisons of P1 or N1 ERP components (measures of visual perceptual processes which are modulated by attention) and temporal order judgments are powerful means of verifying that enhanced perceptual sensitivity, afforded by the orienting of attention in response to a peripheral stimulus, does not interact with the semantic value of that stimulus.

Mapping the temporal profile of these independent semantic effects in more detail could be achieved by replication using a broader range of stimulus onset asynchronies. Using ERP techniques to measure lateralised readiness potentials, considered to reflect unilateral preparation of a manual motor response, could be used in concert to determine the temporal profile of the response priming processes observed to be operating in the manual discrimination tasks documented in Chapter 3 .

Regarding the extent to which the influence from semantic information is automatic, many of the finer features and necessary preconditions could be easily determined, for example, by manipulating cue duration or employing backward visual masks to investigate whether an influence on performance remains when awareness of the semantic nature of the stimuli is absent. Another example could involve testing the necessity of orienting to the semantic stimuli to observe their influence.

Electromyography techniques could be used to check the validity of the induced alertness or readiness interpretation of facilitation effects observed in Chapter 1, by examining whether the amplitude and temporal properties of electric potentials following cue presentation correlate with behavioural RT measures of the general facilitation effect.

It was speculated (at least for the influence of sociobiologically significant stimuli on saccadic responses) that such semantic priming effects may have neural underpinnings within the basal ganglia. This is only informed conjecture at present, which would warrant further research to test these claims. In addition to the abovementioned investigations proposed, functional magnetic resonance imaging techniques would be particularly useful in pinpointing the neural mechanisms involved in response facilitation, by examining potential baseline differences in activity within the basal ganglia following brief peripheral cue stimuli of varying sociobiological significance. Single-unit recordings from macaque monkeys, particularly within the caudate nucleus, could prove an even more useful tool in testing the more specific claims of the underlying neural basis.

Overt Attention can be both Preferentially Captured and Held by Semantically Salient Information Encountered in Visual Environments

Sociobiological semantic information had a strong influence on overt orienting when objects competed for attention. Both capture and hold processes of overt attention were affected by semantic information associated with objects in the change detection task, even when such information was irrelevant to current goals.

Sociobiologically significant stimuli appeared to receive preconscious automatic processing by overt attention (Bargh, 1992), which operated via capture and hold processes of overt selective attention to influence task performance.

It would be crucial to determine whether this semantic influence on overt orienting, like covert orienting, depends on competitive conditions, as would be suggested by Ro et al.'s (2001) findings. Further attempts should also be made to replicate the semantic influence on oculomotor correlates of overt attention using a range of semantic manipulations and paradigms. An example of the latter could involve utilising a visual search paradigm where the sociobiological significance of the stimuli would be irrelevant to the target feature necessary for the task.

Research by Lavie, Ro, and Russell, (2003) would suggest that attentional load would not affect the preferential processing of sociobiologically significant stimuli such as faces; however, it would be interesting to investigate whether the preference for both capture and hold of attention would be similarly immune to attentional load.

Concluding Comments

Taken together, this thesis has shown semantic information in the visual environment influences action, but not always via attentional orienting. Rather than a simple all-or-none conception of a semantic influence on visual orienting processes, for covert orienting at least, the relationship seems much more interesting and complex, whereby influence on attentional mechanisms appears to depend on the presence of certain conditions.

Such findings have significant applications for scenarios where it is crucial to locate and respond to important information rapidly. Considering the vast amount of visual information that we are constantly required to process, an understanding of the unique characteristics of how different aspects of the visual attention system are affected by semantic information becomes extremely useful. This knowledge can be used to inform designs seeking to create the most efficient and effective means for perceiving and responding to important information. Such research has obvious applications within the advertising industry (e.g., increasing the visual impact of billboard displays). However, potentially the most important applications might involve assistance in situations where there is a lot of information to process, yet where timely responding to important subsets of visual information can have immense consequences in terms of safety, such as the design of visual displays for cars and navigational flight systems in airplane cockpits. Aspects of the display which are more likely to only receive covert processing (e.g., peripheral locations), could be used to prime appropriate responses, rather than attracting overt attention to the signal itself. Those aspects which are more often foveated (e.g., more central, or receiving frequent overt scanning) would be more suitable for signals whose interpretive complexity requires the attracting and holding of overt attention for more fine-grained processing.

I went in to this project having a simple conception of what the effect of semantics on the attentional system might be. I have concluded by forming a far more interesting and complex picture which, true to the scientific tradition, has produced more questions than answers. The visual attentional system has a multifaceted

relationship with semantic information encountered in the visual environment.

Semantic information has a differential influence on selective orienting processes that depends on the form of orienting employed and a range of circumstances under which attentional selection takes place.

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