

THE MODULATORY EFFECTS OF  
ATTENTION AND SPATIAL LOCATION  
ON MASKED FACE-PROCESSING:  
INSIGHTS FROM THE REACH-TO-TOUCH PARADIGM

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## THESIS ABSTRACT

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In masked priming paradigms, targets are responded to faster and more accurately when preceded by subliminal primes from the same category than a different category.

Intriguingly, where these congruence priming effects elicited by word and number stimuli depend on the allocation of attention, masked faces produce priming regardless of how well attention is focused. The research presented in this thesis exploits this unique property to examine the temporal dynamics of nonconscious information processing, and the factors which modulate this hidden cognitive process. Using congruence priming effects for masked faces as an index of nonconscious perception, I present four empirical studies that examine how processing below our level of conscious awareness is affected by manipulations of spatial and temporal attention. In Study 1, I show that the allocation of both spatial and temporal attention facilitates nonconscious processing at less than 350ms of stimulus-processing time. These results suggest that attention modulates nonconscious information processing in a *graded* fashion that mirrors its influence on the perception of consciously presented stimuli. Study 2 investigates the differential benefit of attention between the vertical hemifields, and documents the breakthrough finding that face-processing is supported better in the upper-hemifield than the lower-hemifield. Study 3 explores whether this upper-hemifield advantage generalises to recognition of a nonface object (human hands). Study 4 investigates and dispels the possibility that the pattern of vertical asymmetry effects for face-perception relates to an upward bias in participants' visuospatial attention. The final chapter of this thesis summarises the findings from these four studies and discusses their implications within a broader research context.



## STATEMENT OF AUTHENTICATION

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This thesis is submitted in partial fulfilment of the requirements of the degree of Combined Doctor of Philosophy / Master of Clinical Neuropsychology.

I declare that the research presented in this thesis is my original work. I have appropriately acknowledged help or assistance that I have received during the preparation of this thesis, as well as any sources of information that I have used.

All research presented in this thesis was approved by Macquarie University Ethics Review Committee (Human Research), reference number: HE22FEB2008-R05671 and 5201300060. Documentation of these approvals is given in Appendix One.

Signed:

Date: 23<sup>rd</sup> July, 2014

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## AUTHOR NOTE

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This thesis has been prepared in the format of ‘Thesis by Publication’. The reference style and formatting largely conform to standards laid out by the APA Publication Manual (6<sup>th</sup> edition). Due to the ‘Thesis by Publication’ format, there is some degree of repetition between the chapters, particularly in the introductory sections of Chapters 3 & 4. I have tried to avoid repetition as much as possible while still allowing each chapter to stand in isolation. I am the first author of the four empirical studies presented in this thesis.





# CHAPTER ONE

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## GENERAL INTRODUCTION

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## ***1.1. Gorillas in our midst: A review of attention and awareness***

Selective attention and awareness are indisputably intertwined. Directing attention to an object makes us conscious of its attributes, leaving pertinent features of less-attended objects outside the boundary of conscious awareness. The now famous ‘invisible gorilla’ experiment (Simons & Chabris, 1999) provides a classic demonstration of the intimate coupling between these two aspects of human cognition. Two teams of basketball players are passing a ball; you are told to count silently the number of passes made between the players wearing white. You follow the white team closely and a few minutes later, report your answer. The experimenter notes down your response and then asks you if you noticed anything unusual in the video. Nothing? Not the gorilla-suited woman who lazily wandered through the basketball game, looked into the camera for a few seconds, and thumped her chest before shuffling away? In the original study by Simons and Chabris (1999), over 50% of naïve observers failed to perceive this otherwise highly salient object in the scene, simply because their attention was engaged elsewhere. This phenomenon, termed **inattention blindness** (Mack & Rock, 1998; Wolfe, Horowitz, & Kenner, 2005), nicely demonstrates our reliance on selective attention to filter the enormous sensory input that assails us at every moment, and bring the currently relevant information into our conscious awareness.

In fact, the relationship between attention and awareness is so intimate that some have considered the two processes to be functionally identical (De Brigard & Prinz, 2010; Mack & Rock, 1998; O'Regan & Noë, 2001; Posner, 1994). Yet over the last several decades, evidence has accumulated to suggest that attention and awareness are functionally distinct cognitive phenomena which should not be equated (Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006; Koch & Tsuchiya, 2007; Tsuchiya & Koch, 2008; van

Boxtel, Tsuchiya, & Koch, 2010). In support of this proposition are studies of patients with the rare neurological condition **blindsight**. In this condition, patients with damage to primary visual cortex retain the ability to detect, localise, and discriminate stimuli presented in regions where they subjectively report being blind (Weiskrantz, Warrington, Sanders, & Marshall, 1974). For example, patient GY, described by Kentridge and colleagues, could perform well above-chance in detecting and discriminating stimuli presented in his blind field, despite reporting little to no subjective awareness of them (Kentridge, Heywood, & Weiskrantz, 1999a; 2004). Of critical importance is the observation that directing GY's visual attention to the unseen target's location produced a response time (RT) advantage in both detection and discrimination. GY was significantly faster to report both the presence and orientation of an "invisible" target when it was preceded by a valid spatial cue (e.g. an arrow pointing to the upcoming target's location). Since the allocation of attention was able to facilitate processing of targets that GY never became aware of, the authors concluded that attention cannot be a sufficient condition for awareness (Kentridge et al., 1999a; 2004).

### ***1.1.1. An introduction to masked priming***

Outside the cognitive neuropsychology literature, another strand of research that has proved fruitful in the quest to disentangle attention and awareness is **masked priming** (Forster & Davis, 1984). In masked priming paradigms, participants respond to a visible stimulus (the target) that is preceded by another stimulus which cannot be consciously identified (the prime). In the now widely-used 'sandwich' version of this paradigm, the prime is rendered invisible to the participant by presenting it for a very brief duration (typically 50ms or less), and 'sandwiching' it between a forward mask and the visible target item (Forster & Davis, 1984). Priming is said to occur when information carried by the masked prime item facilitates or interferes with the response to the visible target item

(Kinoshita & Lupker, 2003). Because masked priming effects necessarily reflect the degree to which the nonconscious prime item was processed by the brain, they are commonly used as an index of nonconscious information processing (Dehaene et al., 1998; Finkbeiner & Caramazza, 2008; Forster & Davis, 1984; Kouider & Dehaene, 2007).

Masked priming techniques have a long history within the **visual word recognition** literature, in which several different types of priming have been identified (for an extensive review of this literature, see Kinoshita & Lupker, 2003). For example, participants engaged in lexical decision tasks tend to respond faster and more accurately when the target is preceded by a repetition or identity prime that is the same as the upcoming target (e.g. *foal-FOAL*) (Bodner & Masson, 1997; Forster & Davis, 1984; Grainger, Diependaele, Spinelli, Ferrand, & Farioli, 2003; Matsumoto, Iidaka, Nomura, & Ohira, 2005). The response to a target word can also be facilitated by a form prime that is similar in orthography to the target (e.g. *goal-FOAL*) (Ferrand & Grainger, 1994; Forster, 1987; Forster, Davis, Schoknecht, & Carter, 1987), or a semantic prime which is associatively related to the target (e.g. *horse-FOAL*) (Dell'Acqua & Grainger, 1999; Kiefer & Brendel, 2006; Kinoshita & Norris, 2012; McNamara, 2004; Neely, 1991; Neely, Keefe, & Ross, 1989). Yet another variant of this paradigm is **masked congruence priming**, in which the relationship between the prime and target item is manipulated across categories (R. L. Abrams, Klinger, & Greenwald, 2002; Finkbeiner & Caramazza, 2008; Finkbeiner & Friedman, 2011; Kinoshita & Hunt, 2008; Naccache, Blandin, & Dehaene, 2002). Here the participant is asked to evaluate the category membership of a target (e.g. “Is it an animal or a fruit?”). As is common in all masked priming paradigms, the visible target is preceded by a prime item diminished in awareness. The critical manipulation in such designs is whether the prime and target are congruent or incongruent in category membership – i.e., whether they belong to the same category (e.g. *donkey-HORSE*), or different categories (e.g. *orange-HORSE*). The typical result obtained is the so-called

masked congruence effect (MCE), in which the categorisation response is faster and more accurate for targets preceded by congruent primes than incongruent primes (Dehaene et al., 1998; Finkbeiner & Friedman, 2011; Finkbeiner, Song, Nakayama, & Caramazza, 2008; Kinoshita & Hunt, 2008; Naccache et al., 2002).

### ***1.1.2. Attending to the unconscious***

Whilst the mechanisms which underlie masked priming effects remain hotly debated (e.g. Bodner & Masson, 2001; 2003; Damian, 2001; Kiefer, 2002), it is generally assumed that since information about the masked prime never reaches conscious awareness, any observable priming effects are not likely to be the result of any conscious appreciation of the relationship between the prime and the target item (Forster, 1999; Forster & Davis, 1984). As such, masked priming effects have historically been considered to be “**automatic**” (Forster, 1999; Forster & Davis, 1984; Jacobs & Grainger, 1992; Kouider & Dupoux, 2001; 2005; Marcel, 1980; Neumann & Klotz, 1994), in so far as they are elicited independently of top-down factors such as attention, intention, or conscious strategy (Eysenck, 1984; Posner & Snyder, 1975; Schneider & Shiffrin, 1977). In more recent years, however, researchers have used masked priming techniques to interrogate the assumption that processes below the level of conscious awareness must necessarily be independent of attention. The results of these investigations, explored in detail below, provide strong evidence for a functional dissociation between attention and awareness (Kentridge et al., 2004; Koch & Tsuchiya, 2007; Lamme, 2003; Tsuchiya & Koch, 2008; van Boxtel et al., 2010). Moreover, they sharply constrain the view of nonconscious information processing as autonomous and independent of higher level resources such as attention (Eysenck, 1984; Posner & Snyder, 1975; Schneider & Shiffrin, 1977). As we will see in the following section, not only is it possible to attend to information which is below the level of conscious awareness, nonconscious processing arguably depends on the

appropriate allocation of attention to proceed (Kiefer & Brendel, 2006; Lachter, Forster, & Ruthruff, 2004; Naccache et al., 2002).

Naccache and colleagues (2002) were the first to argue for the essential role of attention in nonconscious processing. These authors used a masked priming number comparison task in which participants classified target digits as either greater or smaller than 5 by pressing one of two buttons. The visible target digit was preceded by either a congruent or incongruent prime (29ms) that was suppressed from conscious awareness using forward and backward masking. The authors embedded both critical stimuli in a stream of geometric masks presented at central fixation, and varied the participant's ability to successfully deploy temporal attention to the prime and target across three separate paradigms. In the first experiment, they manipulated temporal attention implicitly by varying the predictability of target onset. They observed reliable congruence priming effects only when the target systematically appeared at the same point during each trial, allowing participants to voluntarily allocate temporal attention to the point in time when the target appeared. In the second experiment, Naccache et al. used a bright green cue embedded in the trial sequence to involuntarily focus participants' attention at different points in time. Consistent with their first experiment, priming was evident when the cue captured attention *just before* the prime–target pair, but not when it appeared elsewhere in the trial sequence. In the third experiment, a manipulation of endogenously directed temporal attention revealed a similar pattern. Here participants received a nonpredictive verbal cue prior to each trial which told them when to expect the target during the sequence (“early” or “late”). Since the information given by the cue was valid on 80% of trials, the authors expected that participants would respond to the cue by focusing their attention on the first or second half of the trial sequence. Consistent with experiments 1 and 2, masked priming effects were evident exclusively on validly cued trials. Taken together, the results

of these three experiments by Naccache and colleagues strongly suggest nonconscious processing of number stimuli is contingent on the allocation of temporal attention.

At the time of their report, these breakthrough findings represented a radical divergence from the previously mainstream opinion that nonconscious processing proceeds in an automatic way. Following this initial advance, however, supporting evidence that unconscious perception can indeed be modulated by attention quickly accumulated. Still within the realm of temporal attention, Kiefer and Brendel (2006) showed masked semantic priming effects reflected in the N400 event related potential (ERP) to be strongest when the prime appeared within an attended time window following an exogenous cue. Similarly, Fabre, Lemaire, and Grainger (2007) reported focussed temporal attention to be a prerequisite for masked congruence priming effects elicited by both nonconscious number and word stimuli. Yet the dependence of masked priming effects on attention is not limited to the temporal domain. Indeed, compelling evidence now also suggests nonconscious processing to be contingent upon the allocation of **spatial attention**. In an extension of Broadbent's (1958) selective filter theory, Lachter and colleagues (2004) proposed that masked word stimuli presented outside the focus of spatial attention receive very little processing beyond simple physical features such as colour or orientation. In a series of masked priming experiments designed to maintain strict control over the locus of spatial attention, they showed that semantic access to a masked word prime (i.e., what the authors term "identification") depends critically on focussed spatial attention. Participants in their study completed a lexical decision task in which the prime and target appeared in vertically adjacent locations (e.g. if the prime appeared in the top position, then the subsequent target appeared in the lower position). An exogenous visual cue embedded in the trial sequence involuntarily captured spatial attention to either the prime or target's location, resulting in prime-attended and prime-unattended conditions. Critically, masked repetition priming effects emerged only in the prime-attended condition, suggesting



participants could not process nonconscious word stimuli to the point of lexical access in the absence of focussed spatial attention.

The findings of Lachter et al. (2004) are by no means isolated in the literature. Several studies have now replicated the observation that masked priming effects for word stimuli depend critically on spatial attention (Besner, Risko, & Sklair, 2005; Lien, Ruthruff, Kouchi, & Lachter, 2010), with similar reports for masked repetition priming studies using letter stimuli (Marzouki, Grainger, & Theeuwes, 2007; Marzouki, Midgley, Holcomb, & Grainger, 2008). For example, masked letter primes presented to the left or right of fixation appear to only affect alphabetic decisions for subsequent central target letters when the peripheral prime stimulus is spatially attended (Marzouki et al., 2007). Such attentional modulation of masked letter processing is also evident in a neural index of repetition priming, the P3 ERP component (Marzouki et al., 2008). Finally, masked congruence priming effects elicited by picture stimuli (e.g. animals, tools, vegetables) also appear to depend critically on the allocation of spatial attention, arising only when attention is captured to the prime's location, and not when focussed elsewhere (Finkbeiner & Palermo, 2009).

### ***1.1.3. Interim Summary***

Several important conclusions can be drawn from the burgeoning literature which couples masked priming techniques with systematic manipulations of attention. First, the fact that attention and awareness can be orthogonally manipulated convincingly undermines the suggestion that the two cognitive processes are functionally identical (O'Regan & Noë, 2001; Posner, 1994). Rather, these findings support the interpretation of attention and awareness as **distinct cognitive phenomena** which may be disentangled through careful experimentation (Dehaene et al., 2006; Koch & Tsuchiya, 2007; Lamme, 2003; Tsuchiya & Koch, 2008; van Boxtel et al., 2010). Second, that masked priming

effects appear to *depend* on attentional allocation constitutes a formidable challenge to the widely-held classical assumption that that nonconscious processing proceeds in a purely automatic fashion (Eysenck, 1984; Posner & Snyder, 1975; Schneider & Shiffrin, 1977). In fact, the evidence rather appears to favour the very opposite perspective – that nonconscious or “automatic” information processing is critically dependent on top-down factors such as attention (Lachter et al., 2004; Naccache et al., 2002). As a result, newer theories of unconscious processing have been obliged to revise the definition of automaticity to be a conditional one, wherein automatic processes that are deployed in an ostensibly independent fashion are still dependent on the precise configuration of the cognitive system (Dehaene et al., 2006; Kiefer, 2007; Kiefer, Adams, & Zovko, 2012; Kiefer & Martens, 2010).

## ***1.2. Nonconscious face-processing: An exception to the rule***

Thus far we have examined the origins of the long-standing view that nonconscious “automatic” processes are independent of attentional influence (Eysenck, 1984; Posner & Snyder, 1975; Schneider & Shiffrin, 1977). We have reviewed the masked priming literature that challenges this classical perspective, and watched it subsequently give way to the very opposite opinion – that attention is mandatory for subliminally presented letters, numbers, and words to engage cognitive processes (Dehaene et al., 2006; Kiefer, 2007; Kiefer et al., 2012; Kiefer & Martens, 2010; Lachter et al., 2004; Naccache et al., 2002). Unconscious processing of one particular stimulus type, however, remains difficult to resolve with either the (classic) “complete independence” view or the (newer) “complete dependence” view. Where nonconscious processing of many other stimulus types appears ‘gated’ by attention (Lachter et al., 2004), increasing evidence suggests that the visual system is able to process **nonconscious face information** presented outside the

focus of spatial attention (Finkbeiner & Palermo, 2009; Harry, Davis, & Kim, 2012; Khalid, Finkbeiner, Konig, & Ansorge, 2013).

The following section examines the literature which supports the claim that nonconscious face-processing proceeds regardless of attentional focus. Before embarking on this, however, I would highlight that the focus of this review is restricted to those studies which contrast face-processing under spatially-attended and spatially-unattended conditions (e.g. Finkbeiner & Palermo, 2009; Harry et al., 2012; Khalid et al., 2013; Reddy, Moradi, & Koch, 2007; Reddy, Reddy, & Koch, 2006; Reddy, Wilken, & Koch, 2004). It is important to note the distinction here between these investigations and those studies which have compared face-processing between “attended” and “unattended” conditions defined by *task relevance* (Yi, Kelley, Marois, & Chun, 2006). This latter comparison has been the focus of a long line of functional magnetic resonance imaging (fMRI) studies which have examined how attention modulates face-specific activity in the fusiform face area (FFA). For example, participants in a study by Wojciulik and colleagues viewed displays comprised of two faces and two houses around a central fixation cross (Wojciulik, Kanwisher, & Driver, 1998). Across separate epochs, they were tasked with matching either the concurrent faces or houses. The spatial location of the task-relevant stimulus was predictable for participants, as each stimulus type appeared along the same meridian axis (e.g. faces shown above and below, houses shown left and right) for the duration of a full epoch. The authors observed that face-specific blood-oxygen-level dependent response (i.e., BOLD activity), was reliably stronger during face-matching than house-matching. On this basis, they concluded that face-processing in the FFA depends upon voluntary attention. While this inference itself is under no dispute, what is not clear from this study and those like it (e.g. Kanwisher, McDermott, & Chun, 1997; O'Craven, Downing, & Kanwisher, 1999; Pessoa, McKenna, Gutierrez, & Ungerleider, 2002; Vuilleumier, Armony, Driver, & Dolan, 2001) is the *nature* of the observed attentional

effects. That is, since participants knew and could covertly monitor the locations of the upcoming to-be-matched stimuli (e.g. left/right or upper/lower), a comparison of the face-matching and house-matching conditions does not allow one to tease apart the relative contributions of task-based attention and spatial attention (for a further discussion, see Reddy et al., 2007). As such, the following review of the known influence of spatial attention on masked face-processing is restricted to the literature which does not conflate the effects of task-based and focal spatial attention – studies which do not distinguish between these two attentional components are deliberately excluded from this discussion.

### ***1.2.1. Masked priming effects for faces do not depend on attention***

The predominant line of evidence supporting the claim that nonconscious processing of face information does not depend on attention is our old friend, masked priming. Finkbeiner and Palermo (2009) were the first to employ the masked priming paradigm to contrast the effects of attention on nonconscious perception of face and nonface stimuli. Participants in this series of experiments categorised both line drawings of nonface targets (e.g. “Is it an Animal or a Tool?”; “Is it an Animal or a Vegetable?”), as well as photographs of faces (“Is it a Male or Female face?”). In all experiments, the prime and target appeared in fixed locations, vertically displaced relative to a central fixation point (prime above, target below). Masked primes were either category-congruent or category-incongruent with the target. The authors employed the same robust manipulation of spatial attention used by other priming researchers (Lachter et al., 2004; Lien et al., 2010) – a briefly presented exogenous spatial cue which captured spatial attention at either the prime or target location. The breakthrough finding of this paper was that spatial attention modulated the masked congruence effect reflected in RTs *differently* in the face and nonface tasks. Specifically, nonface stimuli elicited reliable congruence effects only when the spatial cue captured attention to the masked prime’s location, whilst masked face

primes produced priming regardless of where spatial attention was focused. This result and its subsequent replication (Khalid et al., 2013) would suggest that the visual system is able to process sex information carried by nonconscious faces even when attention is elsewhere. Still within in the masked priming literature, Harry et al. (2012) have reported similar results using a famous face identification task. In their study, masked face primes produced a repetition priming effect regardless of whether an exogenous spatial cue captured spatial attention to the prime's location or elsewhere.

### ***1.2.2. Convergent evidence from dual-task studies***

At present, direct evidence for the claim that nonconscious face-processing does not depend on attention appears limited to the masked priming studies discussed above. Nonetheless, analogous results may be found in dual-task studies which have examined attentional costs associated with *visible* face discrimination (Reddy et al., 2007; Reddy et al., 2006; Reddy et al., 2004). In typical variants of the dual-task paradigm (Braun & Julesz, 1998; Braun & Sagi, 1990; Sperling & Melchner, 1978; Sperling, 1986), participants perform two different tasks, either one at a time (single-task condition) or concurrently (dual-task condition). By contrasting performance for a given task between these conditions, the researcher can glean the extent to which the additional task interferes with the cognitive processes that support the first task. Dual-task interference effects are thus often taken as an indication that both tasks place demands on a shared cognitive resource such as effort or attention (Kahneman, 1973; Kerr, 1973; Moray, 1967; Navon & Gopher, 1980; Pashler, 1994). Across a series of studies, Reddy and colleagues have made particular use of this paradigm to explore the remarkable resilience of conscious face-perception to attentional load. These authors showed that participants' ability to classify the sex of a peripherally presented face does not suffer significantly when spatial attention is engaged centrally by a demanding discrimination task (e.g. differentiating rotated 'L's

and ‘T’s) (Reddy et al., 2004). Sex-categorisation performance was equally good when participants could covertly attend to the peripheral face without limit (i.e., single-task condition) and when spatial attention was predominantly engaged elsewhere in the display (i.e., dual-task condition). Similarly, the same manipulation of spatial attention does not appear to modulate the BOLD response for peripherally presented faces, provided these faces remain task-relevant (Reddy et al., 2007). The same authors have reported very similar effects for face identity judgements, demonstrating that face-identification is only modestly impaired in the near-absence of focal spatial attention (Reddy et al., 2006). The authors infer from this series of studies that (conscious) face-processing in the periphery proceeds even when little spatial attentional resources are available<sup>1</sup>.

### **1.2.3. Interim Summary**

Taken together, the findings reviewed above suggest that, unlike processing of many other masked stimulus types (e.g. words, letters, and numbers), nonconscious face-processing does not rely on the allocation of attention. The strongest support for this claim comes from the masked priming literature itself (Finkbeiner & Palermo, 2009; Khalid et

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<sup>1</sup> Note that the findings of Reddy and colleagues cannot speak to whether face-processing proceeds in the absence of spatial attention, since the attentional manipulation employed is unlikely to have completely prevented peripheral stimuli from drawing on spatial attention resources. Certainly the central discrimination task was sufficient to *predominantly* engage spatial attention, as evidenced by its ability to interfere with a peripheral control task known to be attentionally-demanding (bisected disc discrimination). However, because the authors used a fixed stimulus onset asynchrony (SOA) between the central letters and peripheral face (26ms), the onset of the central letter task may have acted as a temporal cue for the peripheral face’s onset – conditions which ideally promote what Lachter et al., (2004) have termed “attentional slippage”. According to Lachter, ‘slips’ of attention occur when attentional resources are allocated, often unintentionally, to the “unattended” information channel as a result of inadequate attentional control. Moreover, it is also quite possible that the relatively long duration of the peripheral faces (140-167ms) may have allowed these stimuli to “capture” attention themselves (See Langton, Law, Burton, & Schweinberger, 2008; Theeuwes & Van der Stigchel, 2006; Vuilleumier, 2000). As a result, it cannot not be claimed that the faces in this set of studies were processed entirely outside the focus of spatial attention.

al., 2013), with analogous findings reported in dual-task studies which demonstrate there to be little attentional cost to conscious face-processing (Reddy et al., 2007; Reddy et al., 2006; Reddy et al., 2004). Why nonconscious processing of faces should be less affected by manipulations of spatial attention than other stimulus types is not yet well understood. Nevertheless, early work in this area has pointed to the possibility of a subcortical face-processing route, predominantly sensitive to low spatial frequencies, which may be less vulnerable to the influence of cortical processes such as attention (see Awasthi, Friedman, & Williams, 2011a, 2011b; Goffaux & Rossion, 2006; Johnson, 2005; Khalid et al., 2013; Vuilleumier, Armony, Driver, & Dolan, 2003). Regardless of its underlying mechanism, the finding that nonconscious face-processing can proceed even when attention is engaged elsewhere has necessitated the development of a third position in the debate regarding the role of attention in nonconscious information processing. This third view stands in contrast to both the “complete-independence” and “complete-dependence” views, instead proposing that dependence of nonconscious processing on attention is modulated by information type (Finkbeiner & Palermo, 2009). In the following section, I will argue that this finding represents a breakthrough development in the collective endeavour to understand how attention and awareness interact.

### ***1.3. Using faces as a tool to study attention and awareness***

We have seen in the preceding sections that the role of attention in nonconscious perception varies with information type. Masked priming effects for nonface stimuli (e.g. letters, numbers, and words) appear to come and go categorically on the basis of attentional allocation. The collective conclusion of the priming studies employing nonface stimuli then has been that nonconscious information processing is critically contingent on the allocation of temporal and spatial attention. This discovery has both turned existing

theories of automaticity in nonconscious perception on their head, and contributed to the conceptualisation of attention and awareness as distinct cognitive phenomena. It must be acknowledged, however, that the categorical way in which attention modulates priming for nonface stimuli limits the inferences we can draw about the nature of the attentional mechanism at work here. Indeed, while there have been numerous explanations put forward concerning how attention improves visual perception of conscious stimuli (Cameron, Tai, & Carrasco, 2002; Carrasco, Penpeci-Talgar, & Eckstein, 2000; Carrasco, Williams, & Yeshurun, 2002; Lu & Doshier, 1998; Luck, Hillyard, Mouloua, & Hawkins, 1996; Yeshurun & Carrasco, 1998), the question of how attention might modulate nonconscious information processing has received comparatively little attention (but see Bahrami, Carmel, Walsh, Rees, & Lavie, 2008; Shin, Stolte, & Chong, 2009; Tapia, Breitmeyer, Jacob, & Broyles, 2013).

In championing Broadbent's (1958) selective filter theory of attention, Lachter et al. (2004) have characterised the effect of attention on nonconscious processing as largely binary. In this account, attention is proposed to gate information processing at a very early stage of the visual hierarchy, such that only attended nonconscious information is processed to the level of "identification" that produces observable masked priming effects. On the other hand, it could be the case that attention modulates nonconscious processing in a *graded* way that mirrors its influence on visible stimulus processing. That is, attention might facilitate nonconscious perception by enhancing the signal carried by the unconscious stimulus or diminishing the impact of external noise that is coextensive with the unconscious stimulus (Cameron, Tai, & Carrasco, 2002; Carrasco, Penpeci-Talgar, & Eckstein, 2000; Carrasco, Williams, & Yeshurun, 2002; Lu & Doshier, 1998; Luck, Hillyard, Mouloua, & Hawkins, 1996; Yeshurun & Carrasco, 1998).



Importantly, masked priming effects elicited by nonface stimuli can provide no insight as to whether the influence of attention on nonconscious processing is categorical or graded in nature. That is, because nonface stimuli only elicit a measurable priming effect when they are attended to, their capacity to index the effect of attention on nonconscious perception is necessarily *digital*. The same cannot be said, however, for masked priming effects elicited by face stimuli. Since nonconscious faces elicit priming effects regardless of attentional allocation, priming effects for faces are capable of revealing a graded effect of attention on unconscious information processing, insofar as the size or onset of this priming effect can be shown to vary as a function of attention. This represents the overarching goal of this thesis. In the four empirical chapters presented in this thesis, I will exploit the unique ability of faces to elicit masked priming effects under unattended conditions to explore how attention (chapter 2) and spatial location (chapters 3-5) modulate the way the visual system processes information below the level of conscious awareness.

#### ***1.4. Discrete and continuous indices of cognitive processing***

Having established that subliminal face-processing can be used as a tool to elucidate the role of attention in nonconscious perception, we now turn our focus to consider how best to *operationalise* nonconscious face-processing. The obvious candidate here is the masked congruence priming paradigm introduced above. The use of masked priming techniques in the context of face-perception tasks is already relatively well established (Finkbeiner & Palermo, 2009; Harry et al., 2012; Henson, Mouchlianitis, Matthews, & Kouider, 2008; Khalid et al., 2013; Kouider, Eger, Dolan, & Henson, 2009) – indeed, Finkbeiner and Palermo (2009) used just this technique in their breakthrough demonstration that nonconscious face-processing can proceed outside the focus of spatial attention. The

research in this thesis will call on this same masked congruence effect (MCE) to serve as an index of nonconscious face-processing. At this juncture, however, there is an obvious hurdle to address. That is, if previous research employing similar techniques has reported no effect of spatial attention on the MCE elicited by faces (Finkbeiner & Palermo, 2009; Harry et al., 2012; Khalid et al., 2013), why then should we expect to observe attentional modulation of this same index of nonconscious processing here? In the follow sections, I will suggest the answer lies in the dissociation between discrete and continuous behavioural response measures.

#### ***1.4.1. The limitations of discrete response measures***

The most widely used dependent measure in the cognitive psychology toolbox is undoubtedly response time (RT), typically produced by asking participants to press one or more buttons to indicate their response to a stimulus. In categorisation tasks, for example, participants might indicate category membership of a target by pressing the left button when they see a picture of an animal, and the right button when they see a picture of a tool (e.g. Experiment 1a, Finkbeiner & Palermo, 2009). While the button-press task has a venerable and productive history in cognitive psychology, it does have limitations. On any given trial for any given task, a button-press response can tell us a) if the participant made the right or wrong decision about the stimulus, and b) the total duration of all the various mental and motoric processes that happened between the appearance of the target and the participant's final response. What discrete measures given by a button-press response *cannot* reveal, however, is the dynamic interaction of such internal states during this period of several hundred milliseconds (Song & Nakayama, 2009). With this in mind, it seems a reasonable possibility that the discrete, button-press responses employed by previous investigations of attention and nonconscious face-processing may well have been too “blunt” to reveal subtle attentional modulations of robust face-recognition processes. That

is, on the assumption that the processes which support face recognition, and sex-categorisation in particular, are highly efficient (Bruce & Young, 1998; Clutterbuck & Johnston, 2004), then it may be the case that attention can only facilitate face-processing during the early stages of stimulus processing in which critical information about the face target is still being accrued. If this is indeed the case, how then should we try to index experimental effects present early on during stimulus processing? As both a discrete and relatively ‘late’ index of cognitive processes, RT is unlikely to be sensitive to such early and fleeting differences between attended and unattended conditions. What is needed, then, is a measure that can reflect internal mental processes *as they unfold* during stimulus-processing time.

#### ***1.4.2. The history of continuous reaching measures***

One dependent measure which has been argued to do just this is **continuous reaching movements**. Studies of arm movements have been prolific within the motor control literature examining how the central nervous system generates and executes goal-directed motor plans (Chapman et al., 2010a, 2010b; Goodale & Milner, 1992; Milner & Goodale, 1995; Rosenbaum, 2009). More recently, however, cognitive psychologists have appropriated this measure as a tool to study mental processes associated with the interpretation of *abstract* stimuli. In this new approach, the observable properties of reaching movements are treated as an index of underlying internal states in much the same way as RTs have been for the last hundred years (see Posner, 2005). While variants of the Reach-to-Touch response paradigm have been used since the early 1990s (e.g. Tipper et al., 1998; Tipper, Lortie, & Baylis, 1992), the breakthrough work in this area was arguably that of Spivey, Grosjean, Knoblich, and McClelland (2005). In this seminal study, participants viewed two laterally positioned pictures (one target and one decoy) at the upper left and right corners of a computer monitor (e.g. a picture of a candle and a candy).

The task on each trial was to pair a spoken target word (e.g. “*candy*”) with the matching target picture by dragging a mouse cursor from a central start point to either the left or right picture. What is most important to note about Spivey’s version of the arm movement paradigm is that it removes the target stimulus from the response locations. That is, the participant’s task was *not* to reach out and touch the location where the target appeared (cf. Tipper et al., 1998; Tipper et al., 1992), but rather to *interpret* a target stimulus and make an appropriate arm movement in response. As a result, Spivey et al. argued that the reaching response on each trial would not be governed by the location of the target stimulus, but instead by the participant’s internal processing of this item (in this case, the phonological and semantic processing of the spoken target word). This stands in contrast to the wealth of visuomotor control studies in which researchers have investigated how perceptual and attentional load interferes with participants’ ability to reach towards a physically represented target stimulus (Goodale & Milner, 1992; Milner & Goodale, 1995; Tipper et al., 1998; Tipper et al., 1992). Critically, Spivey and colleagues observed that participants’ mouse trajectories curved towards the decoy picture more when there was high phonological overlap between the target word and the decoy picture (e.g. “*candle*” and *candy*). By comparison, trajectories were straighter when the target and decoy did not share any sounds (e.g. “*candle*” and *jacket*). The authors took this difference in mouse trajectory curvature as evidence of online competition between partially active lexical representations, claiming that continuous sampling of the reaching response enabled them “... to track the temporal dynamics of lexical activations during real-time spoken-word recognition...” (p. 10393, Spivey et al., 2005).

### ***1.4.3. Continuous but not concurrent: Contrasting “stimulus-processing time” with “response-execution time”***

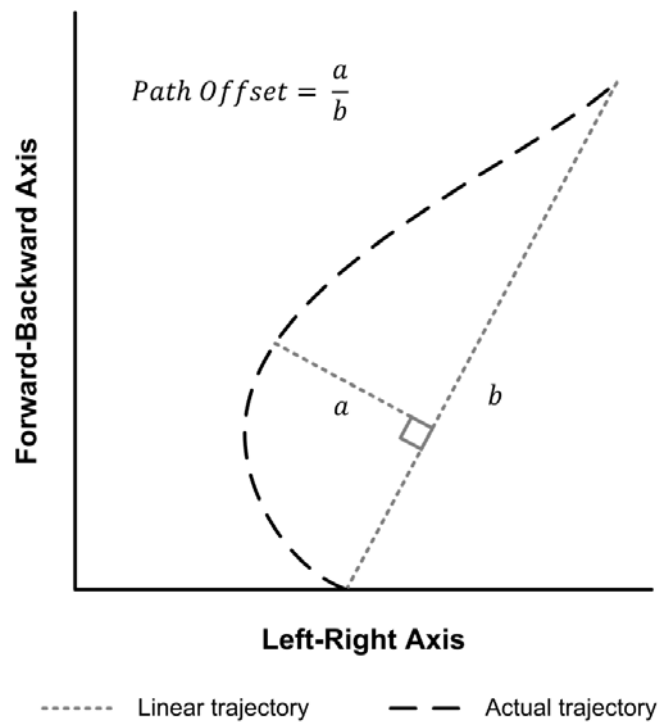
Spivey and colleagues are by no means alone in their claim that continuous behavioural measures are capable of revealing “online” information processing as it unfolds in “real-time”. In fact, a central assumption within the burgeoning reaching trajectory literature has been that since the flow of mental processing is continuous and dynamic, a measure which continuously samples a dynamic behavioural response should be able to provide a moment-to-moment index of this fluid processing (Dale, Kehoe, & Spivey, 2007; Freeman, Ambady, Rule, & Johnson, 2008; Freeman, Dale, & Farmer, 2011; Song & Nakayama, 2008; 2009; Spivey, 2006; Spivey & Dale, 2006). Otherwise known as the **continuity assumption** (Spivey, 2006), the claim here is that the ongoing position of the hand as it moves through response-space is contiguous with the unfolding of a “cognitive trajectory” through decision-space (Spivey & Dale, 2006) (for a detailed critique of this assumption, see Finkbeiner, Coltheart, & Coltheart, 2014). Indeed, this position has been championed by many of the leaders of the reaching trajectory movement within cognitive psychology. For example, Freeman and colleagues (2008) claimed that streaming the *xy* coordinates of hand movements during a face-sex categorisation task could reveal “real-time” dynamic competition between multiple social category alternatives. Similarly, in their comprehensive review of how continuous hand movements can be used to reveal internal processing, Song and Nakayama (2009) stated that “[t]he continuity of reaching movements enables each sample point to be modulated by the real-time progress of a wide range of internal processes” (p. 360, Song & Nakayama, 2009). While the potential of reaching movements to reveal temporal unfolding of hidden cognitive states is undeniably appealing, a closer inspection of this premise suggests that the current approaches to continuous reaching trajectory data have yet to deliver on this promise. I will argue below that this shortcoming is the result of a misguided assumption

that experimental effects reflected in *response-execution time* should reflect cognitive phenomena unfolding during *stimulus-processing time*<sup>2</sup>.

To date, most cognitive psychology studies using continuous reaching measures have taken as their dependent measure a value termed “path offset”, or curvature. Path offset is most often calculated as the perpendicular distance between the hand and a linear trajectory connecting the first and last samples of the hand’s movement (see Figure 1). By generating a path offset value for each recorded sample, the experimenter can choose to either analyse the maximum path offset value for each trial (see Finkbeiner et al., 2008), or else treat the continuous values as a time series dataset (Finkbeiner & Friedman, 2011). While this second approach brings with it the not insignificant challenge of dealing with the problem of multiple comparisons (for details and a proposed solution to this issue, see Finkbeiner & Friedman, 2011), its obvious advantage is that it can provide temporal information about *when* an experimental effect of interest becomes reliable. By asking whether the conditional mean path offset values at each sample differ from one another, the experimenter can produce a timecourse analysis that reveals the magnitude, emergence, and perhaps also decay, of experimental effects (for a more extensive discussion of the limitations of path offset analyses, see Finkbeiner et al., 2014).

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<sup>2</sup> Note that I am not disputing the claim that action and cognition dynamics are richly contiguous with one another (R. A. Abrams & Balota, 1991; Cisek, 2007a, 2007b; Gold & Shadlen, 2000; 2001; Rosenbaum, Cohen, Jax, Weiss, & van der Wel, 2007). It is now quite well established that the motor system is more than a simple “effector” of higher order central processes (cf. Fodor, 1983).



*Figure 1.* Schematic depiction of path offset, the typical dependent measure used to operationalise experimental effects reflected in reaching trajectory data. At any given sample, path offset is equal to the perpendicular distance between the hand’s actual trajectory (large dash line) and an ideal linear trajectory between the first and last samples of the response (small dash line).

The question of critical interest here, however, is whether this continuous measure reveals processes as they unfold in “real-time”, as has so often been claimed (Dale et al., 2007; Song & Nakayama, 2009; Spivey & Dale, 2006; Spivey et al., 2005). Importantly, because experimental effects observed in path offset analyses are necessarily reflected during response-execution time, the claim that these effects reflect “real-time” cognitive processing can only be supported if the participant executes their reaching movement whilst stimulus-processing is still ongoing. Finkbeiner and colleagues (2014) have suggested that this is unlikely to be case, given that participants in reaching studies usually

perform their movements over the course of 1-2 seconds (where 0 is stimulus onset). By way of an example, let us consider how we might interpret a strong effect of word frequency in a lexical decision task which used path offset as its dependent measure. If we believe the claim that the temporal sensitivity of continuous reaching trajectories really does reveal the temporal unfolding of cognitive processes in an “online” way, then perhaps we will conclude that the word frequency effect arises after 500-600 milliseconds of lexical processing, as this is the path offset sample at which the high frequency path condition is statistically higher than the low frequency condition. But can this really reflect the *true* temporal onset of the word frequency effect? After all, evidence from the ERP literature suggests to us that proficient readers should be able to distinguish high and low frequency words much earlier than this, at a point closer to 200ms after target onset (Cuetos, Barbón, Urrutia, & Domínguez, 2009; Hauk & Pulvermüller, 2004). This temporal discrepancy forces us to consider the possibility that perhaps divergences in path offset values do not index real-time updates in stimulus processing at all, but rather reflect ‘leakage’ of earlier cognitive states into the final motor output, much as we assume is the case for effects realised in RTs. Indeed, one could argue that while path offset as a measure itself is continuous, its ability to reveal experimental effects remains quite digital, insofar as it is limited to providing only the point in time during the reaching response itself that an effect becomes significant.

#### **1.4.4. *Interim Summary***

The central aim of this thesis is to elucidate the role of attention in nonconscious information processing by examining the effect of attention on masked priming effects elicited by faces. I have proposed that since face-recognition is a highly robust process (Bruce & Young, 1998), the effect of attention for this stimulus type could well be early and transient. I have further suggested that as a discrete and relatively “late” index of



cognitive processing, RTs may lack the sensitivity to reveal attentional effects of this nature (see Finkbeiner & Palermo, 2009; Harry et al., 2012; Khalid et al., 2013). Ideally, we want to be able to index the effect of attention on masked face-processing *while stimulus processing is still ongoing*. On first inspection, continuous reaching trajectories would appear to be a promising behavioural measure in this regard, with some advocating that they are capable of revealing the unfolding of dynamic cognitive processes in real-time (Dale et al., 2007; Song & Nakayama, 2008; 2009; Spivey & Dale, 2006; Spivey et al., 2005). I have countered, however, that despite their exquisite temporal sensitivity, reaching trajectory analyses in their current form fall short of this claim. That is, insofar as continuous reaching measures reveal experimental effects during *response-execution time*, rather than *stimulus-processing time*, they cannot be claimed to be a “real-time” index of underlying cognitive processes.

The cause is not lost, however. Recent work has refined the analysis of continuous reaching trajectories in a way that does enable the researcher to use reaching trajectories as a valid means of inference about online stimulus processing (Finkbeiner et al., 2014). In the next section, I provide a brief introduction to this new version of the Reach-to-Touch paradigm, and highlight its empirical relevance to the guiding research question of this thesis.

### ***1.5. Opening the window on stimulus-processing time: A new version of the Reach-to-Touch paradigm***

In the preceding sections I have made the case that the potential of reaching movements to reveal “real-time” cognitive processing depends on the co-occurrence of these two things. One way to ensure that reaching movements are executed whilst critical

stimulus-processing is still ongoing is to require participants to initiate their reaching response at an early stage of stimulus-processing, before they have accrued enough information about the target to be certain of their final response. Unlike button-press designs, in a reaching task there is very little ‘cost’ to the participant to begin responding before they are certain of their final decision, since they can continue accumulating evidence to guide their choice while the finger is in flight. There are several ways in which participants can be encouraged to begin their reaching response during an early stage of information-processing. One is to instruct participants to commence their reaching response as soon as they see the target appear. This can be somewhat counterintuitive for participants, however, as there is a strong temptation to withhold the response until they are more certain about the target. An alternative method is to train participants to begin moving in response to an imperative go-signal that is not the target onset itself. The version of the Reach-to-Touch paradigm employed in this thesis achieves this by requiring participants to initiate their reaching response in synchrony with an auditory go-signal – the third tone in a series of three beeps of ascending pitch (Finkbeiner et al., 2014). By varying the temporal proximity of the target to this go-signal (i.e., the point of movement initiation), the researcher can examine reaching trajectories initiated across a wide range of target viewing times. By asking how kinematic properties of the reaching movement vary as a function of target-viewing time, one can observe the gradual growth and emergence of experimental effects as they unfold during stimulus-processing time, rather than response-execution time. Given the window it provides on the earliest stages of stimulus-processing, this new version of the Reach-to-Touch paradigm would seem an ideal tool with which to explore the temporal dynamics of nonconscious face-processing and the factors which modulate this hidden cognitive process.

## **1.6. Overall summary & chapter outline**

It is well established that the human visual system is capable of processing information presented below the level of conscious awareness (Dehaene et al., 2006; Dehaene et al., 1998; Kouider & Dehaene, 2007; Kouider & Dupoux, 2001; 2005; Kouider et al., 2009). According to classical theories, these unconscious automatic processes are assumed to be autonomous and independent of top down factors such as attention (Posner & Snyder, 1975; Schneider & Shiffrin, 1977). Over the last several decades, however, masked priming research has strongly suggested that nonconscious processing is in fact “gated” by attentional allocation (Fabre et al., 2007; Kiefer & Brendel, 2006; Lachter et al., 2004; Lien et al., 2010; Naccache et al., 2002). Against the backdrop of this dichotomy, a third stance put forward by Finkbeiner and Palermo (2009) suggests the modulatory effects of attention on nonconscious perception may vary with stimulus type. Where processing of nonconscious words, letters, and numbers appears to depend on attention (Fabre et al., 2007; Lachter et al., 2004; Marzouki et al., 2007; Marzouki et al., 2008; Naccache et al., 2002), perception of masked faces seems able to proceed even when attention is engaged elsewhere (Finkbeiner & Palermo, 2009; Harry, Davis, & Kim, 2012; Khalid, Finkbeiner, Konig, & Ansorge, 2013). The principle goal of this thesis is to exploit this unique property of face-processing to explore the interaction between awareness and factors such as attention and spatial location. Particular focus is given to examining the temporal dynamics of these cognitive processes. In pursuit of this goal, each of the empirical chapters presented in this thesis employs the novel version of the Reach-to-Touch paradigm introduced above, in which I couple rapid sampling of reaching movements with a response-signal procedure to examine the unfolding of experimental effects in stimulus-processing time. The principle research questions and key findings of each empirical chapter are outlined in the following sections.

### **1.6.1. Chapter 2 – Study 1**

#### ***“Spatial and temporal attention modulate the early stages of face processing: Behavioural evidence from a reaching paradigm”***

Chapter 2 addresses the guiding research question of this thesis by asking whether the allocation of spatial or temporal attention can modulate nonconscious face-processing. In this chapter, I contrast behavioural face-perception studies that suggest face-processing to be insensitive to the effects of attention with the neurophysiological literature that documents attentional modulation of the neural response to faces. I attempt to resolve this discrepancy by using the Reach-to-Touch paradigm to examine how attention modulates the very early stages of face-processing. Using this method, I document the temporal unfolding of the masked congruence effect for faces and provide compelling behavioural evidence that the early stages of nonconscious face-processing are indeed sensitive to manipulations of spatial and temporal attention.

### **1.6.2. Chapter 3 – Study 2**

#### ***“Face-sex categorisation is better above fixation than below: Evidence from the reach-to-touch paradigm”***

Having established the sensitivity of nonconscious face-perception to the effects of attention, in Chapter 3 I turn my focus to examine whether the visual system’s ability to process faces might also depend on spatial location. In this chapter, I contrast the well-known laterality effects in face-processing with the relatively unexplored possibility of vertical asymmetry in face-perception, and highlight several lines of evidence which suggest face-processing may be supported better in the upper visual field (UVF) compared to the lower visual field (LVF). Chapter 3 draws on the same behavioural methods and

analyses as Chapter 2, and reports the breakthrough finding that nonconscious face-processing is more efficient in the upper-hemifield than the lower-hemifield.

### **1.6.3. Chapter 4 – Study 3**

#### ***“Gaining the upper hand: Evidence of vertical asymmetry in sex-categorisation of human hands”***

Chapter 4 explores the key finding of Chapter 3 within the context of a functional specialisation account of vertical asymmetry in visual perception. I introduce the possibility that the upper-hemifield advantage may extend beyond face-recognition to object recognition processes more generally. I seek initial evidence for this position by examining how vertical hemifield modulates information-processing of a nonface object – human hands. Similar to our findings for face stimuli, we found evidence of an upper-hemifield superiority in this task, suggesting that the UVF may enjoy a broader advantage in object recognition (Previc, 1990).

### **1.6.4. Chapter 5 – Study 4**

#### ***“The upper-hemifield advantage for masked face-processing: Not just an attentional bias”***

The last empirical study presented in this thesis examines whether the upper-hemifield advantage reported in chapters 3 and 4 relates to an upward bias in visuospatial attention. I present two experiments in which I systematically manipulate participants’ voluntarily directed spatial attention across testing sessions. As in the previous chapters, I employ the Reach-to-Touch paradigm to reveal the temporal dynamics of nonconscious face-processing, and provide strong evidence to dispel the claim that the UVF advantage for nonconscious face-processing can be explained by a bias in voluntarily directed spatial attention.

### ***1.6.5. Chapter 6 – General Discussion***

In the final chapter of this thesis, I will reprise the specific findings of each empirical study, discuss their implications within a broader research context, and highlight a number of avenues of ongoing and future research.

## 1.7. References

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MODULATE THE EARLY STAGES OF  
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SPATIAL & TEMPORAL ATTENTION MODULATE THE EARLY  
STAGES OF FACE-PROCESSING:  
BEHAVIOURAL EVIDENCE FROM A REACHING PARADIGM

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## **2.1. Abstract**

A presently unresolved question within the face perception literature is whether attending to the location of a face modulates face processing (i.e., spatial attention). Opinions on this matter diverge along methodological lines – where neuroimaging studies have observed that the allocation of spatial attention serves to enhance the neural response to a face, findings from behavioural paradigms suggest face processing is carried out independently of spatial attention. In the present study, we reconcile this divide by using a continuous behavioural response measure that indexes face processing at a temporal resolution not available in discrete behavioural measures (e.g. button press). Using reaching trajectories as our response measure, we observed that although participants were able to process faces both when attended and unattended (as others have found), face processing was not impervious to attentional modulation. Attending to the face conferred clear benefits on sex-classification processes at less than 350ms of stimulus processing time. These findings constitute the first reliable demonstration of the modulatory effects of both spatial and temporal attention on face processing within a behavioural paradigm.

## 2.2. *Introduction*

Of the many objects we encounter in the visual world, faces are perhaps the most biologically and socially significant. Accordingly, faces hold a particularly important status within the human visual system, eliciting specific neural responses in the Fusiform Face Area (FFA) (Allison et al., 1994; Farah, Wilson, Drain, & Tanaka, 1998; Kanwisher, McDermott, & Chun, 1997; Puce, Allison, Asgari, Gore, & McCarthy, 1996), and readily capturing visual attention over other objects in a scene (Kanwisher & Wojciulik, 2000; Langton, Law, Burton, & Schweinberger, 2008; O'Craven, Downing, & Kanwisher, 1999; Ro, Russell, & Lavie, 2001). Although the relationship between attention and faces has been widely examined in the literature, much of the existing research has documented the effects of object- or task-based attention, in which participants direct their attention to face- or non-face-stimuli according to the task instructions (Lueschow et al., 2004; Williams, McGlone, Abbott, & Mattingley, 2005; Wojciulik, Kanwisher, & Driver, 1998; Yi, Kelley, Marois, & Chun, 2006). A comparatively unresolved question concerns how directing attention to the *location* of a face modulates the processing of this stimulus. Intriguingly, it is now well-established that face processing can in fact proceed in the near-absence of spatial attention. For example, Reddy and colleagues have shown that participants' ability to classify the sex or identity of peripheral faces does not suffer significantly when spatial attention is held centrally by a demanding discrimination task. Face performance in this dual task condition was not significantly different to when they explicitly attended to the peripheral face (Reddy, Moradi, & Koch, 2007; Reddy, Reddy, & Koch, 2006; Reddy, Wilken, & Koch, 2004). Similarly, we have reported elsewhere that the sex of a briefly presented masked face (called the prime) affects participants' classification of a subsequent target face to the same degree regardless of whether spatial attention had been captured to the prime's location or elsewhere (Finkbeiner & Palermo, 2009). Comparative effects have been observed for face-fame judgement tasks (Harry, Davis, & Kim, 2012). However,



where these behavioural studies might suggest face processing is carried out independently of attention, functional magnetic resonance imaging (fMRI) research has demonstrated that the allocation of attention to the region of space in which a face appears enhances the associated haemodynamic response in the FFA (Downing, Liu, & Kanwisher, 2001; Henson & Mouchlianitis, 2007; Pessoa, McKenna, Gutierrez, & Ungerleider, 2002; Vuilleumier, Armony, Driver, & Dolan, 2001). For example, Vuilleumier and colleagues (2001) used a four placeholder crossed display to have participants report identical matches for face or house stimuli. Prior to each block, participants saw a cue that indicated which pair of placeholders they should attend to (vertical or horizontal), and were instructed to ignore stimuli appearing in the uncued, irrelevant locations. The authors were thus able to compare the blood-oxygen-level-dependent (BOLD) response for spatially attended and unattended faces in the same physical location, finding greater activation in the FFA for the former. Similar effects have been reported elsewhere (Downing et al., 2001; Henson & Mouchlianitis, 2007; Pessoa et al., 2002). At present, this discrepancy in the face perception literature remains unresolved – is face processing carried out independently of spatial attention, as existing behavioural data might suggest (Finkbeiner & Palermo, 2009; Harry et al., 2012; Reddy et al., 2007; Reddy et al., 2006; Reddy et al., 2004) ? Or are faces just more robust to manipulations of spatial attention than non-face stimuli (Besner, Risko, & Sklair, 2005; Kiefer & Brendel, 2006; Lachter, Forster, & Ruthruff, 2004; Marzouki, Grainger, & Theeuwes, 2007)? We reconcile this issue in the present study by demonstrating for the first time reliable effects of both spatial and temporal attention on sex-classification processes within a behavioural task (Esterman et al., 2008; Finkbeiner & Palermo, 2009; Harry et al., 2012)

One possible explanation for the lack of observable attentional effects in previous behavioural studies relates to the measure they typically employ: button-press responses. Although widely used in cognitive research, we suggest that this discrete measure of

cognitive processes may not be sufficiently sensitive to reveal the modulatory effects of spatial/temporal attention in face classification tasks. Sex-categorisation, for example, is extremely efficient. Even in the absence of overt gender cues (e.g. hairstyle or facial hair), participants are able to discriminate the sex of a target face very quickly (Bruce & Young, 1998; Clutterbuck & Johnston, 2004). Accordingly, we might expect that any attentional benefit relating to this process would be difficult to detect, since performance is already very close to ceiling. Sreenivasan and colleagues have documented this, showing no attentional modulation of the face-specific event-related potential (ERP) known as the N170 for highly discriminable faces, but a clear attentional benefit on the same component when the perceptual quality of faces is degraded, effectively reducing the signal-to-noise ratio (Sreenivasan, Goldstein, Lustig, Rivas, & Jha, 2009). Given that attentional effects are clearest with degraded faces, it is reasonable to think that the modulatory effects of attention would be fleeting, if they are present at all, with non-degraded faces. With this in mind, we reasoned that the possibility of observing attentional effects would be the greatest during the earliest stages of stimulus processing, when perceptual evidence is still being accumulated. In support of this supposition are neurophysiological findings that spatial attention modulates the early stages of sensory processing for faces (Jacques & Rossion, 2007; Sreenivasan, Goldstein, Lustig, Rivas, & Jha, 2009; Wijers & Banis, 2012). For example, Jacques and Rossion (2007) showed that spatial attention modulates visual processes effects as early as 80ms after stimulus onset, as well enhancing the N170 component. Similarly, a recent study by Wijers and Banis (2012) observed that directing participants' spatial attention to the location of a face enhanced the mean amplitude of early visual components P1 and N1 elicited by this stimulus. Taken together, these neurophysiological findings would suggest that spatial attention is capable of modulating the *early* stages of visual processing for faces, within ~300ms from stimulus onset. Importantly, button-press data are unable to index this early stage of visual processing, as

both the response time (RT) and accuracy measures obtained on a given trial necessarily represent the endpoint, or culmination, of target processing. Given that the typical latency for button-press responses (~500-600ms) far exceeds the period in which ERP studies have reported modulatory effects of spatial attention in face-classification tasks, it is perhaps not surprising that behavioural studies have thus far failed to observe attentional effects.

In the present study, we sought to document the behavioural complement of these early neurophysiological effects of spatial attention. Our response paradigm was specifically designed to examine face processing during the first 350ms of stimulus processing. Rather than pressing a button to indicate their response, in our task participants classified the sex of a target face by reaching out to touch the left or right side of the computer monitor. Importantly, we used a motion-capture device (Optotrak) to sample the position of the hand during the reaching response, which resulted in a high resolution continuous dataset on each trial. There is now a burgeoning literature on the use of such continuous movement measures in cognitive psychology (Chapman et al., 2010a; Dale, Kehoe, & Spivey, 2007; Song & Nakayama, 2008; 2009; Spivey, Grosjean, Knoblich, & McClelland, 2005), which are purportedly able to capture dynamic interactions between multiple cognitive processes reflected in motor output (Cisek & Kalaska, 2005). The principal advantage of reaching responses in the present study is that they enable participants to *begin* their classification response very early without penalty. We required participants to initiate their reaching movement within 350ms of the target's onset, ensuring that the initial stages of their classification movements were (frequently) made while participants were still accumulating evidence about the target. In light of the effects documented in the ERP literature, we reasoned that the attentional effects on face processing would be most visible during this early stage of stimulus processing. We combined this continuous behavioural measure with an adaptation of the masked priming paradigm (Forster & Davis, 1984), in which the target face always appeared in the lower of

two vertically displaced panels (see Figure 1), and was temporally preceded by a prime face that always appeared in the upper panel. The prime stimuli were either the same sex as the target (i.e., congruent), or of the opposite sex (incongruent), were presented very briefly (50ms) and immediately backward masked, such that participants were generally unable to report seeing the prime (see Finkbeiner & Palermo, 2009). We assessed the extent to which the masked face was processed by examining how prime–target congruence modulated participants’ overt response to the target. In button-press versions of this paradigm, participants typically respond faster and more accurately to congruent prime–target pairings than to incongruent pairs, a result termed the Masked Congruence Effect (MCE) (Dell’Acqua & Grainger, 1999; Fabre, Lemaire, & Grainger, 2007; Finkbeiner & Palermo, 2009; Naccache, Blandin, & Dehaene, 2002). The MCE thus provides an index of prime processing – the key question here is whether the allocation of attention to the prime’s location (in space or time) modulates prime processing at all (i.e., larger congruence effects for attended primes).

To answer this question, we examined the MCE evident in participants’ reaching trajectories in the context of manipulations of both spatial attention (Expt 1A) and temporal attention (Expt 1B). In Expt 1A, we adapted a spatial cueing procedure introduced by Lachter and colleagues (2004) in which an exogenous cue localised participants’ transient spatial attention at either the prime or target location (upper or lower panel – see Figure 1). Variants of this paradigm, widespread in the masked priming literature (Besner et al., 2005; Finkbeiner & Palermo, 2009; Lien, Ruthruff, Kouchi, & Lachter, 2010; Marzouki et al., 2007), typically yield robust spatial cueing effects. Importantly, Lachter et al. have highlighted that this paradigm actively prevents ‘slips’ of spatial attention, and, by extension, the possibility that experimental effects observed outside the locus of spatial attention might actually be due to slippage of attention to the supposedly unattended stimuli. In the present design, we have adhered to the steps

recommended by Lachter to prevent attentional slippage by (1) presenting targets in a fixed location, thereby encouraging participants to direct endogenous attention to the target location; (2) using a sudden onset spatial cue to capture spatial attention exogenously; and (3) presenting prime items briefly (50ms) to prevent shifts of attention to them before being backward masked (Lachter et al., 2004). In Expt 1B we examined how the allocation of temporal attention to the prime–target pair modulated face processing. To this end, we took advantage of the fact that participants can anticipate temporally predictable events with high precision (Treisman, Faulkner, Naish, & Brogan, 1990) by manipulating the predictability of target onset. The target could occur after one of four fixation durations (900ms, 1150ms, 1400ms or 1650ms), thereby yielding an increasing conditional probability that the target would appear at a particular moment given that it had not already been presented (i.e., the hazard function). Ghose and Manusell (2002) demonstrated that attentional modulation of neural firing rates in the visual cortex (V4) of rhesus monkeys increases as probability of target onset does. In humans, temporal orienting has also been shown to improve perceptual sensitivity (indexed by  $d'$ ) (Correa, Lupiáñez, & Tudela, 2005). For example, Westheimer and Ley (1996) had participants make orientation and stereoscopic depth discriminations for stimuli that could occur at either a fixed or random temporal interval. Discrimination thresholds for both stimulus types were significantly lower when participants could reliably anticipate stimulus onset (fixed interval), suggesting that temporal orienting can enhance perceptual preparation (Correa, Lupiáñez, Madrid, & Tudela, 2006; Coull, Frith, Buchel, & Nobre, 2000; Naccache et al., 2002; Nobre, Correa, & Coull, 2007; Westheimer, 1996) but see (Los & Van Den Heuvel, 2001).

In keeping with previous findings (Finkbeiner & Palermo, 2009; Harry et al., 2012), we expected to find a masked congruence effect (MCE) in participants' reaching trajectories in both experiments irrespective of attentional allocation. Critically however, we hypothesized that our manipulations of spatial (Expt 1A) and temporal (Expt 1B)

attention would modulate the MCE and that this modulatory effect would be most apparent in those reaching responses that were initiated within ~200ms of stimulus onset. More specifically, we predicted that the MCE would be strongest when participants' spatial attention was captured to the prime's location (Expt 1A), and as participants' temporal attention became increasingly focused with the increase in the hazard function (Expt 1B).

## **2.3. General Methods**

### **2.3.1. Ethics**

Experimental protocol was approved by the Human Research Ethics Committee of Macquarie University. All procedures were in compliance with the NH&MRC Australian Code for the Responsible Conduct of Research and the National Statement on Ethical Conduct in Human Research (2007). All participants provided written informed consent prior to partaking in the experiments.

### **2.3.2. Participants**

Sixteen undergraduate Macquarie University students aged between 19 and 33 years were recruited to participate in Expt 1A. A subsequent group of 16 different students (ages 19-26 years) participated in Expt 1B. All participants were right-handed and financially compensated for their participation.

### **2.3.3. Stimuli**

Stimuli were greyscale photographs of male and female faces drawn from the Psychological Image Collection at Stirling database (PICS, <http://pics.psych.stir.ac.uk/>). Six exemplars of each sex were cropped to exclude face contours and adjusted so that their low-level properties were comparable. Five male and five female faces were assigned as

targets, with a single exemplar of each sex allocated as the novel prime for that category. These primes only ever appeared under masked conditions, and were never consciously presented as target stimuli. Each finished stimulus subtended  $4.2^0 \times 3.37^0$  of visual angle from a viewing distance of 68cm.

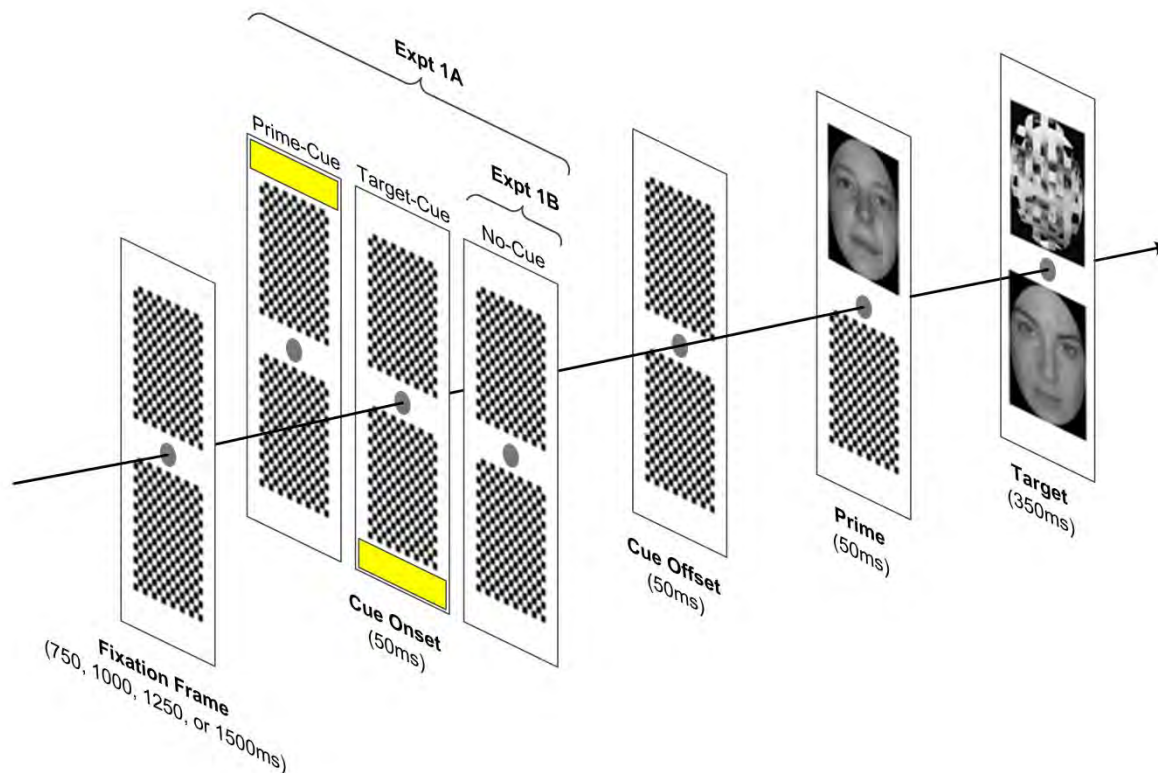
### **2.3.4. Design**

In Expt 1A we used a  $2 \times 2 \times 2$  fully-crossed factorial design with the factors Cue Presence (present vs. absent), Cue Location (prime location vs. target location) and Prime Type (congruent vs. incongruent). The factor Cue Location was included as a dummy factor on cue-absent trials to ensure an equal number of cue-present and cue-absent trials. To increase uncertainty, we randomly varied the Fixation-Target SOA between 900ms, 1150ms, 1400ms or 1650ms. The latter manipulation was included as a factor in Expt 1B, as part of a  $4 \times 2$  fully crossed factorial design (SOA  $\times$  Prime Type). There were 80 trials per block; in each experiment participants completed one practice block (not analysed), five experimental blocks and a subsequent prime classification block in which we assessed their prime awareness.

### **2.3.5. Apparatus & Procedure**

All details pertain to both Expts 1A and 1B; see Figure 1 for trial structure differences between the tasks. Participants sat at a rigid table before a  $70 \times 39$ cm touchscreen monitor fixed 60cm from the table edge. Throughout testing the monitor displayed peripheral response buttons marked 'M' and 'F' (side counterbalanced across participants). The stimulus display consisted of two panels ( $75 \times 100$  pixels), displaced vertically around a fixation dot (see Figure 1). On each trial, the prime face appeared for 50ms in the upper panel before being backward masked; the target face subsequently appeared for 350ms below fixation. This brief target duration increased the difficulty of the

task for participants, motivating them to direct their attention to the lower panel, *away* from the critical prime stimulus.



*Figure 1.* Trial structure for Experiments 1A & 1B. Here we depict a congruent trial, in which the prime and target were of the same sex (i.e., female). Each frame consisted of two vertically displaced panels and a central fixation point, presented for identical durations within each frame. Prime and target items always appeared in the upper and lower panels respectively. Both experiments used a variable fixation duration (750ms – 1500ms); in Expt 1A, the sudden onset and offset of a yellow bar captured participants' transient spatial attention at the prime (upper) or target (lower) location.



The trial sequence commenced when the participant depressed a start button aligned with the body midline, 3.5cm from the table edge. Participants were instructed to lift off the button as soon as the target face appeared in the lower panel, and immediately classify its sex by reaching out to touch the appropriate response button on the left or right edge of the screen. On each trial, we recorded participants' response initiation time (LiftOff Latency), defined as the time in milliseconds from target onset until the participant released the start button and began their reaching movement. LiftOff Latency serves as a proxy for Target-Viewing Time, in that it reflects the amount of time the participant had to accumulate target evidence prior to commencing their classification response. Whilst this duration varies on each trial, it is critical to note that Target-Viewing Time values are always preceded by 50ms of exposure to the masked prime stimulus. Importantly, we encouraged participants to initiate their reaching response quickly by giving negative feedback (a loud buzz) and aborting the trial if their LiftOff Latency exceeded 350ms from target onset. In contrast, reaching responses to classify the target were not speeded, unfolding over ample time (~3 seconds) for the finger to change direction or correct its course. The stimulus display was controlled using Presentation software (Neurobehavioral Systems); custom software was written to interface the stimulus display with a motion capture device (OptotrakCertus, NDI). This device recorded participants' reaching trajectories by sampling the position of a small light-emitting diode fixed to the tip of their right index finger at a rate of 200Hz. This enabled us to record the finger's position in xyz space every 5ms.

We assessed participants' awareness of the masked prime stimuli at the conclusion of the experiment proper. Participants were informed of the prime's presence and instructed to complete a final block of trials in which each target classification was followed by an untimed forced-choice identification of the prime on that trial. Participants

indicated which face appeared as the prime by touching one of two faces presented side-by-side (the real prime and a foil).

## **2.4. Experiment 1A: Spatial Attention**

In Expt 1A we used a non-predictive exogenous cue to orient *spatial attention* either toward or away from the prime location. We predicted that masked congruence effects evident in participants' classification movements would be stronger for trials on which spatial attention was captured to the prime's location (prime-cue condition), rather than to the target's location (target-cue), or when attention remained diffuse over the whole display (no-cue).

### **2.4.1. Data Analysis & Results**

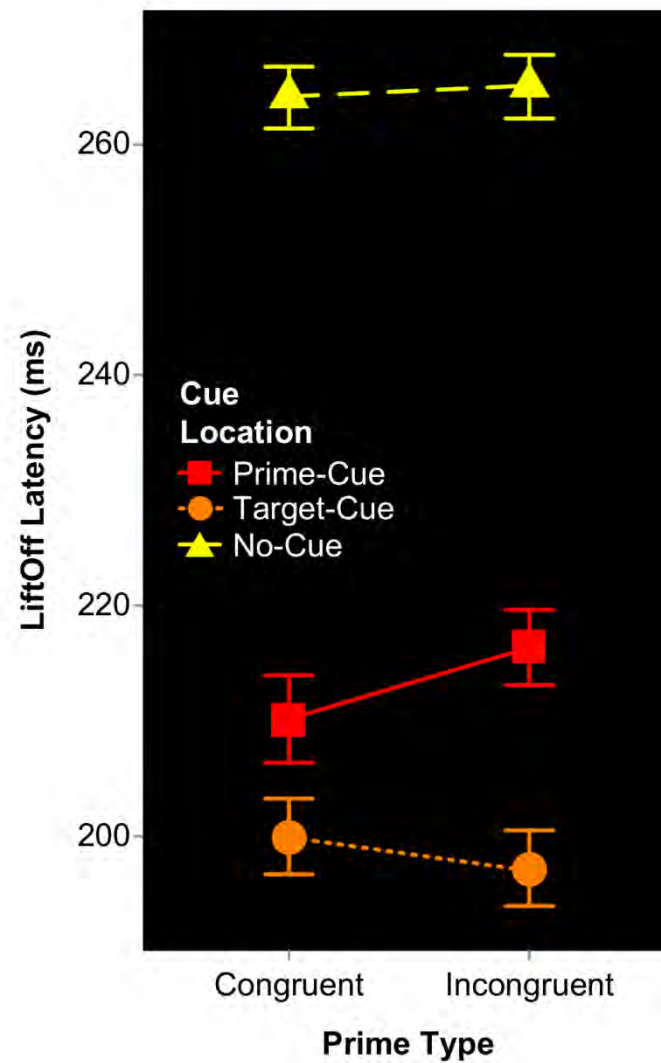
#### **2.4.1.1. Accuracy**

The mean accuracy in target classification averaged across participants was 99.79%. Accuracy rates were entered into a repeated measures analysis of variance (ANOVA) with the factors Cue Location (prime-cue, target-cue, no-cue) and Prime Type (congruent, incongruent). Results confirmed neither factor influenced participants' accuracy rates (all  $p$  values  $> .1$ ).

#### **2.4.1.2. LiftOff Latency**

We entered the mean LiftOff Latencies into the same repeated measures ANOVA described above. Here we observed a clear effect of Cue Location,  $F(2,30) = 130.14$ ,  $p < .001$ , in that LiftOff Latencies (see Figure 2) were fastest in the target-cued condition ( $M = 196\text{ms}$ ), next fastest in the prime-cued condition ( $M = 210\text{ms}$ ) and slowest in the no-cue conditions ( $M = 264\text{ms}$ ). All differences were reliable (Tukey HSD; all adjusted  $p$  values  $<$

0.01), suggesting the spatial cue was effective in localising participants' spatial attention. In contrast, Prime Type had no effect on LiftOff Latencies ( $p = .404$ ), nor was the interaction significant ( $p = .373$ ).



*Figure 2.* Conditional mean LiftOff Latencies for Expt 1A. Participants began their reaching movement earliest when the exogenous cue captured attention to the target's location. Prime Type had no effect on when participants began their reaching response.

### **2.4.1.3. Reaching Trajectories**

We time-normalised reaching trajectories prior to analysis by re-sampling each to produce 100 evenly spaced increments between the point corresponding to 5% of peak tangential velocity<sup>1</sup> and the point at which the finger touched the response button. At each sample we then calculated  $x$ -velocity, a signed value indicating the velocity of the finger along the left-right dimension ( $x$ -axis). This is the dimension along which participants indicate their classification response (e.g. “left for male” and “right for female”). Furthermore, because  $x$ -velocity is a signed value (positive for movements in the correct direction and negative for movements in the incorrect direction), we assume that this measure can be used as a momentary index of the participant's response certainty. That is, the more positive  $x$ -velocity is, the more quickly the finger is moving in the correct direction. With this measure, congruence effects are typically reflected in higher  $x$ -velocities on congruent trials at earlier points in time.

As a consequence of the imposed response initiation deadline in this paradigm, participants must begin their reaching movement before they are really certain which way to go. It is unsurprising then that the quality of this initial classification movement depends on how long participants viewed the target prior to initiating their response (i.e., LiftOff Latency). There is a positive relationship between these measures, in that the longer participants wait to begin responding, the longer they have to view the target and accumulate evidence about where to reach when they lift off the start button. To exploit this relationship between Target-Viewing Time and  $x$ -velocity, we employed a modified version of the Orthogonal Polynomial Trend Analysis (OPTA) procedure developed by Woestenburg (Woestenburg, Verbaten, & Slangen, 1983) and recently adapted by

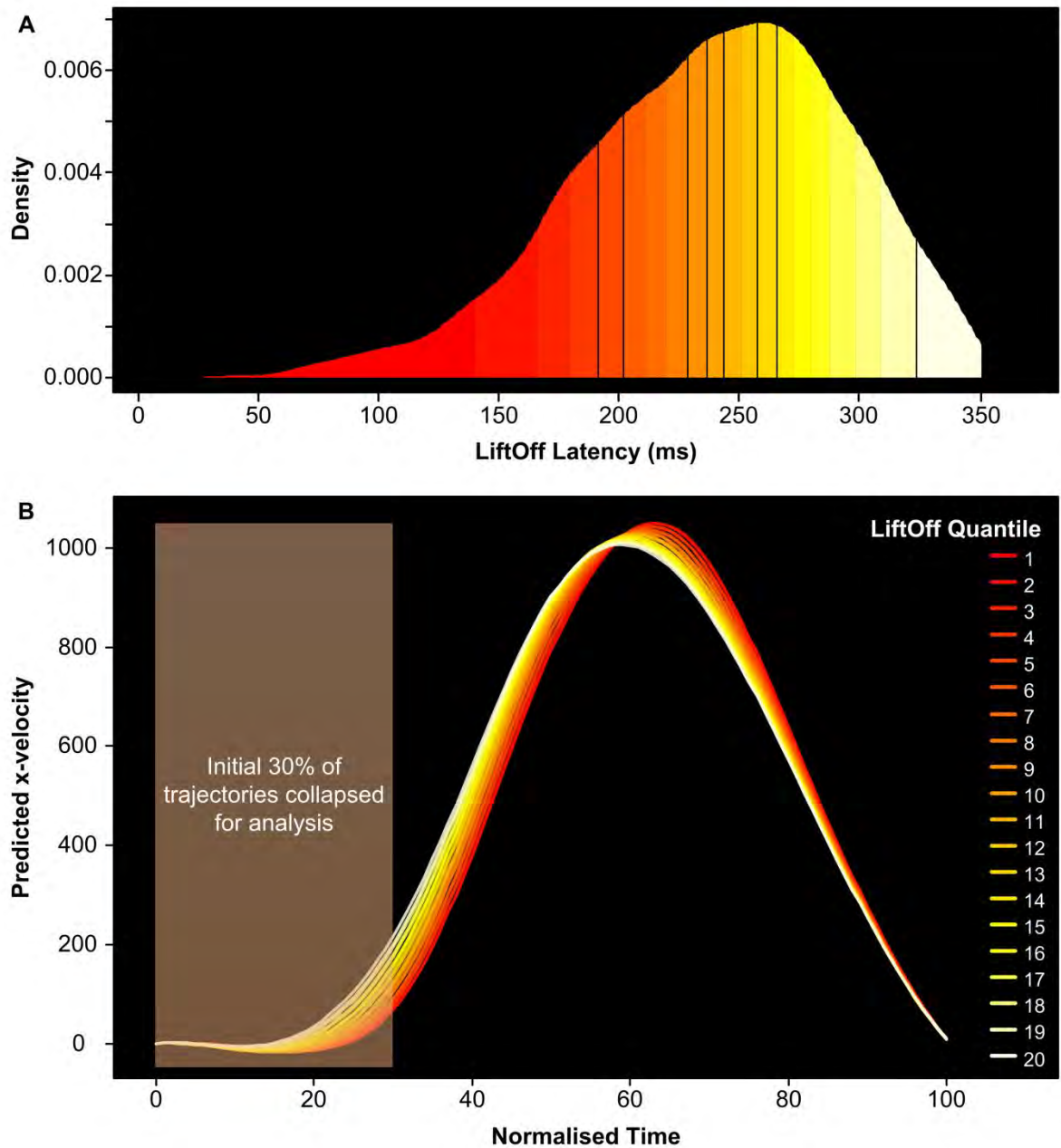
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<sup>1</sup> Tangential velocity is a positive value which reflects the hand's velocity (in any direction) at any one point in time. It is defined as the sum of squares of each 'angular' velocity (i.e. velocity along the  $x$ ,  $y$ , and  $z$  axes)

Karayanidis and colleagues (Karayanidis, Provost, Brown, Paton, & Heathcote, 2011). In the present case, the individual trial LiftOff Latencies are used as a covariate in a polynomial regression model of our dependent variable,  $x$ -velocity, allowing for a detailed analysis of how reaching responses vary as a function of Target-Viewing Time. The technique has the advantage of being able to estimate  $x$ -velocity at the individual trial level, rather than averaging across many trials, consequently improving the signal-to-noise ratio (SNR). For example, Karayanidis et al. (2011) reported OPTA improved the SNR by 2.5 times compared to simple averaging.

In the present experiments, the OPTA procedure described below was implemented using custom-software written in R ([www.r-project.org](http://www.r-project.org)). Trials with correct responses in each experimental design cell (i.e., Participant, level of Cue Location, level of Prime Type) were ranked according to their LiftOff Latency, from the shortest (ranked 1st) to longest (ranked  $n^{\text{th}}$ , where  $n$  is the number of trials for that participant in this design cell). A polynomial regression model was then fitted to the  $x$ -velocities using LiftOff Latency Rank as the covariate and polynomial terms up to the 6th order. Polynomial terms that did not account for a significant proportion of variance were removed, and the remaining coefficients used to generate *predicted*  $x$ -velocity values (one per trial for all participants). To visualise the effect of Target-Viewing Time on reaching responses predicted trajectories were averaged into semi-decile intervals, resulting in 20 predicted trajectories per experimental condition, per participant (see Figure 3). The first of these Quantiles represents those trials corresponding to the fastest 5% of LiftOff Latencies; the second represents the next fastest 5% of LiftOffs, and so on. Because we were interested in the participants' classification responses at the time of movement initiation, we restricted our analysis to the initial 30 samples of the predicted trajectories (i.e., first 30% of the trajectory). We computed the mean  $x$ -velocity across this initial portion of the trajectory, resulting in a single value for each trial, which was then submitted to a linear mixed-effects

model (LMM) with LiftOff Latency semi-decile included as a fixed effect. Note that although the duration of the initial 30% of trajectories is not uniform across trials (see Figure S2 & S4 in the supplementary materials), we have found that *x*-velocity is better predicted by the information available at the point of movement initiation (i.e., LiftOff Latency) than total duration (i.e., LiftOff Latency plus the duration of the initial movement). Further details regarding this appear in the supplementary materials.



*Figure 3.* Grouping trajectories by Target-Viewing Time. (A) Analysis begins with the distribution of LiftOff Latencies (i.e., Target-Viewing times), estimated relative to target onset. A modified version of OPTA is used to fit a polynomial regression model to the x-velocity profile for each trial. The model includes LiftOff Latency percentile as a covariate (see text). (B) Predicted x-velocity profiles are grouped into semi-decile intervals. Red colours indicate trials with short LiftOff Latencies (beginning at the 1st semi-decile); white-colours correspond to longest LiftOff Latencies (20th semi-decile). Note the clear effect of LiftOff Latency: the longer participants wait to begin moving, the faster the finger moves in the correct direction.

The OPTA procedure described above yielded 188,480 observations from 16 participants, corresponding to average values for the initial 30% of the trajectory. These data were subjected to analysis using the linear mixed-effect modelling technique (LMM) (Baayen, Davidson, & Bates, 2008; Bates, 2005) implemented in R with the lmer4 package (Bates, Maechler, & Bolker, 2011). This approach allowed us to simultaneously consider both fixed and random effects in detail (rather than averaging across participants) and evaluate the contribution of each term to the model by comparing that model with a one that excluded the effect under inspection. In each case, Likelihood tests (AIC & BIC) were used to indicate which model should be preferred. These values provide a measure of two or more models' relative goodness-of-fit, penalising them for the number of free parameters to prevent over-fitting. We further report coefficients, standard errors (*SE*), and *t*-values for the resulting models selected.

Our incremental model comparison procedure resulted in a model that included random slopes between LiftOff Quantile and Participant, together with fixed effects of LiftOff Quantile (1 to 20), Cue Location (prime-cue, target-cue, no-cue), and Prime Type (congruent, incongruent). Each two-way interaction between the latter three fixed effects was similarly verified as significantly improving the model, as well as a final three-way interaction between LiftOff Quantile, Cue Location, and Prime Type. Table 1 presents the regression coefficients, standard errors (*SEs*), and *t* values given by this final model. Here the intercept represents a modified group mean corresponding to the first level of each factor. Thus, the Prime-Cue:Congruent condition forms the reference category from which the other effects deviate. As is typical in LMM analyses (Kliegl, Masson, & Richter, 2010; Kliegl, Wei, Dambacher, Yan, & Zhou, 2011; Rolfs, Laubrock, & Kliegl, 2008; Staudte & Crocker, 2011), we have taken a coefficient magnitude of at least twice its standard error (i.e.,  $|t| > 2$ ) as our criterion for significance. For a dataset of the present size, this 2-SE



criterion approximates the traditional two-tailed .05 significance level (Baayen et al., 2008).

Table 1.

<i>Fixed effects for Expt 1A estimated with LMM<sup>a</sup>.</i>	<i>b</i>	<i>SE</i>	<i>t</i>
(Intercept) <sup>b</sup>	-10.928	6.30	-1.74
LiftOff Quantile	2.149	0.39	5.51
Prime Type (incongruent)	-8.585	1.29	-6.67
Cue Location (target-cue)	2.720	1.29	2.11
Cue Location (no-cue)	18.374	1.11	16.58
LiftOff Quantile×Prime Type (incongruent)	-0.684	0.11	-6.35
LiftOff Quantile×Cue Location (target-cue)	-0.465	0.11	-4.32
LiftOff Quantile×Cue Location (no-cue)	-0.129	0.09	-1.39
Prime Type (incongruent)×Cue Location (target-cue)	-5.775	1.83	-3.17
Prime Type (incongruent)×Cue Location (no-cue)	-1.086	1.57	-0.69
LiftOff Quantile×Prime Type (incongruent)×Cue Location (target-cue)	1.344	0.15	8.80
LiftOff Quantile×Prime Type (incongruent)×Cue Location (no-cue)	0.839	0.13	6.39

<sup>a</sup> LMM: Predicted *x*-velocity ~ 1 + LiftOff Quantile\*Prime Type\*Cue Location + (1 + Quantile | Subject)

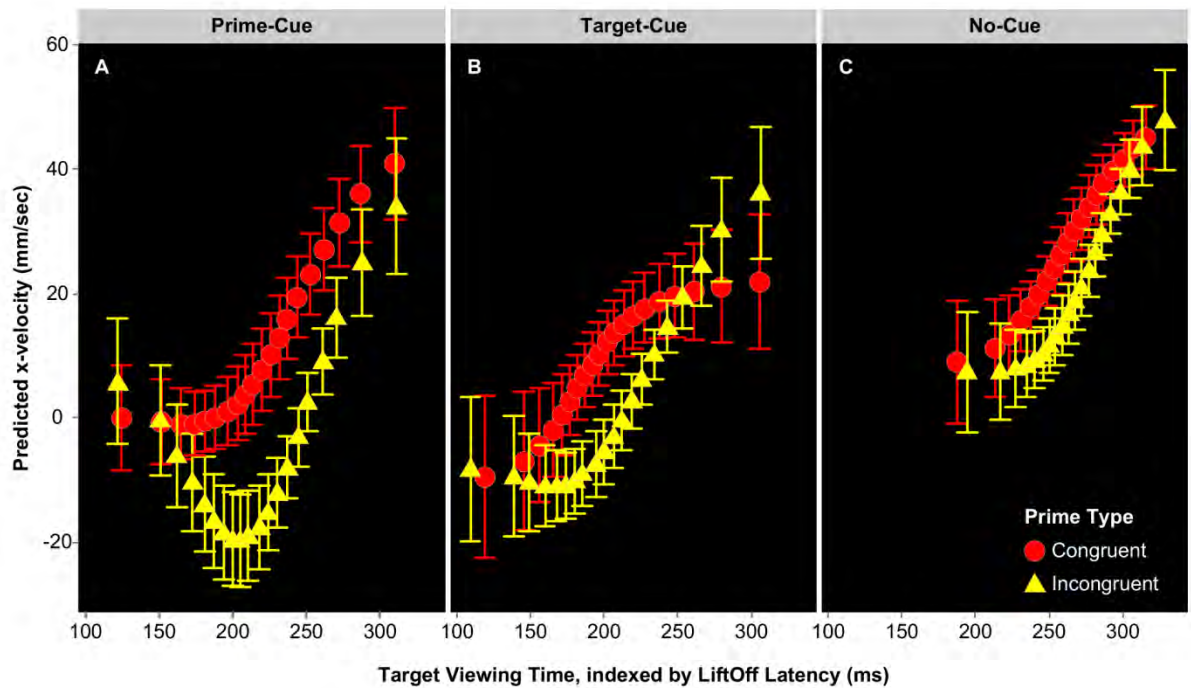
<sup>b</sup> A modified group mean for the Prime Type (congruent): Cue Location (prime-cue) condition.

Figure 4 shows conditional mean *x*-velocity values averaged across the initial 30% of trajectories. *X*-velocity is shown here as a function of LiftOff Latency, our proxy for Target-Viewing Time. The main effect of LiftOff Quantile is clear, in that the longer participants take to initiate their response, the faster their finger moves in the correct

direction. The expected effect of Prime Type is also present, with incongruent primes producing smaller  $x$ -velocity values than congruent primes. With regards to Cue Location, prime-cue trials produced smaller  $x$ -velocity values than both target-cue and no-cue trials. An inspection of Figure 4 indicates that these higher  $x$ -velocity values associated with the No-Cue condition result because participants initiate their responses much later on these trials than they do when there is a cue present (see Figure 2). Since they begin responding later in time, participants have accrued more information about the target by the time they commence their classification response, resulting in more certain movement towards the correct response button.

To ascertain the nature of the significant three-way interaction confirmed in our model comparison procedure, we fitted individual models for each level of Cue Location. These included fixed effects of LiftOff Quantile and Prime Type together with random slopes for LiftOff Quantile $\times$ Participant. Here the reference category (intercept) for each model corresponds to the group mean for congruent Prime Type condition. Model comparison and likelihood testing identified the fully interactive model to be preferable for both the prime-cue and target-cue conditions. In both cases we observed significant main effects of LiftOff Quantile (prime-cue:  $b = 2.160\text{mm/sec}$ ,  $SE = 0.507\text{mm/sec}$ ,  $t = 4.26$ ; target-cue:  $b = 1.655\text{mm/sec}$ ,  $SE = 0.729\text{mm/sec}$ ,  $t = 2.27$ ) and Prime Type (prime-cue:  $b = -8.898\text{mm/sec}$ ,  $SE = 1.217\text{mm/sec}$ ,  $t = -7.31$ ; target-cue:  $b = -14.505\text{mm/sec}$ ,  $SE = 1.179\text{mm/sec}$ ,  $t = 12.30$ ), together with a reliable interaction between these factors (prime-cue:  $b = -0.668\text{mm/sec}$ ,  $SE = 0.102\text{mm/sec}$ ,  $t = -6.56$ ; target-cue:  $b = -0.662\text{mm/sec}$ ,  $SE = 0.099\text{mm/sec}$ ,  $t = 6.71$ ). As can be seen in Figures 4A and 4B, Target-Viewing Time (i.e., LiftOff Quantile) affects priming in both cue conditions, however effects are strongest for the prime-cue condition. In contrast, model comparison for the no-cue condition indicated the additive model to be preferable, resulting in significant main effects of LiftOff Quantile ( $b = 2.073\text{mm/sec}$ ,  $SE = 0.423\text{mm/sec}$ ,  $t = 4.90$ ) and Prime Type ( $b = -7.942\text{mm/sec}$ ,  $SE =$

0.452mm/sec,  $t = -17.58$ ), but no interaction between the two. This suggests priming does not vary as a function of Target-Viewing Time for the no-cue condition (see Figure 4C).



**Figure 4.** Predicted x-velocity as a function of Target-Viewing Time for each cue condition (A, B, C). Values reflect x-velocity averaged over the initial 30% of the reaching response. Target-Viewing Time (x-axis) is the duration for which the participant viewed the target prior to initiating their movement (note this value is always preceded by 50ms of prime-processing). The slopes clearly indicate that the longer subjects wait to begin their response, the faster they will be moving in the correct direction during the early stages of their movement. Error bars calculated using within-subjects *SE*.

#### **2.4.1.4. Prime Detection Analyses**

Analysis of  $d'$  scores in Expt 1A confirmed the masking procedure was effective. Participants' mean  $d'$  scores ( $M = -0.017$ ) did not differ significantly from zero,  $t(15) = -0.31$ ,  $p = .76$ , nor did they differ across levels of Cue Location,  $F(2, 30) = 1.20$ ,  $p = .315$ . This suggests participants' awareness of the prime was minimal even when their attention was captured at the prime location. Though we agree with those researchers who have suggested that the procedure of regressing participants' mean priming effects over their  $d'$  scores often leads to spurious claims of subliminal priming (Doshier, 1998; Pratte & Rouder, 2009), we acknowledge that this is a common practice in the masked priming literature and so we have included this analysis here. To this end, we calculated a Standardised Priming Index (SPI: (incongruent – congruent)/congruent) using participants' maximum path offset values (i.e., peak  $xy$  deviation). SPI values were regressed over  $d'$  scores for each level of Cue Location. In all cases,  $d'$  did not significantly predict SPI values (prime-cue:  $R^2 = 0.09$ ,  $F(1, 14) = 1.32$ ,  $p = .270$ ; target-cue:  $R^2 = 0.22$ ,  $F(1, 14) = 3.90$ ,  $p = .068$ ; no-cue:  $R^2 = 0.005$ ,  $F(1, 14) = 0.07$ ,  $p = 0.797$ ). See Figure S1 in the supplementary materials for further details.

#### **2.4.2. Experiment 1A Discussion**

The purpose of Expt 1A was to examine the effect of transient spatial attention on the processing of masked faces. The observed results suggest several key points. Firstly, the data highlight the importance of taking stimulus-processing time into consideration when examining masked priming effects. For trials on which participants commence their classification relatively early during face processing (i.e., LiftOff < 150ms from target onset & < 200ms from prime onset), the sex of the masked prime exerts little influence over participants' classification of the target face. This is perhaps unsurprising, as at this early stage of evidence accumulation participants have not yet formulated a strong response to

the target for the prime to exert an influence on. Rather, congruence priming effects are strongest when participants initiate their response between 150-200ms of Target-Viewing Time. These congruence effects rapidly decrease however, with values for congruent and incongruent conditions converging in the slowest LiftOff Quantiles. This attenuation of congruence effects is clearly evident in the no-cue condition (Figure 4C), in which the priming effect is reduced across all LiftOff Quantiles, due primarily to the comparatively late time at which participants initiate their movements in this condition.

Secondly, our results are consistent with existing research that suggests the visual system is able to process faces in the near-absence of attention (Finkbeiner & Palermo, 2009; Harry et al., 2012; Reddy et al., 2006; Reddy et al., 2004), in that our masked face primes influenced participants' classification of the subsequent target even when attention was captured at another location. Lastly, although the MCE did not depend on the appropriate allocation of spatial attention, our results provide compelling evidence that spatial attention is indeed capable of modulating the processing of masked faces. By examining the early stages of participants' sex-classification movements as a function of Target-Viewing Time, we observed that our manipulation of spatial attention, designed to prevent slips of attention (see Lachter et al., 2004), not only facilitated participants' ability to *initiate* a response to the target, but critically also modulated the extent to which the masked prime affected their target classification movement. Congruence effects were largest when the cue captured spatial attention at the prime's location.

## **2.5. Experiment 1B: Temporal Attention**

In Expt 1B we investigated the effects of *temporal attention* on masked face processing. The trial structure was identical to that of the no-cue condition in Expt 1A (i.e.,

no exogenous cues); critically, however, we manipulated the predictability of target onset by varying Fixation-Target SOA. Target onset followed a hazard function (Ghose & Maunsell, 2002), occurring after one of four randomly selected durations (900ms, 1150ms, 1400ms or 1650ms). In this manipulation, participants' temporal attention to the critical stimuli is optimally focused when target onset is most predictable (at the longer SOAs) and conversely minimally focussed when target onset is least predictable (at the shortest SOA). Accordingly, we expected that the longest SOAs would facilitate masked congruence effects relative to the shorter SOAs. For ease of exposition, we have collapsed these fixation-target intervals into Short SOA (900ms, 1150ms) vs. Long SOA (1400ms, 1650ms) conditions.

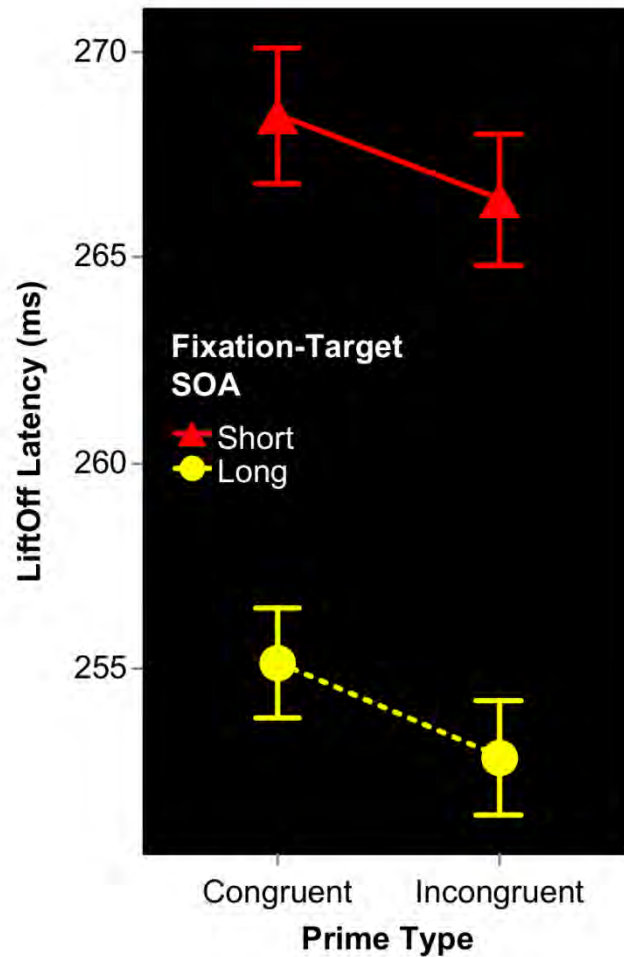
## **2.5.1. Results**

### **2.5.1.1. Accuracy**

Overall mean sex-classification accuracy for Expt 1B was 99.84%. Mean accuracy rates were entered into a repeated measures ANOVA with the factors SOA (short, long) and Prime Type (congruent, incongruent). Neither of these fixed effects approached significance,  $F(1,15) = 4.64, p = .995$  and  $F(1,15) = 2.53, p = 1$  respectively); their interaction was also not reliable,  $F(1,15) = 4.71, p = .503$ .

### **2.5.1.2. LiftOff Latency**

LiftOff Latencies were entered into the same 2×2 ANOVA described above for Accuracy. As is clear in Figure 5, SOA significantly affected LiftOff Latencies,  $F(1,15) = 33.34, p < .000$ , with participants initiating their responses sooner on Long SOA trials. In contrast, the effect of Prime Type was not significant,  $F(1,15) = 1.56, p = .231$ , neither was the SOA×PrimeType interaction, ( $F < 1$ ).



*Figure 5.* Conditional mean LiftOff Latencies for Expt 1B. Temporal attention modulates LiftOff Latency, in that subjects began their reaching movements earlier when Fixation-Target SOA was long. In contrast, the effect of Prime Type on LiftOff Latency was non-significant.

### **2.5.1.3. Reaching Trajectories**

Reaching trajectory data for Expt 1B were prepared for analysis using the same OPTA procedures described above. We averaged values across the initial 20% of the OPTA-generated trajectory responses, with the resulting 194,215 observations then subjected to linear mixed-effects modelling and model comparison procedures. It should be noted that the effects reported here are not critically dependent on this selected cutoff of 20%, as directionally similar results were obtained using alternate cutoffs of both 30% and

40%. The preferred model identified using likelihood testing contained random slopes for LiftOff Quantile×Participant, fixed effects of LiftOff Quantile, Prime Type, and SOA, together with their interactions. Critically, the three-way interaction between these factors also significantly improved the model (LiftOff Quantile×PrimeType×SOA. Table 2 presents the regression coefficients, *SE* and *t*-values given by this model. As per Expt 1A, effects twice the size of their *SE* were taken as significant ( $|t| > 2$ ).

Table 2.

<i>Fixed effects for Expt 1B estimated with LMM<sup>a</sup>.</i>	<i>b</i>	<i>SE</i>	<i>t</i>
(Intercept) <sup>b</sup>	51.536	10.34	4.99
LiftOff Quantile	4.393	0.10	4.40
Prime Type (Incongruent)	-19.461	1.68	-11.61
SOA (Long)	-8.204	1.68	-4.90
LiftOff Quantile×PrimeType (incongruent)	-0.119	0.14	-0.85
LiftOff Quantile×SOA (Long)	0.994	0.14	6.75
PrimeType (incongruent)×SOA (Long)	-21.254	2.37	-8.97
LiftOff Quantile×PrimeType (incongruent)×SOA (Long)	1.481	0.20	7.48

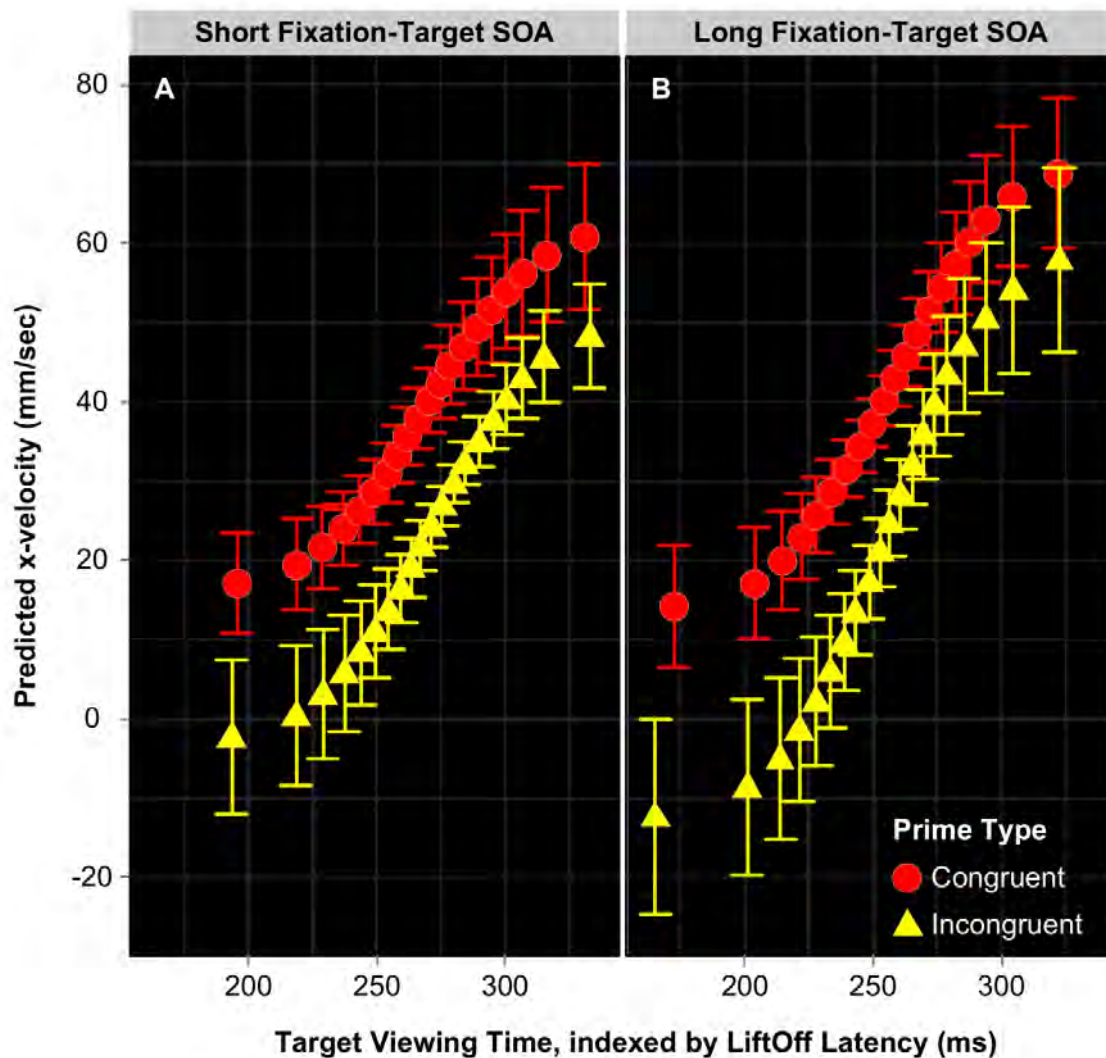
<sup>a</sup> LMM: Predicted *x*-velocity ~ 1 + LiftOff Quantile\*Prime Type\*SOA + (1 + Quantile | Subject)

<sup>b</sup> A modified group mean for the Prime Type (congruent): SOA (short) condition

To examine the nature of the three-way interaction further, we followed the same procedure as Expt 1A, fitting an individual model for the Short and Long SOA conditions. In each case, we included LiftOff Quantile and Prime Type as fixed effects, together with



random slopes for LiftOff Quantile×Participant. In the Short SOA condition, likelihood testing indicated the additive model to be preferable. We observed significant effects of both LiftOff Quantile ( $b = 4.325\text{mm/sec}$ ,  $SE = 0.969\text{mm/sec}$ ,  $t = 4.46$ ) and Prime Type ( $b = -20.691\text{mm/sec}$ ,  $SE = 0.806\text{mm/sec}$ ,  $t = -25.68$ ). The absence of the interaction between these factors suggests congruence priming effects are unaffected by Target-Viewing Time (see Figure 6A). In contrast, the preferred model for the Long SOA condition included significant effects of LiftOff Quantile ( $b = 5.338\text{mm/sec}$ ,  $SE = 1.161\text{mm/sec}$ ,  $t = 4.59$ ) and Prime Type ( $b = -40.812\text{mm/sec}$ ,  $SE = 1.66\text{mm/sec}$ ,  $t = -24.58$ ), together with a reliable interaction between these factors ( $b = 1.372\text{mm/sec}$ ,  $SE = 0.139\text{mm/sec}$ ,  $t = 9.90$ ). In contrast to the Short SOA condition, congruence effects for trials using a longer fixation-target SOA (Figure 6B) are strongest at the earliest Target-Viewing times, attenuating as Target-Viewing time increases.



*Figure 6.* Predicted x-velocity as a function of Target-Viewing Time for short (A) and long SOA (B). All values correspond to an average of the initial 20% of the reaching response. Target-Viewing Time (always preceded by 50ms of prime processing) positively modulated participants' classification certainty, such that the longer they waited to begin their reaching response, the faster their finger moved in the correct direction during the early stages of their movement. Error bars calculated using within-subjects *SE*.

#### **2.5.1.4. Prime Detection Analyses**

Expt 1B  $d'$  scores ( $M = 0.125$ ) were not significantly different from zero ( $t(15) = 1.16, p = .26$ ). Additionally, we calculated participants' mean  $d'$  scores for the short and long SOA conditions and entered these scores into a one-way ANOVA. The effect of SOA was not reliable,  $F(1,15) = 0.94, p = .348$ , suggesting that participants' awareness of the prime stimuli did not increase with their increasing anticipation of an upcoming stimulus. As in Expt 1A, we regressed participants' maximum  $xy$  pathoffset SPI values (see Expt 1A for details) over  $d'$  scores for each SOA. In both cases,  $d'$  did not significantly predict SPI values (short SOA:  $R^2 = 0.02, F(1,14) = 0.32, p = .583$ ; long SOA:  $R^2 = 0.11, F(1,14) = 1.74, p = .209$ ). See Figure S2 in the supplementary materials for more details.

#### **2.5.2. Experiment 1B Discussion**

In Expt 1B we employed the procedure used by Ghose and Manusell (2002) to manipulate temporal attention to the prime–target pair through the use of the hazard function. Target onset could occur after one of four fixation durations, such that the onset of the target was most predictable at the longest fixation-target SOA. Accordingly, we predicted that the MCE would be strongest at this long SOA, as participants' temporal attention should be optimally focussed in this condition. There are several key findings suggested by the data. Firstly, we found support for the findings of Expt 1A, in that our masked face primes influenced participants' sex-classification responses regardless of how well their attention was focused in time. Secondly, results validated the efficacy of our attentional manipulation, in that participants initiated their responses fastest when target onset was most predictable. Lastly, and most importantly, we found further evidence to suggest that masked face processing can indeed be modulated by the allocation of attention – in this case, temporal attention. We observed larger and earlier congruence priming effects when participants were most prepared for the onset of the critical stimuli.

## 2.6. *General Discussion*

In the present study we sought to address the current divide between the neurophysiological and behavioural literatures concerning the effects of spatial attention on face processing. Where fMRI studies have documented clear and replicable effects of spatial attention on the neural response for faces (Downing et al., 2001; Holmes, Vuilleumier, & Eimer, 2003; Jacques & Rossion, 2007; Vuilleumier et al., 2001; Wijers & Banis, 2012), the behavioural evidence for this position has been inconsistent (Esterman et al., 2008; Finkbeiner & Palermo, 2009; Harry et al., 2012; Reddy et al., 2007; Reddy et al., 2006; Reddy et al., 2004). In the present study, we have reconciled this issue by demonstrating a reliable effect of both spatial and temporal attention on an overt behavioural response to a face target. We employed a behavioural measure designed to index an early stage of stimulus processing thought to be comparable to the time period in which ERP studies have documented modulatory effects of attention on face processing (Holmes et al., 2003; Jacques & Rossion, 2007; Wijers & Banis, 2012) – less than 350ms from stimulus onset. We here report two key findings from this novel paradigm which, taken together, provide the basis for a more coherent understanding of the relationship between face processing and attention.

Firstly, we have verified that face-processing does not *depend* upon the allocation of spatial attention to proceed. This finding replicates and supports previous studies that have reported findings consistent with this claim (Finkbeiner & Palermo, 2009; Harry et al., 2012; Reddy et al., 2007; Reddy et al., 2006; Reddy et al., 2004). In addition, the results of our second experiment serve to extend this claim to include temporal attention as well, further establishing the unique status of faces within the human visual system. Where masked priming effects elicited by word, letter, and number stimuli are well-documented to rely upon both temporal and spatial attention (Besner et al., 2005; Fabre et al., 2007;

Lachter et al., 2004; Marzouki et al., 2007; Marzouki, Midgley, Holcomb, & Grainger, 2008; Naccache et al., 2002), here we have demonstrated that masked faces are able to influence the participant's response to a target stimulus irrespective of both spatial and temporal attention.

Secondly, and more importantly, we have provided compelling behavioural evidence that, while face processing does not depend on focussed spatial or temporal attention, face processing is nevertheless *modulated* by both spatial and temporal attention. Our results in this respect are clear cut – in both the spatial and temporal domain, the allocation of attention to the masked prime stimulus enhanced the masked congruence effect. This critical finding is at odds with much of the existing behavioural research that has failed to observe clear modulatory effects of spatial attention on face processing (Finkbeiner & Palermo, 2009; Harry et al., 2012; Reddy et al., 2004). We suspect the key distinction that underlies the discrepancy between these studies and our own is the behavioural response measure employed. Support for this suggestion can be found in a comparison between the present study and one we have reported previously (Finkbeiner & Palermo, 2009). Using a near-identical trial structure and attentional manipulation, but with an RT measure, Finkbeiner and Palermo found no evidence of attentional modulation of masked face processing. Nevertheless, the very same paradigm in the present study yielded robust effects of attention reflected in participants' continuous reaching responses. We suggest that the divergent results obtained with these behavioural measures relate directly to the stage of stimulus processing they are able to index. Responding via a reaching movement allows participants to *initiate* their categorisation response very early in stimulus processing without penalty, thereby allowing the researcher to observe experimental effects as they emerge in stimulus processing time. In the present case, we were able to document attentional benefits for face processing occurring at less than 200ms of stimulus processing time. These findings are in accord with ERP studies that document

modulatory effects of spatial attention on early visual components elicited by face stimuli (e.g. the N170) (Holmes et al., 2003; Jacques & Rossion, 2007; Wijers & Banis, 2012). In contrast, button-press responses are cumulative in nature, in that they necessarily reflect the endpoint of stimulus processing. Executed at a latency of around ~500-600ms, button-press responses index target processing at a stage that may simply be too late to reveal clear attentional effects on a process as robust as sex-discrimination (Finkbeiner & Palermo, 2009; Reddy et al., 2004). By providing a behavioural measure capable of examining the early stages of stimulus processing, the current study represents a point of coherence between the previously discrepant neuroimaging and behavioural findings concerning the role of spatial attention in face processing.

Although we have shown here that face processing is not impervious to attentional modulation, the fact remains that in contrast to other stimulus types, the visual system prioritises faces such that they may nevertheless be processed outside the focus of attention. What mechanism gives rise to this unique characteristic? We have previously suggested (Finkbeiner & Palermo, 2009) that face-sex discrimination processes, thought to rely on low spatial frequency information that is predominantly carried by magnocellular channels (Awasthi, Friedman, & Williams, 2011; Schyns, Bonnar, & Gosselin, 2001), may be supported by a subcortical face processing route that escapes attentional modulation (Johnson, 2005; Vuilleumier, Armony, Driver, & Dolan, 2003). A recent study using non-face stimuli may provide some support for this claim. Dobromir and colleagues observed implicit processing of peripheral low-level motion coherence when spatial attention was engaged elsewhere (Rahnev, Huang, & Lau, 2012). Although the issue remains debated (Skottun & Skoyles, 2006), some researchers have suggested that, like face-sex discrimination, the perception of coherent motion may be largely supported by the magnocellular system (Schiller, Logothetis, & Charles, 1990). Thus, coherent motion may represent one of the only stimulus-types outside of face-sex that the visual system is

capable of processing in the near-absence of spatial attention. Research capitalising on this and other stimulus-types favoured by magnocellular channels will be important to pursue to further elucidate the conditions under which attention is able to influence this subcortical route.

### **2.6.1. Conclusion**

The present study reports two main findings. First, using a novel version of the reach-to-touch paradigm, we have replicated previous findings showing that masked face primes are processed regardless of whether they are spatially attended or not. We have extended this finding by showing that the same positive effect of priming can be obtained when manipulating temporal attention. Second, we have shown for the first time that the masked congruence priming effect obtained with faces is sensitive to manipulations of both spatial and temporal attention. That is, while we found positive masked priming effects for both attended and unattended face primes, our results reveal that these positive priming effects are nevertheless modulated by manipulations of attention. To our knowledge, this is the first study to report an interpretable modulatory effect of attention on the processing of face-sex in a behavioural paradigm. We have suggested that the critical difference between previous studies and ours is the continuous behavioural measure used in the present study. The virtue of the reach-to-touch paradigm is that it allows participants to initiate their response with impunity very early on in stimulus processing. This, in turn, provides the opportunity to observe the emergence of effects (and their modulations) within the first few hundred milliseconds of stimulus-processing time. This level of temporal resolution is not available in discrete behavioural measures (e.g. button presses), which have been used previously.

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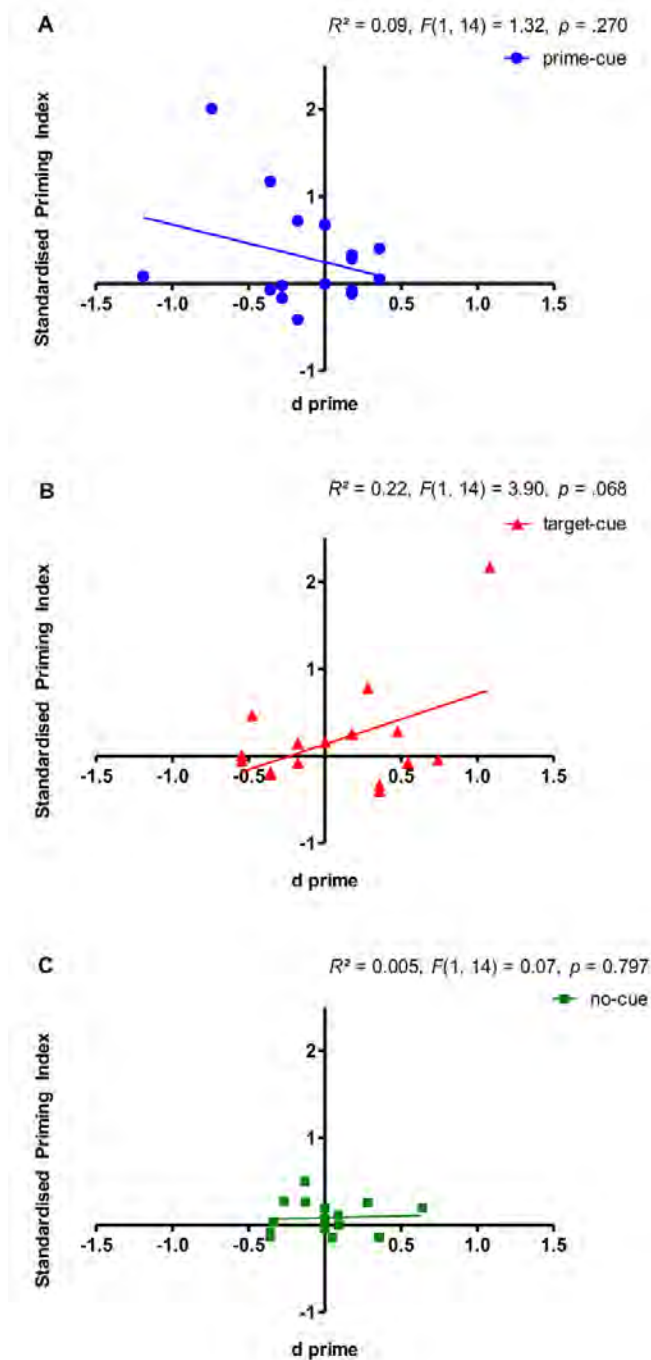
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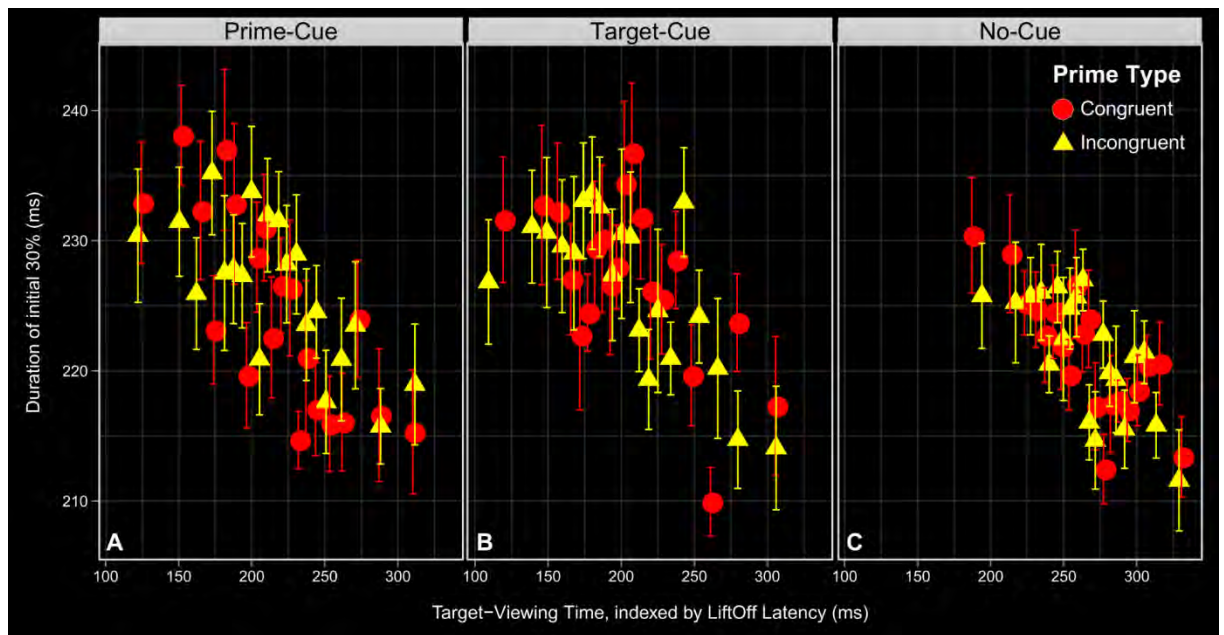
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## 2.8. Appendix A (Supplementary Materials)

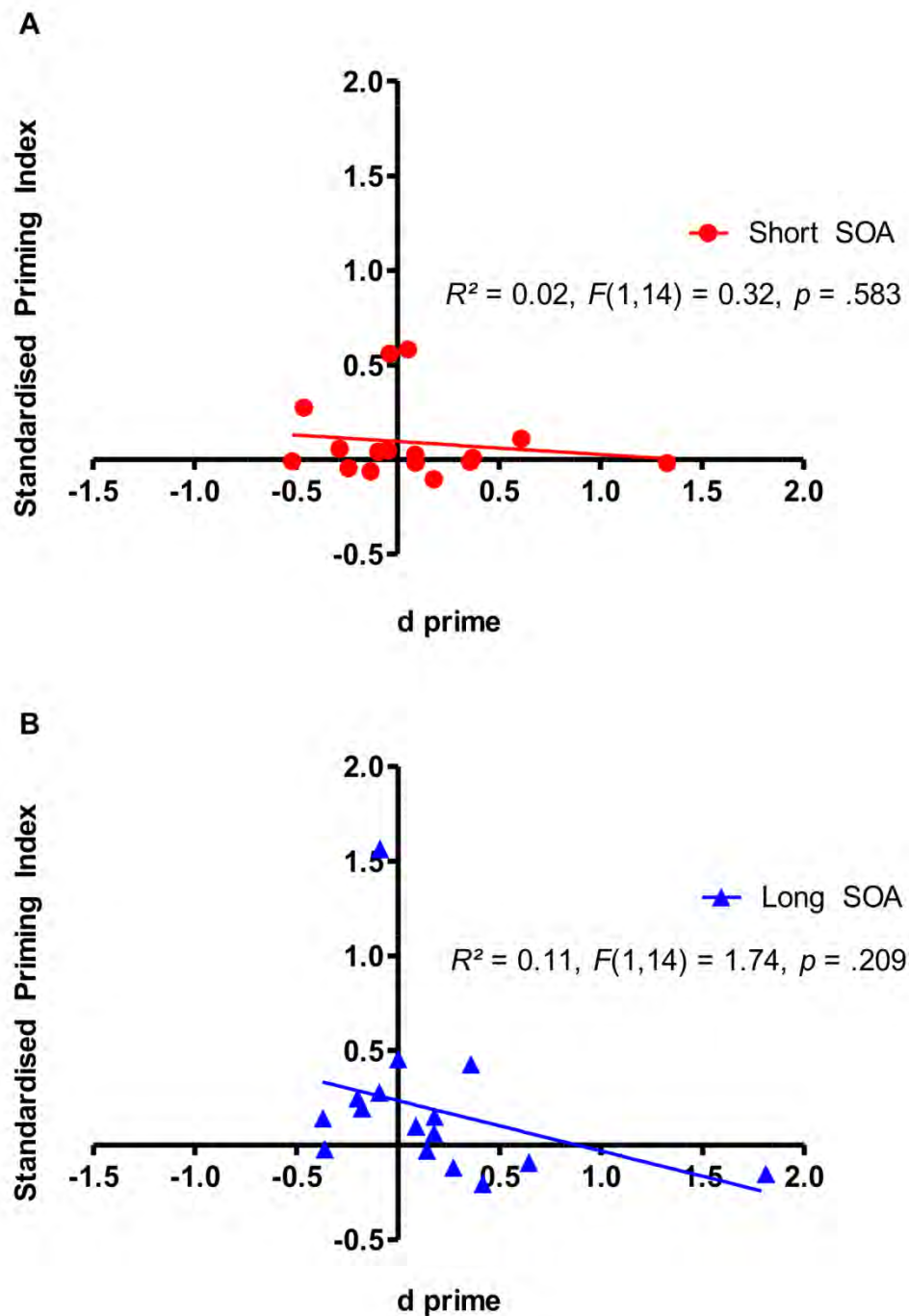


*Supplementary Figure 1.* Correlation of the MCE and  $d'$  for prime-cue (A), target-cue (B), and no-cue (C) trials. To assess whether the MCE in Expt 1A systematically varied with prime visibility, we calculated a Standardised Priming Index (SPI) using peak xy deviation, and regressed SPI over participants'  $d'$  scores for each cue condition. The relationship did not reach significance for any of the cue conditions.

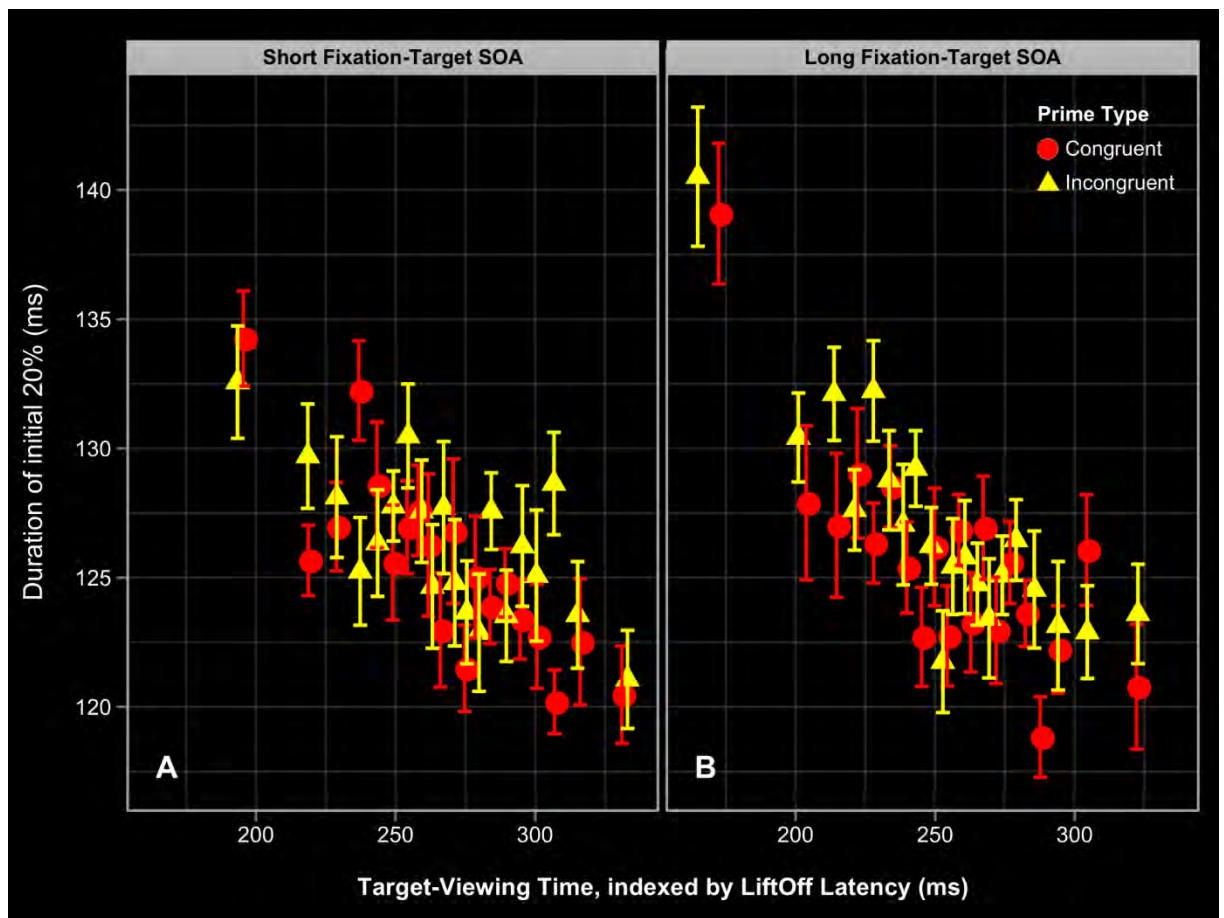




*Supplementary Figure 2.* Conditional mean durations of the initial 30% of Expt 1A trajectories, shown as a function of Target-Viewing Time. Our primary analysis for Expt 1A examines how x-velocity (averaged over the initial 30% of trajectory responses) varies with Target-Viewing Time (i.e., LiftOff Latency). Here we present the conditional mean *duration* of this initial 30%. Duration is clearly affected by Target-Viewing Time, in that earlier LiftOff Latencies result in longer trajectory durations and, thus, the initial 30% spans a longer period of time. Since duration varies between trials then, one might think that duration might affect x-velocity during the initial 30%, and that it should therefore be incorporated into our primary analysis. To establish whether this is the case, we compared a Linear Mixed Effects Model (LMM) that included LiftOff Latency as a predictor of initial x-velocity (Model 1) with Model 2 that substituted LiftOff Latency for Total Duration (i.e., LiftOff Latency + Duration of Initial 30%). Both models have the same number of parameters. If Total Duration is a better predictor of initial x-velocity, then Model 2 should provide a better fit to the data. However, AIC, BIC, and Log Likelihood comparisons indicated that the predictive power of Model 2 was no better than that of Model 1. This finding suggests that the initial reaching movement is no more strongly influenced by the information that is accumulated during the initial movement as it is by the information present at the beginning of the initial movement. For this reason, we have chosen to depict initial x-velocity as a function of LiftOff Latency as opposed to Total Duration.



*Supplementary Figure 3. Correlation of the MCE and  $d'$  for short SOA (A) and long SOA (B) trials. As in Expt 1A, we assessed the relationship between the MCE and prime visibility by regressing a Standardised Priming Index (SPI) over  $d'$  values for each level of SOA.  $d'$  did not significantly predict SPI in either case.*



*Supplementary Figure 4.* Conditional mean durations of the initial 20% of Expt 1B trajectories, shown as a function of Target-Viewing Time. As in Expt 1A, we inspected the conditional mean durations of the selected analysis period for Expt 1B (initial 20% of trajectories). Again, duration decreases as a function of Target-Viewing Time, with later LiftOff Latencies corresponding to shorter durations for the initial 20% of the response. To assess whether the total duration (LiftOff Latency + duration of initial 20%) was a better predictor of initial x-velocity than just LiftOff Latency, we compared a Linear Mixed Effects Model (LMM) that included LiftOff Latency with a model that substituted this term with Total Duration (both models have the same number of parameters). As in Experiment 1A, AIC, BIC, and Log Likelihood comparisons favoured Model 1, suggesting LiftOff Latency to be a better predictor of initial x-velocity than total duration (LiftOff Latency + duration of initial 30%).



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FACE-SEX CATEGORISATION IS BETTER  
ABOVE-FIXATION THAN BELOW:  
EVIDENCE FROM THE REACH-TO-TOUCH PARADIGM

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### **3.1. Abstract**

The masked congruence effect (MCE) elicited by nonconscious faces in a sex-categorisation task has recently been shown to be sensitive to the effects of attention. Here we investigate how spatial location along the vertical meridian modulates the MCE for face-sex categorisation. Participants made left and right reaching movements to classify the sex of a target face which appeared either immediately above or below central fixation. The target was preceded by a masked prime face which was either congruent (i.e., same sex) or incongruent (i.e., opposite sex) with the target. In the Reach-to-Touch paradigm, participants typically classify targets more efficiently (i.e., their finger heads in the correct direction earlier and faster) on congruent trials compared to incongruent. We observed an upper-hemifield advantage in the timecourse of this masked congruence effect (MCE), such that primes affected target classification sooner when presented in the upper visual field (UVF) compared to the lower visual field (LVF). Moreover, there was a differential benefit of attention between the vertical hemifields, in that the MCE was dependent on the appropriate allocation of spatial attention in the LVF, but not the UVF. Taken together, these behavioural findings suggest that the processing of faces qua faces (e.g. sex-categorisation) is more robust in upper-hemifield locations.

*Keywords:* face-processing, upper visual field, location variance, priming, attention

### **3.2. *Introduction***

In masked priming paradigms, a prime stimulus presented below the threshold of conscious awareness can influence the processing of a subsequent visible target, such that response times (RTs) are typically faster when the prime–target pair are congruent (i.e., associated with the same response). Such masked congruence effects (MCE) have been repeatedly demonstrated to be contingent upon the allocation of attention. For example, the MCE in number-comparison tasks (Naccache, Blandin, & Dehaene, 2002) and semantic categorisation tasks (Fabre, Lemaire, & Grainger, 2007) has been shown to depend critically upon temporal attention to the prime. Focused spatial attention to the prime also appears to be a prerequisite for the MCE to emerge in the context of semantic categorisation of words (Lien, Ruthruff, Kouchi, & Lachter, 2010) and picture stimuli (Finkbeiner & Palermo, 2009). However, where these congruence priming studies using word, number, and picture stimuli would suggest that nonconscious information processing depends upon attention to proceed (Lachter, Forster, & Ruthruff, 2004), the MCE elicited by face stimuli contradicts this notion, occurring even when attention is directed away from the prime. Finkbeiner and Palermo (2009) have shown that sex information carried by a nonconscious prime face is capable of modulating the subsequent sex-categorisation of a visible target face regardless of whether spatial attention is captured to the prime’s location or elsewhere (Finkbeiner & Palermo, 2009). That the primes in this study did not require attention to influence target processing would certainly suggest that the processes underlying nonconscious sex information processing are robust. It does not imply, however, that these processes are beyond the influence of top down factors such as attention. In fact, we have recently demonstrated that although masked faces do produce congruence priming effects even in the near-absence of attention, the timecourse of this MCE is sensitive to manipulations of attention, in that attended primes yielded earlier congruence effects than do unattended primes (Quek & Finkbeiner, 2013).



Having established that the rapid processing of face-sex information under masked conditions is sensitive to manipulations of spatial attention, we wanted to pursue the interesting and as yet unaddressed possibility that the visual system's ability to process nonconscious sex information could be affected by the spatial position of the face. This seems a likely possibility given that retinal position is known to influence the processing of supraliminal faces (Afraz, Pashkam, & Cavanagh, 2010; Gainotti, 2013). Our primary goal in the present study was to determine whether masked priming effects in face-sex categorisation are affected by the prime's placement along the vertical meridian.

Intuitively, it seems reasonable that the visual system's capacity to discriminate human faces might vary between the vertical hemifields. Specifically, individuals might be better at discriminating faces in the upper visual field (UVF), where faces usually appear, compared to the lower visual field (LVF) in which faces are infrequently encountered. In fact, Previc (1990) has proposed that the visual processing of certain types of information in each hemifield is tuned by location-dependent statistical probabilities. According to this account, processes which support near vision and visuomotor coordination are said to be advantaged in the LVF by virtue of being in 'near space', where individuals reach toward and grasp objects. These include motion processing (Amenedo, Pazo-Alvarez, & Cadaveira, 2007; Edwards & Badcock, 1993; Levine & McAnany, 2005), global processing (Christman, 1993), and perception of coordinate spatial relationships (Niebauer & Christman, 1998). In contrast, Previc asserts that the UVF corresponds to 'far space' and has become specialised for those processes which support object recognition often required in this hemifield, such as visual search (Chaiken, Corbin, & Volkmann, 1962; Fecteau, Enns, & Kingstone, 2000; Previc & Blume, 1993; Previc & Naegele, 2001; Yund, Efron, & Nichols, 1990), local processing (Christman, 1993), and perception of apparent distance

(Levine & McAnany, 2005). On this possibility, we might expect higher level face-processing<sup>1</sup> (e.g. sex-categorisation) to be supported better at above-fixation locations relative to below-fixation locations, as from an early age we encounter human faces more frequently in extrapersonal space (i.e., the UVF) than we do in peripersonal space (i.e., the LVF). Moreover, during close range social interaction, the UVF is typically where the eyes of other people are located, and therefore contains potent social information that informs adaptive behaviour. For example, the eye gaze of another person can direct our visual attention to relevant stimuli nearby (Hood, Willen, & Driver, 1998; Langton, Watt, & Bruce, 2000), and the eye region is thought to be critical in the expression of negative emotions such as fear and anger which may require an immediate response from an observer (Hanawalt, 1944).

Yet despite the intuition that face-perception in humans might exhibit an upper-hemifield advantage, the evidence for this suggestion is equivocal at best. In fact, while some have argued that face perception is position invariant (cf. Schwarzlose, Swisher, Dang, & Kanwisher, 2008), others have shown how face-perception is position-variant with interesting individual differences (Afraz et al., 2010). In contrast, studies that have employed higher temporal resolution measures to examine the possibility of position variance in the initial percept of faces have had better success in observing vertical hemifield effects at the group level. For example, Liu and Ioannides (2010) have reported that magnetoencephalography (MEG) peak latencies in the medial prefrontal cortex (MPFC), left fusiform face area (FFA), and the left occipital face area (OFA) arise earlier within the first 100ms following face presentation when the face appears in the UVF

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<sup>1</sup> We note that the lower-level aspects of face-recognition such as simple detection or discrimination could well enjoy a LVF advantage similar to that observed for other stimulus types – see work by Carrasco and colleagues regarding this (e.g. Carrasco, Penpeci-Talgar, & Cameron, 2001).

compared to the LVF. However, where this might seem to suggest that face information is processed more efficiently at upper-hemifield locations, this interpretation is weakened by the fact that the reverse patterns of results was observed for the right FFA. In this region, LVF faces elicited significantly earlier peaks than did UVF faces, with a directionally similar numerical difference observed for the right OFA (non-significant). In addition, the behavioural measure (accuracy rates) of Liu and Ioannides did not correlate in any clear way with the effects observed in the electrophysiological measure. Within the behavioural literature, Kessler and Tipper (2004) have reported that inhibition effects elicited by previously-seen face stimuli are evident only for faces presented above-fixation, suggesting indirectly that face encoding may be superior in the UVF relative to the LVF. Similarly, detection and localisation of emotional schematic faces in visual search appears to be better in the upper-hemifield (Fecteau et al., 2000), and Coolican, Eskes, McMullen, and Lecky (2008) found that a chimeric mirror image face presented above-fixation is perceived as more similar to the original face than a mirrored face presented below-fixation. However, it is not clear to what extent the upper-hemifield advantage for faces reported in these studies could be due to the fact that participants tend to commence their visual search for targets in the UVF regardless of stimulus type (Chedru, Leblanc, & Lhermitte, 1973; Kraft, Sommer, Schmidt, & Brandt, 2011; Previc & Blume, 1993), a possibility that seems particularly probable given that Fecteau et al. (2000) observed a UVF advantage regardless of whether the targets were schematic faces, letters, or rectangles.

Thus, to date, the evidence that the processing of faces qua faces is sensitive to spatial position is equivocal at best. We suspect that one reason for this is that face discrimination is resolved so quickly in the visual system that only those measures with very high temporal resolution will be able to consistently observe effects of spatial position. With this in mind, we chose to employ a behavioural measure capable of

revealing experimental effects within the same timeframe that Liu and Ioannides (2010) observed the MEG response to face stimuli to be sensitive to manipulations of vertical hemifield (i.e., first ~250ms from target onset). In the standard version of the reach-to-touch paradigm (c.f. Freeman, Dale, & Farmer, 2011; Song & Nakayama, 2009; Spivey, Grosjean, Knoblich, & McClelland, 2005), participants categorise a target by reaching to the left or right while the position of their hand is sampled at a high frequency (e.g. 200 Hz). A range of kinematic properties of the reaching response can be used to document experimental effects of interest, including response time from target onset (RT), overall travel time, time to peak velocity, acceleration, curvature and path offset. Comparing conditional mean values of any of these indices enables one to observe experimental effects of interest during response execution time, or the time period during which the participant actually performs the reaching movement – typically well after stimulus processing has taken place. In the version of the reach-to-touch paradigm that we employ here (see Finkbeiner, Coltheart, & Coltheart, 2013; Quek & Finkbeiner, 2013), we take initial velocity in the correct direction as our index, and examine how it varies as a function of how long the participant viewed the target before commencing their response. In this way, our dependent measure can reveal how much the participant knows about the target at the time of movement initiation, enabling us to map out the onset and growth of an experimental effect in stimulus processing time, rather than response execution time. Being able to observe the unfolding of an effect may be especially important in the present case, since the highly efficient nature of sex-categorisation (Bruce & Young, 1998) means that any effect of vertical hemifield on this process may well be very short-lived. Using this newly developed version of the reach-to-touch paradigm, we show that the extent to which the sex of a nonconscious prime face is able to influence the sex-categorisation of a subsequent conscious target depends on vertical hemifield. Masked face primes presented above-fixation enjoy a temporal processing advantage, in that the MCE reflected in

participants' reaching responses emerges earlier for faces presented in the UVF compared to the LVF.

### ***3.3. Methods for Experiment 1a & 1b***

Our study consisted of two near-identical experiments that both used a  $2 \times 2 \times 2$  fully-crossed factorial design. The factors were Cue Validity (valid vs. invalid), Visual Field (upper vs. lower), and Prime Type (congruent vs. incongruent). In the interest of exposition, we have combined these two experiments and report them as one below.

#### ***3.3.1. Participants***

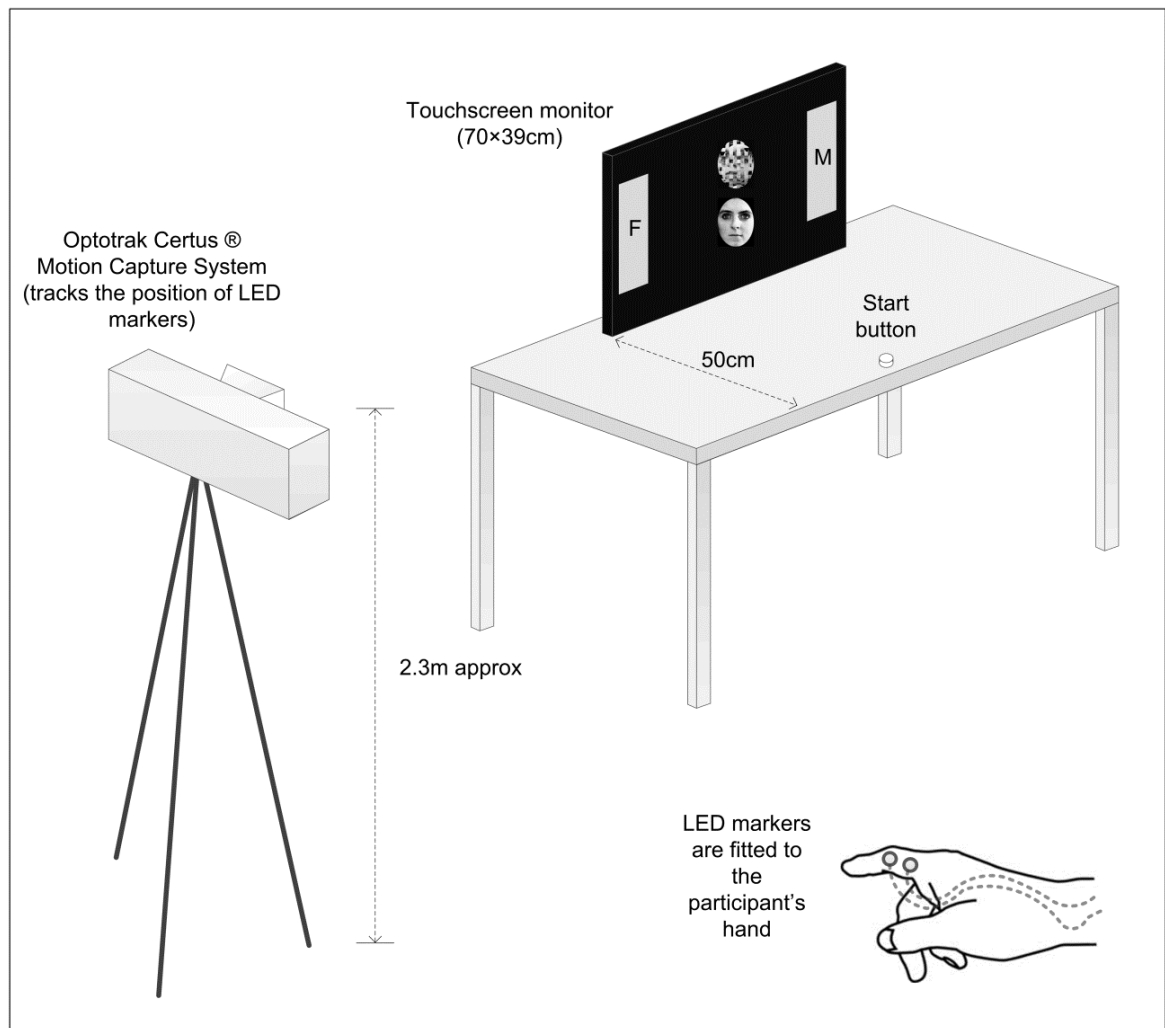
Fifty one individuals aged between 18 and 28 years were recruited from the student population at Macquarie University. Thirty-two participated in Experiment 1a and 19 participated in Experiment 1b. All were strongly right-handed, and received either financial compensation or undergraduate course credit in return for their participation.

#### ***3.3.2. Stimuli***

In total, we used 24 greyscale stimuli matched on luminance and contrast. The stimuli consisted of 12 critical face items (10 target items and two prime items) drawn from the Psychological Image Collection at Stirling database (PICS, <http://pics.psych.stir.ac.uk/>) and cropped to exclude the facial contour and hairline. We also used 12 non-critical animal stimuli (10 distractor items and two foil items) taken from the Hemera Photo Objects Collections (Hemera Photo Objects, Gatineau, Quebec, Canada). Each finished stimulus subtended  $4.2^\circ \times 3.37^\circ$  of visual angle from a viewing distance of 68cm.

### **3.3.3. Apparatus & Procedure**

Participants in Experiments 1a and 1b completed 400 and 480 experimental trials respectively; in both cases, the experiment proper was preceded by a practice block of 80 trials (not analysed). Participants in Exp 1a sat at a rigid table before a 70×39cm touchscreen monitor fixed 50cm from the table edge, with peripheral response panels marked ‘M’ and ‘F’ on either side of the screen. Participants in Exp 1b sat before a 75cm wide rigid table with a CRT monitor fixed 75cm from the front edge and two lateral response panels, 50cm from the front edge, positioned at the left and right desk edges. Figure 1 depicts the testing setup for participants in Exp 1a. In both experiments, the participant’s task was to classify the sex of a target face by reaching out to touch the appropriate response panel. The correct touch position for each sex was counterbalanced across participants. We recorded reaching trajectories using motion capture devices to track the position of the finger in Euclidian space – in Exp 1a, we used an OptotrakCertus, NDI (200Hz) to sample the position of a small light-emitting diode fixed to the tip of the right index finger. We employed the same approach in Exp 1b with a Polhemus Liberty electromagnetic tracking system (240Hz) and a small sensor.



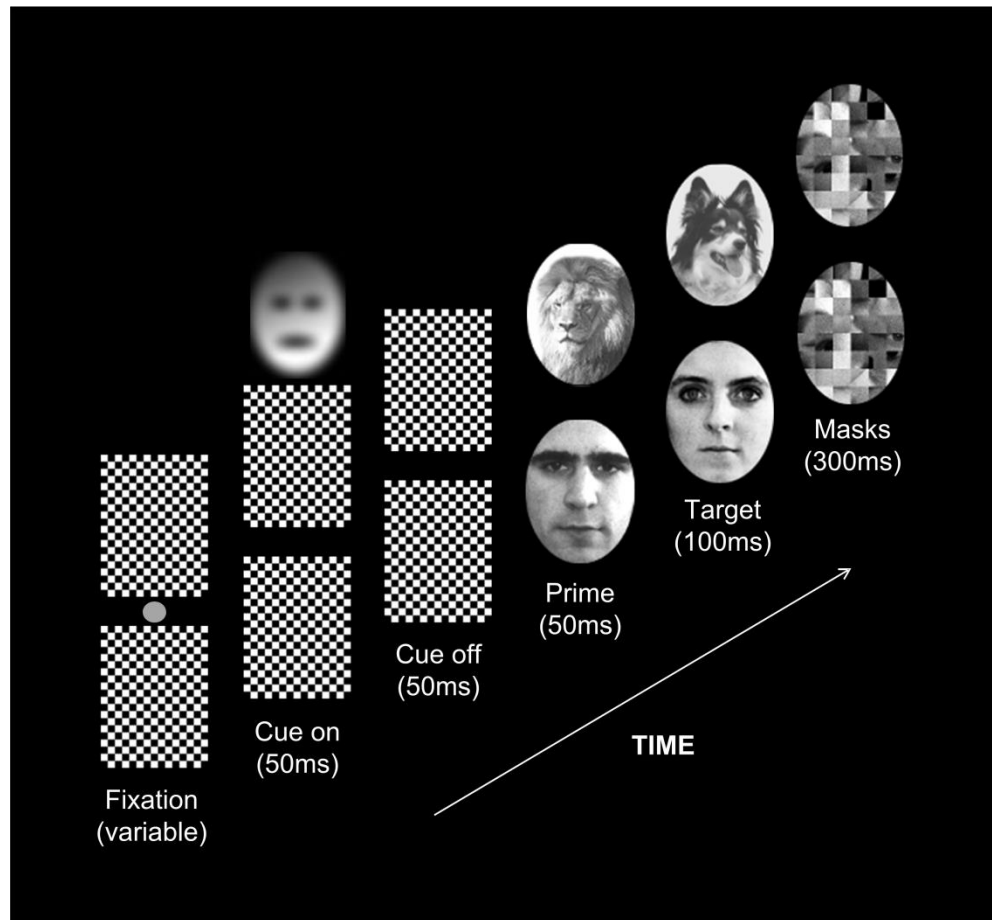
*Figure 1.* Testing set up for Experiment 1a. Participants sat before a LCD touchscreen monitor fixed 50cm from the table edge. Throughout the experiment, response boxes marked 'M' or 'F' appeared at the left and right edges of the screen (order counterbalanced across participants). To initiate each trial, participants depressed a start button aligned with the body midline, fixed 3.5cm from the table edge. When the target appeared, participants had 400ms to release the button and begin reaching towards the monitor. Throughout the experiment, the position of the participant's finger was recorded by an Optotrak Certus motion capture system (200Hz sample rate). Experiment 1b used a very similar testing setup in which the finger's position was recorded using a Polhemus Liberty electromagnetic tracking system (240Hz sample rate).

Figure 2 shows the visual trial structure for both experiments. Each trial frame consisted of two display panels (75×100 pixels) positioned immediately above and below a central fixation point. The trial commenced when the participant moved their finger into the ‘start position’ – a region of space on the body midline at the front edge of the table. Participants first saw two chequerboard forward masks whose duration varied trial-to-trial to increase uncertainty. This fixation frame was followed by the sudden onset and offset of an exogenous spatial cue (a schematic face) presented either above the top panel, or below the lower panel (50ms on, 50ms off). The subsequent prime frame (50ms) contained the critical prime face (either male or female) in one panel and a non-critical animal stimulus in the opposite position. The target face then appeared for 100ms in the same position as the prime, with an animal distractor presented in the other panel<sup>2</sup>. Identical scrambled faces appeared as backward masks in both panels until the participant completed their classification response by reaching out to touch the appropriate response panel. We told participants to fixate on the central dot at the start of each trial and highlighted that the target could appear with equal probability either above or below fixation. Our spatial cueing procedure was a variant of the classic Posner cueing paradigm (Posner, 1980) in which covert attention is “captured” at a location by the sudden appearance of a brief peripheral cue. In these paradigms, in which the cue is always nonpredictive of target location (i.e., 50/50, valid/invalid), the cue is thought to capture attention in a bottom-up, automatic way (Yantis & Jonides, 1990). Thus, we expected the schematic face cue would be effective in capturing spatial attention to the vertical hemifield in which it appeared despite being uninformative of the upcoming target’s location.

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<sup>2</sup> The animal foil and distractor appeared inverted on approximately 50% of trials; the orientation of the foils and distractors had no reliable effect and so we have not included it in the present analysis.





*Figure 2.* Trial structure for Experiments 1a & 1b. Participants saw two identical chequerboard panels displaced around a central fixation dot. The task was to classify the sex of a target face that could appear with equal chance in the upper or lower panel (i.e., UVF or LVF). Targets were preceded by a prime face of the same or opposite sex (i.e., congruent or incongruent). We used an exogenous spatial cueing procedure, whereby the sudden onset/offset of a schematic face was used to cue the participant towards the target location (valid cue) or the opposite location (invalid cue). The ratio of valid to invalid cues was 50:50, such that the spatial cue was non-predictive of target location.

It is important to highlight that the total time between cue-onset and prime-offset was 150ms in our trial structure. This is important to note because reflexive saccade latencies take 200-250ms (Walker, Walker, Husain, & Kennard, 2000). Thus, any cue-induced eye movements in our paradigm would have taken place after the prime stimulus had been extinguished. Hence, we are reasonably confident that our dependent measure, the prime-induced MCE, was not modulated in any systematic way by overt eye movements. It is also worth highlighting how we were careful to minimise the contribution of the hemispheric processing differences for faces between the right and left visual fields (Gilbert & Bakan, 1973; McCarthy, Puce, Gore, & Allison, 1997; Rossion et al., 2000). To this end, where many previous studies have presented target faces at diagonal locations (upper-left, upper-right, lower-left, lower-right), effectively confounding vertical asymmetry effects with the known laterality effects for faces, we chose to present our prime–target face pairs immediately above and below fixation (i.e., along the vertical meridian).

On each trial, we defined the start of participant's reaching movement as the point at which their finger's tangential velocity reached 10cm/second. The time in milliseconds from target onset until this point was noted as that trial's Movement Initiation Time (MIT). How participants initiated their reaching movement differed slightly between Experiments 1a and 1b. In Exp 1a, participants began their reaching movement as soon as they saw the target face appear in either panel. To prevent participants from delaying their movement until they were certain of the target's sex, we gave negative feedback (a loud buzz and visual feedback, e.g. "Too late!") and aborted the trial if they failed to initiate their movement within 400ms of target onset. Thus, MIT latencies in Exp 1a could range from 0ms to 400ms. Aborted trials were cached and re-presented at the end of the block. To prevent anticipatory movements (i.e., moving before target onset), 10% of trials did not include a target and on these "no-go" trials, participants were required to keep their finger

in the start position. In Experiment 1b we wanted to ensure a greater spread of movement initiation times (MIT latencies) relative to target onset, especially within the earliest stages of stimulus processing. To this end, we trained participants to initiate their reaching movement in response to an imperative auditory go-signal, rather than target onset (Finkbeiner, Coltheart, & Coltheart, 2013). On each trial, participants heard a sequence of three beeps of increasing pitch and had to coincide their movement onset with the arrival of the third beep. We allowed participants to begin moving up to 100ms before, and 200ms after, the onset of the third beep – MIT latencies outside this response window were aborted using the procedure described for Exp 1a. We varied the temporal proximity of the target to the go-signal using three different stimulus onset asynchronies (SOAs) such that the target could appear either simultaneously with the third beep (40% chance), 150ms before the third beep (40% chance), or 250ms before the third beep (20% chance). Thus, MIT latencies in Exp 1b could range from -100ms to 450ms<sup>3</sup>. This procedure enables us to examine reaching trajectories initiated across a wide range of target-viewing-times, so as to better observe the emergence of experimental effects as a function of stimulus processing time. To do so we use MIT latency as a proxy for target-viewing-time on each trial, as the longer MIT latency is, the more time the participant had to process the target before commencing their reaching movement. Importantly, where both experiments required participants to initiate their reaching movement within a narrow time window, the classification reaching response itself was not speeded. Participants had over three seconds to reach out and touch a response panel – ample time for the finger to change direction or correct its course.

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<sup>3</sup> In Exp 1b we allowed participants to begin their movement up to 100ms before the auditory go-signal. Thus, on those trials in which the go-signal and the target were presented simultaneously (0ms SOA), participants could initiate their movement prior to target onset, yielding a negative MIT. Having a small percentage of trials with negative MITs was intended as these trials provide a baseline condition.

At the conclusion of both experiments we assessed participants' awareness of the prime stimuli by informing them of the prime's presence and asking them to complete additional prime-detection trials (80 trials in Exp 1a; 160 trials for Exp 1b). The task during these trials was identical to the experiment proper (i.e., reach out to classify the target), save that after completing the reaching response, participants were presented with two faces (the real prime and a lure) and asked to indicate which one of the two was the prime on that trial. We counterbalanced the position of the real prime and lure across trials, and instructed participants to maintain the same strategy for the prime-detection trials as they had for the trials in the experiment proper.

### ***3.3.4. Data Preparation & Analyses***

#### ***3.3.4.1. Response bias identification***

Prior to analysing participants' trajectory data, we inspected their prime-detection data for evidence of response bias. An  $A'$  value (Zhang & Mueller, 2005) for either the congruent or incongruent condition that falls outside the range of .20 to .80 indicates a disproportionately high hit-rate for congruent trials and a conversely low hit-rate for incongruent trials. Such a pattern indicates a response bias in which a participant tended to identify the prime face on the basis of the target's sex (i.e., if the target on that trial was female they tended to select the female prime). Because prime-detection data obtained in such a context cannot give a reliable indication of the participant's ability to identify the prime under masked conditions, we removed any participants who did not meet the above criteria from all subsequent analyses (seven from Exp 1a and four from Exp 1b). The remaining 40 participants' data were included in all subsequent analyses.

#### ***3.3.4.2. Trajectory data preparation***

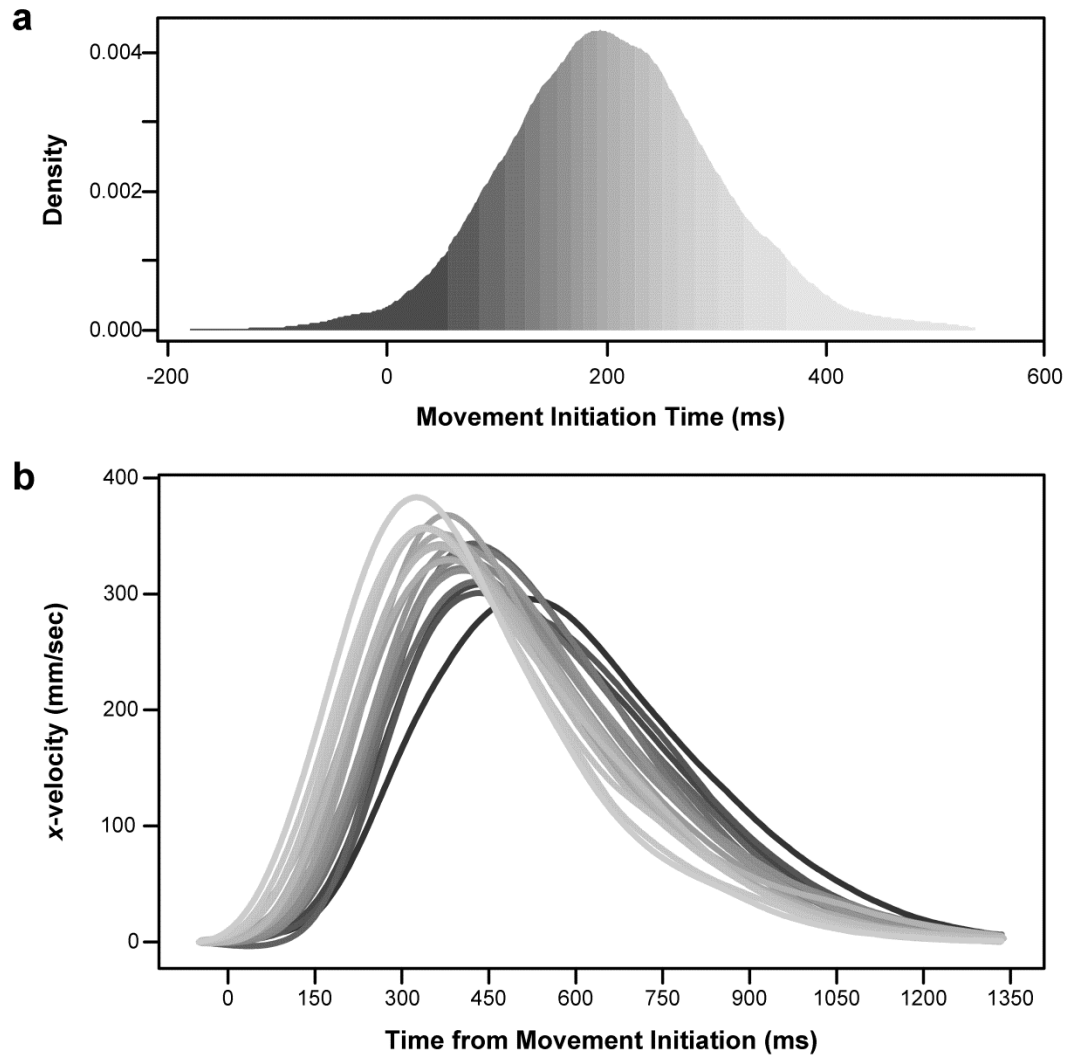
To prepare each trajectory for analysis, we firstly selected the raw samples beginning 50ms before and concluding 300ms after the point of movement onset (i.e., MIT

latency). For each individual sample, we then calculated **x-velocity**, a signed value that reflects the velocity of the finger along the left-right axis (i.e., the target classification dimension, “left for male” and “right for female”). The more positive *x*-velocity is at any given sample, the faster the finger is headed towards the correct response panel at that moment in time. In contrast, a negative *x*-velocity value indicates the finger is moving away from the correct response panel (i.e., in the wrong direction). The measure can be used as a momentary index of the participant’s response certainty, in that the more positive *x*-velocity is, the faster the finger is moving in the correct direction at that particular moment – so the more certain the participant must be regarding their classification. For the present face-sex categorisation task, the MCE is reflected in higher (more positive) *x*-velocities on congruent trials compared to incongruent trials. That is, the finger heads in the correct response direction faster when the prime and target are associated with the same classification response (i.e., congruent) rather than difference responses (i.e., incongruent). This is akin to shorter RT latencies for congruent trials compared to incongruent trials typically observed in masked priming button press experiments (Finkbeiner & Palermo, 2009; Naccache et al., 2002).

#### ***3.3.4.3. Orthogonal polynomial trend analysis (OPTA)***

Before submitting the raw *x*-velocity profiles to statistical analyses, we used a modified version of orthogonal polynomial trend analysis (OPTA, cf. Karayanidis, Provost, Brown, Paton, & Heathcote, 2011; Woestenburg, Verbaten, & Slangen, 1983). In our version of this procedure, we used MIT latency as the sole covariate in a high-degree polynomial regression model of participants’ *x*-velocity profiles. The advantage of this approach is twofold. First, it enables us to examine how *x*-velocity profiles vary as a function of MIT, i.e., target-viewing-time. Because MIT is the duration for which the participant processed the prime–target information prior to initiating their reaching response, yoking any given trial’s *x*-velocity data to its MIT latency enables us to observe

the masked congruence effect while stimulus processing is still ongoing. Secondly, because each individual trial contributes to the regression model, this procedure yields a much better signal-to-noise ratio than simple averaging. For example, the signal-to-noise ratio given by OPTA has been reported by Karayanidis et al. (2011) to be 2.5 times that of simple averaging. Similarly, Woestenburg et al. (1983) have reported that OPTA increases the signal-to-noise ratio over simple averaging and Wiener filtering by up to a factor of ten. In our OPTA procedure, trials within each individual design cell (e.g. participant, level of Cue Validity, level of Visual Field, and level of Prime Type) were ordered by MIT latency from 1 to  $n$ , such that the trial with the shortest MIT was ranked 1st and the trial with the longest MIT was ranked  $n^{\text{th}}$  (where  $n$  is the number of trials in that design cell). We then fitted a polynomial regression model to the  $x$ -velocity profiles that included MIT rank as the only covariate and polynomial terms up to the 15<sup>th</sup> order. Terms that did not explain significant variance were dropped from the model so that only significant coefficients were used to generate predicted  $x$ -velocity profiles (one for each trial). Finally, we averaged the fitted  $x$ -velocity values from the first 300ms of the reaching movement and submitted this mean value, which we refer to as initial  $x$ -velocity, to statistical analysis. To visualise the effect of target-viewing-time (i.e., MIT latency) on the complete reaching response, we used the corresponding MIT rank values to group the  $x$ -velocity profiles into 20 bins of equal proportion (i.e., semi-decile; see Figure 3b). The mean  $x$ -velocity profile (averaged across participants) from each MIT Quantile is presented in the bottom panel of Figure 3. As is clear in this figure, the longer participants wait to begin their reaching movement, the more quickly they reach peak  $x$ -velocity (i.e., the faster they move in the correct direction).



*Figure 3.* Grouping trajectories by target-viewing-time. (a) Analysis begins with the distribution of MIT Latencies from target onset (i.e., a distribution of target-viewing-times). We then fitted a polynomial regression model to the x-velocity profiles incorporating MIT rank as a covariate (see text). (b) Mean predicted x-velocity profiles by MIT Quantile. Darker colours indicate trials with short MIT Latencies (beginning at the 1<sup>st</sup> Quantile); lighter colours correspond to longest MIT Latencies (20<sup>th</sup> Quantile). Note the clear effect of MIT Latency: the longer participants wait to begin moving, the faster the finger moves in the correct direction during the reaching response itself.

### 3.3.4.4. Statistical Analyses

All analyses were carried out using custom software written in R ([www.r-project.org](http://www.r-project.org)). We used the lmer4 package (<http://lme4.r-forge.r-project.org>, cf. Bates, Maechler, & Bolker, 2011) to implement linear mixed-effects modelling (LMM; cf. Baayen, Davidson, & Bates, 2008; Bates, 2005) that enables the experimenter to consider fixed and random effects simultaneously. We used an incremental nested model comparison procedure in which we evaluated the relative contribution of each effect and interaction term by comparing a model that included the effect of interest to one that did not include this effect. For each comparison, we determined which of the two models fit the data better by inspecting the AIC, BIC, and Log Likelihood values for each model (Akaike, 1974; Schwarz, 1978). These values reflect a model's goodness-of-fit, and in the case of AIC and BIC, impose a penalty which increases with the number of estimated parameters. In model comparison procedures, the preferred model is that which minimises AIC and BIC and maximises the Log Likelihood. Below we report the results of the Likelihood ratio test for each model comparison instance. Where appropriate, we also report the coefficients, standard errors (*SE*), and *t*-values for terms included in the final model selected. As is typical for LMM analyses, we take a coefficient magnitude of at least twice its standard error (i.e.,  $|t| > 2$ ) as our criterion for significance<sup>4</sup> (Kliegl, Masson, & Richter, 2010; Kliegl, Wei, Dambacher, Yan, & Zhou, 2011). For each model evaluation, we also report conditional  $R^2$  (notated as  $R^2_{\text{COND}}$ ), or the proportion of variance in the data explained by all factors contained in the model being evaluated. Owing to our use of an incremental model comparison procedure (i.e., a single factor added for each new

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<sup>4</sup> While exact degrees of freedom for *t*-values are not known for LMM analyses, Kliegl and colleagues have argued that incorporating a large number of observations results in a *t* distribution that converges to the standard normal distribution, allowing the two *SE* criterion to approximate the convention of two-tailed 5% significance (Baayen et al., 2008; Kliegl et al., 2010).



comparison), conditional  $R^2$  in the present case provides some indication of the degree to which each new term improves the model's fit.

## 3.4. Results

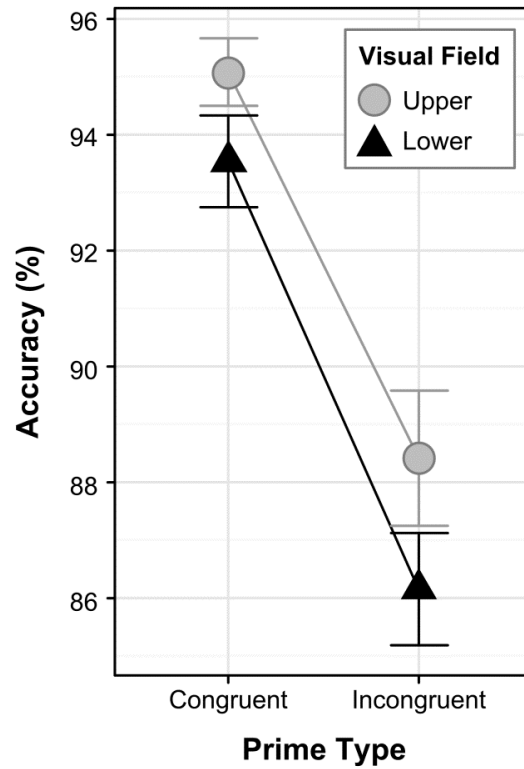
### 3.4.1. Accuracy

After excluding trials on which a movement-initiation error occurred (< 1% averaged across participants), overall mean target classification accuracy was 90.81%. High accuracy rates are typical of the reach-to-touch paradigm, owing to the fact that participants are able to correct any initially wayward reaching movements midflight (see Finkbeiner et al., 2013; Quek & Finkbeiner, 2013). Using LMM with participant as a random factor, we verified that the fixed effect of Experiment (1a or 1b) did not contribute to the fit of the model,  $\chi^2(1) = 2.48, p = .115, R^2_{\text{COND}} = .070$ . We therefore combined the data from both experiments for further analysis. We firstly verified the efficacy of our masked priming paradigm by confirming a significant main effect of Prime Type,  $\chi^2(1) = 242.66, p < .001, R^2_{\text{COND}} = .122$ . As can be seen in Figure 4, our participants were *less likely* to classify the target correctly if it was preceded by an incongruent prime ( $M = 87.30\%$ ) rather than a congruent prime ( $M = 94.32\%$ ),  $b = -0.90, SE = 0.06, z = -15.02$ )<sup>5</sup>. The main effect of Visual Field was also reliable,  $\chi^2(1) = 15.15, p < .001, R^2_{\text{COND}} = .125$ , indicating that target sex-classification was less likely to be correct if the target appeared below-fixation ( $M = 89.86\%$ ) compared to above-fixation ( $M = 91.76\%$ ),  $b = -0.22, SE = 0.06, z = -3.94$ . In contrast, including Cue Validity as a factor did not significantly improve

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<sup>5</sup> For binomial data, positive and negative coefficients obtained using LMM indicate increasing and decreasing probability respectively (Baayen, 2008).

the fit of the model,  $\chi^2(1) = .34, p = .563, R^2_{\text{COND}} = .125$ , nor did the interactions between any of the factors.



*Figure 4.* Mean accuracy values by Prime Type and Visual Field. Sex identification was significantly more reliable when i) the prime–target pair was congruent, rather than incongruent, and ii) the target appeared in the UVF compared to the LVF. The effect of Cue Validity on accuracy scores was not reliable and is not depicted here.

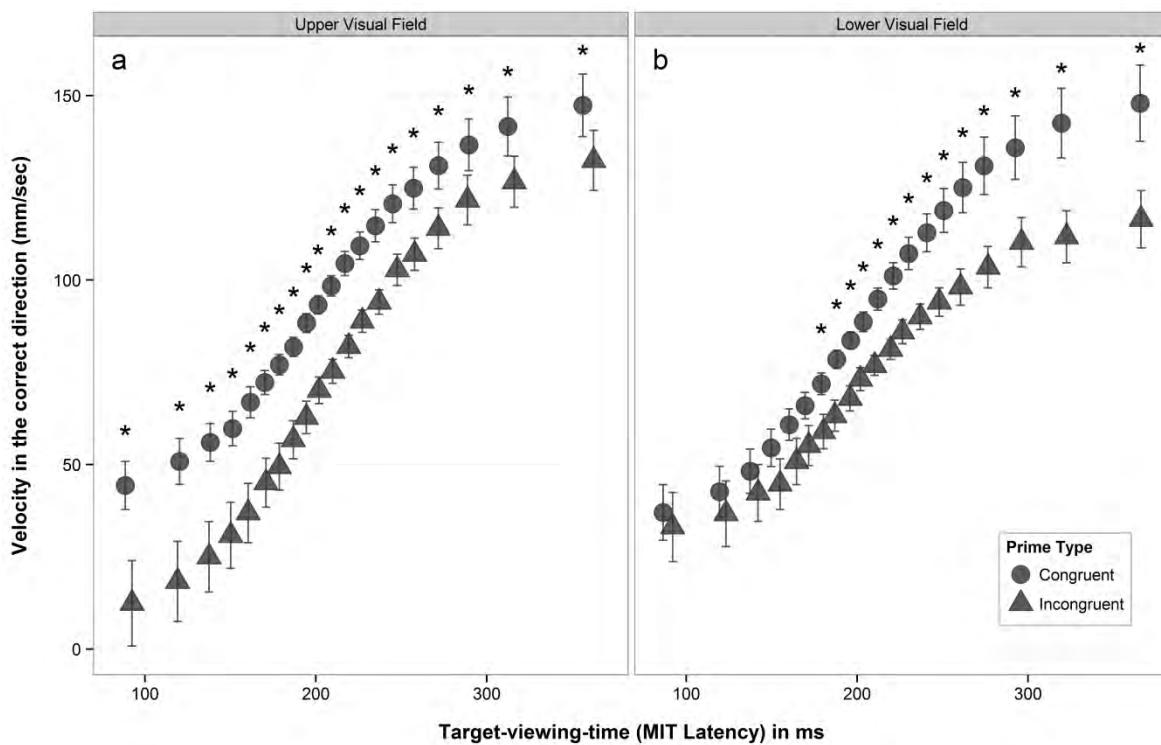
### 3.4.2. Movement Initiation Time (MIT)

LMM analysis of MIT latencies (correct classification trials only) indicated no significant effects of interest, save for a strong main effect of Experiment,  $\chi^2(1) = 39.25, p < .001, R^2_{\text{COND}} = .462$ . Owing to the use of the auditory go-signal in Exp 1b, participants

in this experiment initiated their movements around 100ms earlier ( $M = 145.77$ ) than did participants in Exp 1a ( $M = 250.40\text{ms}$ ),  $b = -104.21$ ,  $SE = 13.09$ ,  $t = -7.96$ .

### **3.4.3. Reaching Trajectories**

The OPTA procedure described above yielded 14,151 initial  $x$ -velocities obtained from 40 participants. These data were subjected to LMM analysis that included random slopes between participant and MIT Quantile. As above, we inspected AIC, BIC and Log Likelihood values to identify the terms that significantly improved the fit of the model, beginning with main effects. There was a clear main effect of MIT Quantile,  $\chi^2(1) = 34.75$ ,  $p < .001$ ,  $R^2_{\text{COND}} = .844$ , indicating that initial  $x$ -velocity tended to increase with each subsequent MIT Quantile ( $b = 5.76$ ,  $SE = 0.77$ ,  $t = 7.52$ ). That is, the longer participants viewed the target prior to beginning their movement, the faster their finger moved in the correct direction during the initial portion of the reaching movement. Figure 5 shows this effect clearly, in that initial  $x$ -velocity values increase dramatically as a function of target-viewing time (i.e., MIT latency). The critical MCE was realised in a strong main effect of Prime Type,  $\chi^2(1) = 1040.6$ ,  $p < .001$ ,  $R^2_{\text{COND}} = .855$ , in that initial  $x$ -velocity was significantly higher, on average, for congruent trials compared to incongruent trials ( $b = -17.06$ ,  $SE = 1.22$ ,  $t = -14.02$ ). That is, the participant's finger moved in the correct classification direction faster when the prime and target were associated with the same sex-classification response. The main effect of Cue Validity was also significant,  $\chi^2(1) = 30.79$ ,  $p < .001$ ,  $R^2_{\text{COND}} = .855$ , with the mean initial  $x$ -velocity on invalid cue trials being slightly higher than that for valid cued trials ( $b = 3.20$ ,  $SE = 1.22$ ,  $t = 2.63$ ). Notably, including the main effect of Visual Field did not improve the fit of the model,  $\chi^2(1) = 2.06$ ,  $p = .151$ ,  $R^2_{\text{COND}} = .855$ , and so this was not included as a fixed effect in the final model. Importantly however, several interactions incorporating Visual Field were highly significant, these are discussed below.



*Figure 5.* Initial x-velocity, or x-velocity values collapsed across the initial 300ms of the reaching movement, shown as a function of MIT latency for the a) upper and b) lower visual fields. Initial x-velocity reflects the velocity of the hand in the correct direction: negative values indicate the finger is headed towards the incorrect response panel, positive values that finger is headed towards the correct response panel. The MCE is evident in the higher initial x-velocities in the congruent condition (circles) compared to the incongruent condition (triangles). The contrast of interest between the UVF and LVF is in the timecourse over which this MCE becomes significant. In the UVF (a), the MCE is significant at even the shortest target-viewing-times (~90ms). In contrast, an additional ~90ms of target-viewing-time is needed before an MCE emerges in the LVF (b). This suggests that participants extracted the sex-information contained in the masked prime faces more efficiently when they appeared in the UVF than in the LVF. Asterisks denote .05 significant contrasts between congruent and incongruent values at each MIT Quantile (FDR corrected).

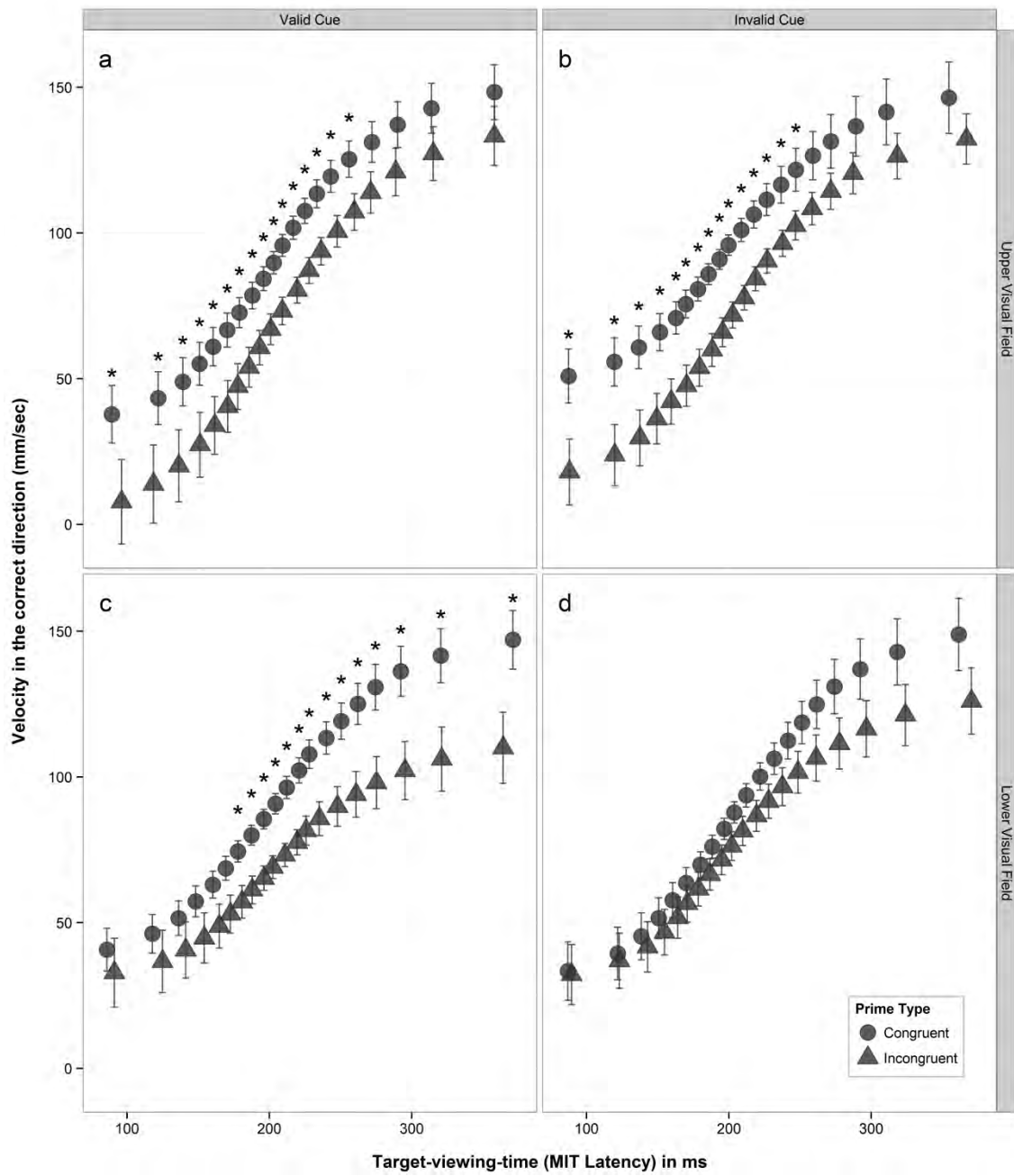
Owing to the multifactorial nature of our design, it was impractical to test the significance of each and every interaction term incrementally. Instead, we restricted ourselves to a series of model comparisons that evaluated interactions of interest identified a priori. First, we examined whether the magnitude of MCE reflected in initial  $x$ -velocity depended on how long participants viewed the target before commencing their reaching movement, observing that the interaction between Prime Type and MIT Quantile did improve the fit of the model,  $\chi^2(1) = 3.56, p = .058, R^2_{\text{COND}} = .855$ . Second, and more importantly, we confirmed that the effect of target-viewing time on the magnitude of the MCE was qualified by vertical hemifield (significant 3-way interaction between Prime Type  $\times$  MIT Quantile  $\times$  Visual Field,  $\chi^2(2) = 17.05, p < .001, R^2_{\text{COND}} = .855$ ). As can be seen in Figure 5, the stage of target-viewing time at which the MCE becomes significant very much depended on whether the prime–target pair appeared in the UVF or LVF. The prime affected the target classification response much sooner (i.e., the MCE was significant) when the stimuli were presented above-fixation compared to below-fixation. Follow up  $t$ -test comparisons between congruent and incongruent initial  $x$ -velocities at each MIT Quantile confirmed that prime–target pairs presented in the UVF elicited the MCE in participants’ initial  $x$ -velocity values at all target-viewing times, from as early as 90ms of target viewing time ( $\alpha = .05$ , corrected using False Discovery Rate, FDR). Moreover, effect size estimates of the MCE for the UVF were very reasonable, ranging between  $r = .42$  to  $.58$  (see Supplementary Materials for a more detailed discussion of the effect size estimates and statistical power associated with the MCE in each vertical hemifield). In contrast, the ability of the prime to influence the target-classification response was substantially delayed when the prime–target pair appeared below-fixation, with the MCE only emerging at  $\sim 180$ ms of target-viewing time (6<sup>th</sup> MIT Quantile). For those MIT Quantiles in which the MCE for the LVF was significant, effect size estimates were comparable to those obtained for the UVF ( $r = .45$  to  $.58$ , see Supplementary

Materials for further details). Interestingly, this difference between the vertical hemifields in the timecourse of the MCE appeared to be carried predominantly by the incongruent trials, in that incongruent primes were able to interfere with the target classification response much sooner in the upper hemifield than in the lower hemifield.

Having confirmed that the temporal unfolding of the MCE is sensitive to spatial position, we then considered the possibility that our manipulation of spatial attention affected the unfolding of the MCE differently in upper- and lower-hemifields. We firstly verified that there was a 3-way interaction between Prime Type  $\times$  MIT Quantile  $\times$  Cue Validity,  $\chi^2(2) = 13.68, p < .005, R^2_{\text{COND}} = .856$ , and then confirmed that this interaction was further qualified by Visual Field,  $\chi^2(2) = 12.92, p < .005, R^2_{\text{COND}} = .856$ . The nature of this 4-way interaction is clear in Figure 6. For faces in the UVF, Cue Validity made little difference to the time at which the MCE emerged (Figure 6, panels a & b). Follow up *t*-tests (FDR corrected) of congruent and incongruent initial *x*-velocities at each MIT Quantile indicated the onset of the MCE in the UVF did not differ as a function of cue validity. That is, both valid and invalidly cued trials showed a significant MCE from the earliest MIT Quantile (i.e., ~90ms of target-viewing time) until around 265ms of target viewing time. Effect size estimates of the MCE for the valid and invalid cue conditions were also comparable (see Supplementary Materials for details of this analysis). Taken together, these results suggest that when the prime and target faces appeared in the UVF, participants did not require focused spatial attention to it in order to extract the task-relevant sex information from the masked prime.

In contrast, when the prime–target pair appeared below-fixation, the MCE depended on the allocation of spatial attention. In the valid cue condition (Figure 6, panel c), the MCE became significant from the 7<sup>th</sup> MIT Quantile onwards, indicating initial *x*-velocity was significantly higher for congruent trials compared to incongruent trials for all

responses commencing after ~180ms of target-viewing time (effect size ranged from  $r = .42$  to  $.51$ , see Supplementary Materials). In contrast, in the invalid cue condition (Figure 6, panel d), although uncorrected  $p$ -values were significant from the 11-15<sup>th</sup> MIT Quantile, FDR corrected  $p$ -values did not reach .05 significance at any MIT Quantile (effect size ranged from  $r = .07$  to  $.31$ , see Supplementary Materials). Thus, the MCE in the LVF, invalid cue condition was very weak, if present at all, suggesting that participants were only able to extract sex information from the masked face primes in the LVF when attention was captured to the prime's location by a valid spatial cue.





*Figure 6.* The MCE reflected in initial x-velocity as a function of Cue Validity, for the UVF (a & b) and LVF (c & d). Here we are interested in *when* the MCE becomes significant. It is clear that this timecourse depends on both vertical hemifield and the validity of the spatial cue. For faces in the UVF, Cue Validity did not affect when the MCE emerged in stimulus processing time. Both the a) valid and b) invalid cue conditions yielded a significant MCE from ~ 90ms of target viewing time onwards (i.e., 1<sup>st</sup> MIT Quantile). In contrast, for faces in the LVF, priming depended on the allocation of spatial attention. In the c) valid cue condition, the MCE emerged around ~180ms of target-viewing time (7<sup>th</sup> MIT Quantile). However, when the spatial cue was d) invalid, the MCE failed to ever reach statistical significance. Asterisks denote .05 significant contrasts between congruent and incongruent values at each MIT Quantile (FDR corrected).

### **3.4.4. Prime Detection**

We assessed participants' awareness of the prime by using their prime detection data to calculate a hit rate, false alarm rate, and  $d'$  value for each experimental condition. A one sample  $t$ -test confirmed that participant's mean  $d'$  scores ( $M = 0.085$ ) were not significantly different from zero ( $t(39) = 1.71, p = .10$ , Cohen's  $d = 0.27$ ), suggesting our masking procedures were effective in preventing primes from reaching participants' conscious awareness. Additionally, we verified that  $d'$  did not vary reliably as a function of Cue Validity ( $t(39) = 0.29, p = .76$ , Cohen's  $d = .06$ ), Visual Field ( $t(39) = .40, p = .69$ , Cohen's  $d = .09$ ), or Prime Type ( $t(39) = -0.11, p = .91$ , Cohen's  $d = .03$ ).

## **3.5. General Discussion**

The present study establishes that the masked congruence priming effect (MCE) for faces in a sex-categorisation task is modulated by spatial location along the vertical meridian. Specifically, we have reported two results that demonstrate that the human visual system's capacity to extract task-relevant sex information from masked faces is superior in above-fixation locations compared to below-fixation locations. By using a behavioural measure capable of revealing the gradual unfolding of experimental effects in the early stages of stimulus-processing time, we were able to observe that the timecourse of the MCE, our index of masked face-processing, differed between the vertical hemifields. A clear UVF advantage was evident in this regard, in that masked prime faces presented above-fixation affected participants' classification of the subsequent target as early as  $\sim 90$ ms after target onset. In contrast, when the prime-target pair appeared below-fixation, participants needed to view the target for some  $\sim 170$ ms before the effect of the prime on target classification was evident. That faces presented in the UVF elicited the MCE some

~80ms sooner than those exact same faces presented in the LVF would suggest that participants processed the sex information in these faces more efficiently when they appeared above-fixation, allowing the prime to be integrated into the target-classification response sooner in the former condition. In addition, we found that the MCE elicited by face primes presented in the upper-hemifield did not depend on the appropriate allocation of attention by a spatial cue – whereas it did for face primes presented in the lower-hemifield. That is, participants were able to process the sex information carried by a nonconscious prime face presented in the upper-hemifield even when attention had been captured away from the prime's location. In the lower-hemifield however, the MCE was restricted to when a valid spatial cue captured attention to the prime. We conclude that this lack of an attentional benefit for faces presented above-fixation suggests that face-sex information is processed more efficiently in the UVF than in the LVF.

Taken together, these findings establish several important points. First, to our knowledge, these findings constitute the first behavioural demonstration that the MCE for face stimuli is sensitive to the influence of spatial location. Together with evidence we have recently provided concerning the modulatory effects of spatial and temporal attention on masked face-processing (Quek & Finkbeiner, 2013), the data reported here undermine the notion that face processing is "special" in the sense that nonconscious face-processing is invulnerable to the influence of factors known to modulate masked priming effects for non-face stimuli (Lachter et al., 2004; Marzouki, Grainger, & Theeuwes, 2007; Naccache et al., 2002). However, where the presence of priming effects for alphanumeric and picture stimuli is modulated categorically as a function of attentional allocation (e.g. Finkbeiner & Palermo, 2009; Naccache et al., 2002), our data suggest that the processes underlying face-sex categorisation are subject to a more subtle modulation by both location within the visual field and spatial attention, one that is reflected in the timecourse of the MCE rather than the presence or magnitude of this effect.

The results reported here also have implications for the wider face-processing literature, in that they suggest that an evolutionarily critical behaviour elicited by a face – i.e., identifying its sex – is faster in the upper-hemifield compared to the lower-hemifield. This result is consistent with existing neurophysiological data that suggests UVF faces elicit shorter MEG peak latencies in face responsive areas than do their LVF counterparts (Liu & Ioannides, 2010). Indeed, the vertical hemifield manipulation in our study modulated participants' behavioural response to face stimuli within the same early stage of stimulus processing in which neural effects have previously been shown (i.e., <200ms from target onset). Importantly however, where Liu and Ioannides' (2010) reported an UVF advantage for face-processing in their neurophysiological (MEG) measure, they did not observe any visual field effects in their behavioural measure. Thus, it is not clear how to establish the relevance of their MEG results to human behaviour. In contrast, by using a behavioural measure in our study, our results point to a functional above-fixation superiority for faces that is clearly relevant to human behaviour. That is, we have provided a compelling demonstration that the processing of faces qua faces (e.g. sex identification) is more efficient in the UVF compared to the LVF – a finding which echoes Previc's (1990) suggestion that the visual capabilities of each vertical hemifield have become specialised to support stimulus processing that tends to occur that region of space. Where some have previously alluded to the possibility of such a UVF advantage for face-processing (Fecteau et al., 2000; Kessler & Tipper, 2004; Liu & Ioannides, 2010), we believe our findings constitute the first behavioural demonstration of such a vertical asymmetry for faces that is not confounded by hemispheric laterality effects or participant search strategies favouring the UVF.

It is worth noting that the temporal UVF advantage for masked face-processing we observed is in opposition to previous work which has suggested that the speed of information accrual is slower in the UVF compared to the LVF (Carrasco, Giordano, &

McElree, 2004). How might we account for our temporal upper-hemifield advantage for face-processing where more low level tasks (e.g. orientation discrimination) exhibit a disadvantage in the UVF relative to the LVF (Cameron, Tai, & Carrasco, 2002; Carrasco et al., 2001)? Following Previc's (1990) suggestion regarding functional specialisation of visual processing, it may be that differences in processing efficiency between the vertical hemifields are stimulus-specific. On this possibility, since the UVF is disproportionately represented in the ventral regions of striate and extrastriate cortex (Felleman & Van Essen, 1991; Sereno et al., 1995; Wandell, Dumoulin, & Brewer, 2007; Zeki, 1969), perhaps presentation above-fixation facilitates more efficient face-sex categorisation due to the more direct projections from early visual ventral areas to the ventral visual pathways suggested to support object recognition (i.e., 'vision-for-perception') (Farah, 1990; Haxby et al., 1991; Ungerleider & Mishkin, 1982). In contrast, the same stimuli presented below-fixation may have to traverse a possibly less efficient pathway for object recognition processing, one that proceeds initially via the dorsal regions of early visual cortex – an area thought to contain more direct projections to higher dorsal areas predominantly specialised for spatial relation processing (i.e., 'vision-for-action') (Haxby et al., 1991; Ungerleider & Mishkin, 1982). It is important to note, however, that, while Previc's (1990) suggestion assumed a preferred relationship between the UVF and faces, it could be that the UVF advantage we have reported here generalizes to other stimulus types as well. This interesting possibility is outside the scope of the present paper however. We have sought here only to provide behavioural evidence that face-processing does indeed exhibit vertical asymmetry – an idea which is far from being well-established in the literature. An obvious avenue for future research then is a contrast of vertical asymmetry effects for face and nonface stimuli.

As a final point, we would suggest that the present findings contribute to the mounting evidence that argues against the long held assumption of position-invariance in

object recognition (Cox, Meier, Oertelt, & DiCarlo, 2005; DiCarlo & Cox, 2007; Marr & Nishihara, 1978). Whilst we do not dispute that the face recognition system is robust to changes in position – after all, we do easily recognise the sex of a face regardless of where it appears – the evidence here suggests that face-sex recognition is not entirely position-invariant. Rather, our capacity for face-processing appears to differ between the vertical hemifields in a subtle and brief way that favours the upper-hemifield.

### **3.5.1. Conclusion**

Using the Reach-to-Touch paradigm to reveal the gradual emergence of experimental effects in stimulus processing time, we have demonstrated that face-sex information processing is supported better in above-fixation locations than below-fixation locations. Sex information contained within a masked prime face is able to affect participants' overt response to the target face sooner when presented in the UVF compared to the LVF. This finding, observed directly in face-perception performance, rather than in neural activity correlated with face-perception, clearly establishes the existence of functional upper-hemifield superiority in face-sex categorisation, which could extend to other aspects of face-recognition as well.

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### **3.7. Appendix A (Supplementary Results)**

#### **3.7.1. Effect Size Estimates of the MCE by Vertical Hemifield**

To estimate effect size in the context of our significant Prime Type  $\times$  MIT Quantile  $\times$  Visual Field (see Figure 4), we examined the magnitude of our observed MCE across four epochs of stimulus processing time, separately for each vertical hemifield. Beginning with the UVF, we calculated each participant's average initial  $x$ -velocity across the first five MIT Quantiles, separately for the congruent and incongruent conditions. We did the same with the next five MIT Quantiles (and so on), to obtain four distinct stimulus-processing epochs (from early to late). Next we evaluated the significance of the MCE during each epoch using a paired-sample  $t$ -test, and used this  $t$  statistic to determine effect size (Pearson's  $r$ ) and statistical power ( $\beta$ ) in each epoch (Rosenthal, 1991; Rosnow & Rosenthal, 2005). Finally, we calculated how many participants would be needed to detect each obtained effect size assuming adequate statistical power of .80. We repeated this entire process for the LVF; Table 1 presents the results for both vertical hemifields.

As can be seen in Table 1, the MCE obtained for prime–target pairs in the UVF was highly significant at all MIT epochs. Moreover, all UVF epochs produced a large effect size (Cohen 1988; 1992) and good statistical power. The same was true for the LVF, save for the first MIT epoch in which the obtained MCE was considered neither reliable nor large. Moreover, we determined that even in the context of high statistical power (i.e.  $\beta = .80$ ), a very large number of participants would be required to detect a significant MCE in this first stimulus processing epoch ( $n$  required = 234). Consistent with our primary analyses, these results indicate that the MCE took substantially longer to emerge in the LVF than it did in the UVF.

Supplementary Table 1.

*The MCE for each MIT Epoch for the Upper and Lower Visual Fields*

Visual Field	MIT Epoch	<i>t</i> -test of the MCE <sup>a</sup>			Effect size & power estimates		
		<i>M</i> <sub>CONG</sub>	<i>M</i> <sub>INCONG</sub>	<i>t</i>	<i>r</i>	$\beta$	<i>n</i> required <sup>b</sup>
UVF	1st	55.66	24.71	3.51 **	.489	.854	35
	2nd	82.63	56.83	4.26 ***	.563	.935	27
	3rd	109.45	88.56	4.48 ***	.583	.949	25
	4th	136.20	120.30	2.85 **	.415	.726	48
LVF	1st	48.57	41.32	1.17 ns	.184	.206	234
	2nd	77.69	6 3.50	3.10 **	.445	.784	42
	3rd	106.99	85.78	4.42 ***	.578	.946	25
	4th	136.53	108.18	4.06 ***	.545	.919	28

\*  $p < .05$ ; \*\*  $p < .01$ ; \*\*\* $p < .001$ ;  $r$  = Pearson's  $r$  estimate of effect size;  $\beta$  = statistical power

<sup>a</sup> Two tailed paired  $t$ -test ( $df = 39$ )

<sup>b</sup> Number of participants required to detect a MCE of size  $r$  assuming adequate statistical power ( $\beta = .80$ )

### **3.7.2. *Effect Size Estimates of the MCE by Vertical Hemifield and Cue Validity***

To determine effect size and statistical power in the context of our significant 4 way interaction (Prime Type  $\times$  MIT Quantile  $\times$  Visual Field  $\times$  Cue Validity, see Figure 5), we followed the same procedure outlined above for each level of Cue Validity, separately for each visual field.

#### **3.7.2.1. *Upper Visual Field***

Table 2 presents effect size and power estimates for the MCE for the valid and invalid cue conditions for the UVF. Consistent with the *t*-test outcomes we report in the main results, the first three MIT epochs for both valid and invalid trials in the UVF yielded significant MCEs of medium to large effect size. By contrast, the final MIT epoch for both cue conditions yielded an unreliable MCE of comparatively smaller effect size, and a larger estimate of required subjects, suggesting the MCE to have decayed by this ‘late’ stage of stimulus processing (see Figure 5a & 5b). Importantly, these results suggest that the magnitude and timecourse of the MCE in the UVF was similar across both valid and invalid trials.



Supplementary Table 2.

*The MCE in the UVF: Valid and Invalid Conditions as a function of MIT Epoch*

Cue Validity	MIT Epoch	<i>t</i> -test of the MCE <sup>a</sup>			Effect size & power estimates		
		<i>M</i> <sub>CONG</sub>	<i>M</i> <sub>INCONG</sub>	<i>t</i>	<i>r</i>	$\beta$	<i>n</i> required <sup>b</sup>
Valid	1 <sup>st</sup>	49.54	20.67	2.33 *	.349	.576	66
	2 <sup>nd</sup>	78.52	53.86	3.13 **	.448	.789	41
	3 <sup>rd</sup>	107.45	86.94	3.23 **	.459	.808	39
	4 <sup>th</sup>	136.63	120.39	1.72 ns	.265	.373	114
Invalid	1 <sup>st</sup>	60.73	29.98	3.58 **	.497	.865	34
	2 <sup>nd</sup>	85.76	59.84	3.95 ***	.535	.910	29
	3 <sup>rd</sup>	111.43	90.22	2.72 *	.399	.692	51
	4 <sup>th</sup>	136.59	120.32	1.45 ns	.226	.286	156

\*  $p < .05$ ; \*\*  $p < .01$ ; \*\*\* $p < .001$ ;  $r$  = Pearson's  $r$  estimate of effect size;  $\beta$  = statistical power

<sup>a</sup> Two tailed paired  $t$ -test ( $df = 39$ )

<sup>b</sup> Number of participants required to detect a MCE of size  $r$  assuming adequate statistical power ( $\beta = .80$ )

### **3.7.2.2. Lower Visual Field**

In contrast to the UVF, the valid and invalid cue conditions in the LVF differed from one another quite substantially (see Table 3). Where the validly cued trials yielded a significant MCE of medium to large effect size in all but the first MIT epoch, the MCE was not reliable for any of the MIT epochs in the invalid cue condition. In addition, even assuming high statistical power, a very large number of subjects would be required for any of these epochs to reveal a significant MCE, suggesting the priming effect for the LVF-invalid condition to be very weak, if present at all.

Supplementary Table 3.

*The MCE in the LVF: Valid and Invalid Conditions as a function of MIT Epoch*

Cue Validity	MIT Epoch	<i>t</i> -test of the MCE <sup>a</sup>			Effect size & power estimates		
		<i>M</i> <sub>CONG</sub>	<i>M</i> <sub>INCONG</sub>	<i>t</i>	<i>r</i>	$\beta$	<i>n</i> required <sup>b</sup>
Valid	1st	51.76	40.69	1.18 ns	.186	.209	229
	2nd	79.85	61.03	2.86 *	.417	.730	47
	3rd	107.78	81.64	3.70 **	.510	.882	32
	4th	136.16	102.10	3.28 **	.465	.818	38
Invalid	1st	45.37	41.48	.45 ns	.072	.073	1516
	2nd	75.87	66.36	1.59 ns	.247	.332	131
	3rd	106.27	91.71	2.06 ns	.313	.488	82
	4th	137.03	116.69	1.86 ns	.285	.420	99

\*  $p < .05$ ; \*\*  $p < .01$ ; \*\*\* $p < .001$ ;  $r$  = Pearson's  $r$  estimate of effect size;  $\beta$  = statistical power

<sup>a</sup> Two tailed paired  $t$ -test ( $df = 39$ )

<sup>b</sup> Number of participants required to detect a MCE of size  $r$  assuming adequate statistical power ( $\beta = .80$ )

### **3.7.3. Appendix References**

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GAINING THE UPPER HAND:  
EVIDENCE OF VERTICAL ASYMMETRY IN  
SEX-CATEGORISATION OF  
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GAINING THE UPPER HAND:  
EVIDENCE OF VERTICAL ASYMMETRY IN SEX-CATEGORISATION  
OF HUMAN HANDS

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## **4.1. Abstract**

Visual perception is characterised by asymmetries arising from the brain's preferential response to particular stimulus types at different retinal locations. Where the lower visual field (LVF) holds an advantage over the upper visual field (UVF) for many tasks (e.g. hue discrimination, contrast sensitivity, motion processing), face-perception appears best supported at above-fixation locations (Quek & Finkbeiner, 2014). This finding is consistent with Previc's (1990) suggestion that vision in the UVF has become specialised for object recognition processes often required in 'extrapersonal' space. Outside of faces, however, there have been very few investigations of vertical asymmetry effects for higher-level objects. Our aim in the present study was thus to determine whether the UVF advantage reported for face-perception would extend to a nonface object – human hands. Participants classified the sex of hand images presented above or below central fixation by reaching out to touch a left or right response panel. We manipulated the locus of covert spatial attention using an exogenous peripheral cueing procedure. We observed that cue validity only modulated the efficiency of the sex-categorisation response for targets in the LVF and not the UVF, just as we have reported previously for face-sex categorisation (Quek & Finkbeiner, 2014). Taken together, the data from these studies provide some empirical support for Previc's (1990) speculation that object recognition processes may enjoy an advantage in the upper-hemifield.

*Keywords:* Vertical asymmetry; upper visual field; lower visual field; attention, sex-categorisation; hands

## **4.2. Introduction**

The notion of vertical asymmetry in visual perception is by no means new. We have known for some time, for example, that the lower visual field (LVF) exhibits an advantage over the upper visual field (UVF) in terms of contrast sensitivity (Cameron, Tai, & Carrasco, 2002; Carrasco, Penpeci-Talgar, & Cameron, 2001; Carrasco, Williams, & Yeshurun, 2002; T. Liu, Heeger, & Carrasco, 2006; Skrandies, 1987), visual acuity (Skrandies, 1987), spatial resolution (Carrasco et al., 2002; Talgar & Carrasco, 2002), hue discrimination (Levine & McAnany, 2005), and motion processing (Rezec & Dobkins, 2004; Levine & McAnany, 2005). By contrast, the UVF appears to enjoy an advantage on tasks involving visual search (Chaiken, Corbin, & Volkmann, 1962; Fecteau, Enns, & Kingstone, 2000; Previc & Blume, 1993), perception of depth (Levine & McAnany, 2005), and object recognition (Chambers, McBeath, Schiano, & Metz, 1999). Such perceptual asymmetries may in part reflect underlying physiological differences between the upper and lower retinae and subsequent visual pathways. For example, better task performance for LVF stimuli could relate to greater cone and ganglion cell densities in the superior part of the retina on which information presented in the LVF falls (Perry & Cowey, 1985). Similarly, studies with non-human primates have suggested that slightly more neural tissue in lateral geniculate nucleus corresponds to representations of the LVF than the UVF (Connolly & Van Essen, 1984), V1 (Tootell, Switkes, Silverman, & Hamilton, 1988; Van Essen, Newsome, & Maunsell, 1984), and MT (Maunsell & Van Essen, 1987). In humans, the same Gabor stimuli have been shown to evoke a larger volume of activity in early visual cortex when presented in the LVF compared to the UVF (T. Liu et al., 2006).

One intriguing possibility is that the differences in visual capabilities between the UVF and LVF relate to their respective associations with far and near space. Previc (1990) proposed that the capabilities of each vertical hemifield have become specialised to support

the visual perception functions most often required in that region of space. According to Previc, visual perception in the LVF has evolved to facilitate visuomotor coordination required in near or “peripersonal” space, the region in which we reach towards and manipulate objects. Conversely, the UVF is linked to the visual search and recognition mechanisms most often required in far or “extrapersonal” space, the region in which we typically search for and discriminate objects and people. While Previc’s functional specialisation account of the vertical anisotropy in visual perception remains contentious (Bracewell, 1990; Williams, 1990; Karim & Kojima, 2010), mounting evidence of an upper-hemifield advantage in face-perception has provided some support for this view (for a review, see Quek & Finkbeiner, 2014). For example, participants in a study by Felisberti and colleagues recognised previously seen faces better if they had initially encoded the faces in the upper-hemifield rather than the lower-hemifield (Felisberti & McDermott, 2013). Others have shown that regions such as the medial prefrontal cortex (MPFC), left fusiform face area (FFA), and left occipital face area (OFA) are activated earlier by faces presented in the UVF compared to the LVF (Liu & Ioannides, 2010). Most recently, we showed that sex-categorisation of human faces is more accurate for UVF face targets than for LVF face targets (Quek & Finkbeiner, 2014). Participants in this study were also able to extract the sex information carried by nonconsciously presented faces to a greater extent when the masked faces appeared in the upper-hemifield compared to the lower-hemifield. Moreover, nonconscious face-processing seemed to depend on the allocation of spatial attention when the faces appeared in the LVF, but not when they appeared in the UVF. Taken together, these results suggest that face-processing may be more efficient in the upper-hemifield than the lower-hemifield.

The notion of an upper-hemifield advantage for face-perception resonates with Previc’s (1990) proposal that vision in the UVF has become specialised to support the visual search and object recognition processes often required in extrapersonal space. After

all, the UVF is where we most frequently encounter faces as we move through the world, and recognising the sex, identity, and expressions of these faces are undeniably some of the most critical forms of object recognition the brain is required to perform. However, while the possibility that object recognition *in general* may be better above-fixation is certainly intriguing, it must be acknowledged that, to date, the UVF advantage for recognition documented in the literature is largely restricted to tasks involving face-perception (Coolican, Eskes, McMullen, & Lecky, 2008; Felisberti & McDermott, 2013; Kessler & Tipper, 2004; L. Liu & Ioannides, 2010; Quek & Finkbeiner, 2014). Only a handful of studies have examined vertical asymmetry effects for objects other than faces, the findings of which are largely equivocal (Chambers et al., 1999; Darker & Jordan, 2004; Goldstein & Babkoff, 2001; Hagenbeek & Van Strien, 2002; Schwartz & Kirsner, 1982). As such, it is not yet established whether the UVF advantage we and other have demonstrated using faces is *stimulus-specific* – a not unreasonable possibility given the relatively “special” status faces enjoy within the visual system (Farah, 1996; Farah, Wilson, Drain, & Tanaka, 1998; Kanwisher, 2000; Kanwisher, McDermott, & Chun, 1997).

Our purpose in the present paper was to establish whether the UVF advantage we have previously reported for face-sex categorisation would extend beyond face stimuli. To this end, we asked whether vertical hemifield presentation would modulate the perception of a nonface object – human hands. Hands are an ideal stimulus with which to pursue this line of enquiry, since they can also serve as the basis for sex-judgments (Gaetano, van der Zwan, Blair, & Brooks, 2014; Kovács et al., 2006). We are thus able to retain the sex-categorisation task we have used previously to demonstrate an upper-hemifield advantage for face stimuli (Quek & Finkbeiner, 2014). To examine the effect of vertical hemifield presentation on hand-sex categorisation, we asked participants to identify the sex of a consciously presented hand image that appeared either immediately above or below central fixation on each trial. Participants indicated their sex-categorisation response by reaching

out to touch one of two response panels positioned to the left and right of the computer monitor. We manipulated whether participants attended to the spatial location of the hand by way of a peripheral precue procedure in which, 100ms before target onset, a spatial cue briefly appeared in a location vertically adjacent to either the upper or lower stimulus position. Peripheral precues have been argued to capture covert attention in a largely ‘automatic’ fashion (Jonides, 1981; Müller & Rabbitt, 1989; Pestilli & Carrasco, 2005; Pestilli, Viera, & Carrasco, 2007; Posner, 1980), and indeed we ourselves have shown the procedure to yield strong cue validity effects (Finkbeiner & Palermo, 2009; Quek & Finkbeiner, 2013; 2014).

If object recognition processes supporting sex-categorisation really do enjoy an advantage in the upper-hemifield, there are two ways this might be reflected in our experiment. First, hand sex-categorisation itself might be more accurate and/or efficient in the UVF compared to the LVF. Second, sex-categorisation of hand stimuli in the upper- and lower- hemifields may be differentially modulated by attention, just as we have seen for face-sex categorisation (Quek & Finkbeiner, 2014). That is, if object recognition processes are superior in the UVF, then on the assumption that covert attention will provide the most aid to the least privileged locations (Carrasco, Giordano, & McElree, 2004; Carrasco & Yeshurun, 1998; Yeshurun & Carrasco, 1998; 1999), our manipulation of focussed spatial attention should modulate target processing more in the (disadvantaged) lower-hemifield than the (advantaged) upper-hemifield. Indeed, it may be the case that object recognition is so efficient in the UVF that responses to targets in this location do not benefit (or suffer) from shifts in spatial attention at all (see Quek & Finkbeiner, 2014). To anticipate our results, we observed that while participants’ accuracy and efficiency in categorising the sex of hand images did not differ between the vertical hemifields, the sex-categorisation response was indeed more sensitive to the effects of spatial attention when the target appeared in the LVF than the UVF. That is, spatial attention modulated the sex-

categorisation response for lower-hemifield hand targets, but not upper-hemifield hand targets.

## **4.3. Materials & Methods**

### **4.3.1. Ethics**

Experimental protocol was approved by the Human Research Ethics Committee of Macquarie University. All procedures were in compliance with the guidelines laid out in the National Health and Medical Research Council (NHMRC) National Statement (2007). We obtained informed written consent from all participants described in this study.

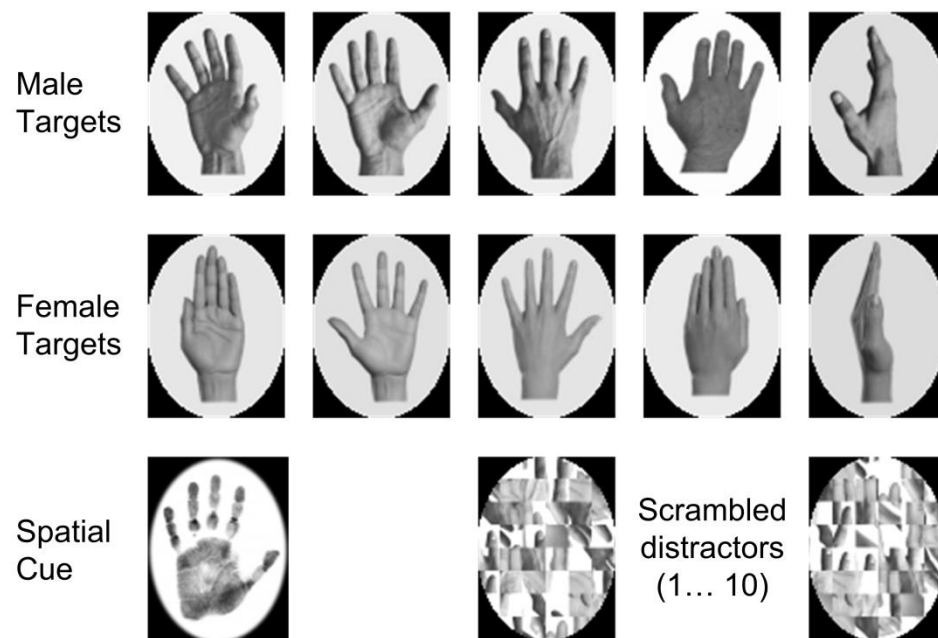
### **4.3.2. Participants**

36 Macquarie University undergraduate students (14 males) completed the experiment in exchange for course credit or financial compensation. Participants ranged in age from 18 to 41 years ( $M = 20.78$ ;  $SD = 3.91$  years). All participants had normal or corrected-to-normal vision, and were identified as strong right handers using the Edinburgh Handedness Inventory (Oldfield, 1971).

### **4.3.3. Stimuli**

Figure 1 presents the stimuli used during the experiment. Targets were 10 greyscale photographs of human hands in various poses on a white oval background (five male and five female). Distractors were 10 greyscale scrambled images created from sample male and female hand images that did not appear as targets. We used the SHINE toolbox written for Matlab to adjust all target and distractor items so their mean luminance and contrast values were comparable (Willenbockel, Sadr, Fiset, Horne, Hosselin, & Tanaka, 2010). The spatial cue was a greyscale handprint on a white background and was

not discernibly male or female. All stimuli appeared on a black background and subtended 1.53 by 2.13 degrees of visual angle from a viewing distance of 1050mm.



*Figure 1.* Targets were five male and five female hand targets in various poses. Distractors were 10 randomly generated scrambled images of male and female hands. We adjusted the low level properties of all targets and distractors so that their mean luminance was comparable. The spatial cue was a hand print image that contained no obvious sex information. All stimuli subtended 1.53 by 2.13 degrees of visual angle from a viewing distance of 1050mm.

#### **4.3.4. Apparatus**

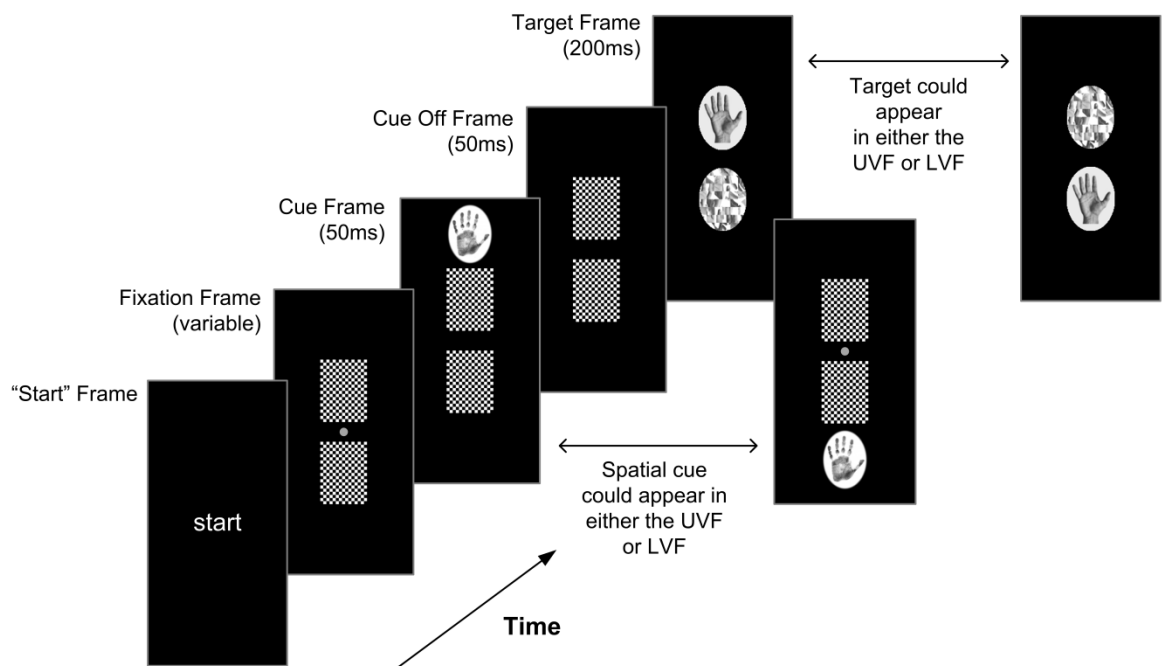
The participant sat before a rigid table with an LCD monitor positioned 850mm from the front edge. Left and right wooden response panels (270×90mm) were fixed 750mm apart, 500mm from the table edge. The participant classified the sex of the target images by using their right (dominant) hand to reach out to touch one of the response panels, with the correct touch position for male and female targets counterbalanced across participants. A Polhemus Liberty electromagnetic tracking system recorded the reaching response in xyz space by sampling the position of a small sensor affixed to the tip of the right index finger at a rate of 240Hz. We used custom software written in Presentation® to present stimuli and interface with the motion capture system.

#### **4.3.5. Procedure**

Figure 2 shows the visual trial structure for this experiment. Each trial was preceded by a “Start” screen that remained onscreen until the participant initiated the trial proper by moving the Liberty sensor attached to their right index finger into a “start region” aligned with the body midline at the front of the testing table. Each frame following this consisted of two identically sized panels vertically displaced around a central fixation point (1.26 degrees of visual angle from fixation to the centre of each panel). First, participants saw a fixation frame of two identical chequerboard forward masks. We varied the duration of this fixation frame to increase participants’ uncertainty regarding target onset. Next, an exogenous spatial cue appeared for 50ms either immediately above or below the top or bottom panel respectively (see Figure 2). At cue offset, the forward masks remained onscreen for another 50ms before being replaced by the critical target image and a randomly selected distractor (200ms duration). A blank screen then remained until the participant completed their response by touching one of the two target panels, after which they received visual feedback on their classification



(“...Correct...” or “... WRONG...”). We used a stimulus onset asynchrony (SOA) of 100ms between the cue and target to maximise the benefit of exogenously captured covert attention, known to occur around 80-120ms following cue onset (Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989).



*Figure 2.* Visual trial structure. Participants began each trial by viewing a “start” screen. This remained present until they initiated the trial sequence by moving their right index finger into the “start region” at the front of the table. The initial fixation frame consisted of two forward chequerboard masks, the duration of which varied trial to trial. We used a briefly presented peripheral cue (50ms) to capture spatial attention to either the upper or lower hemifield. After an ISI of 50ms, the target then appeared for 200ms in either the top or bottom panel, accompanied by a scrambled distractor opposite. There were 40 trials per block. Participants completed 10 experimental blocks preceded by two initial practice blocks (discarded prior to analysis).

We trained participants to initiate their classification reaching movements in response to an imperative auditory go-signal. On each trial, participants heard a train of three ascending beeps and had to begin moving in synchrony with the third beep in the series. We then varied the position of this third beep in time relative to target onset such that the target-to-beep SOA on any given trial could be 0ms (40% probability), 150ms (40% probability), or 250ms (20% probability). By requiring participants to begin moving on the basis of an auditory go-signal, rather than simply in response to the target's appearance, we ensured a wide range of target-viewing times across the whole experiment. This was important insofar as we wanted to observe any experimental effects as they unfolded during stimulus-processing time (see Data Preparation). We defined Movement Initiation Time (MIT) on each trial as the time in milliseconds from target onset until the right index finger's tangential velocity reached 10cm/second. To ensure participants did indeed synchronise their movement onset with our auditory go-signal, we required MIT latency on each trial to fall within a 300ms response window around the third beep (-100ms to 200ms). We aborted any trials on which MIT fell outside this window and cached them for representation at the end of each block, and also presented participants with negative feedback (e.g. "... Too slow!" accompanied by a loud buzz). Over the course of the full experiment then, MIT latencies for each participant ranged from -100ms to 450ms. Importantly, although we maintained strict control of when participants should begin their reaching movement, once initiated the reaching response was quite unhurried. Participants had over three seconds after movement initiation in which they were free to change, correct, and complete their classification response.

#### **4.3.6. Design**

We used a  $2 \times 2$  fully-crossed within subjects design with the factors Visual Field (Upper or Lower) and Cue Validity (Valid or Invalid). Each of the 10 targets appeared in

each of these four experimental conditions once per block and the full experiment was comprised of 10 experimental blocks. There were two practice blocks at the start of the experiment; we excluded data from these blocks from later analyses.

### ***4.3.7. Analysis Methods***

#### ***4.3.7.1. Data Preparation***

Two participants produced accuracy rates less than 70% and were thus discarded from further analyses. We examined the remaining 34 participants' data to remove all trials on which movement error occurred (i.e., moving too early or too late; 10.2% of all trials). As described above, on each trial we sampled the xyz coordinates of the finger's position in space every 4ms, from start of each trial until the participant touched one of the two response panels. To prepare each raw trajectory for analysis, we first determined the movement onset on that trial (i.e., MIT, or the point in time when the finger's tangential velocity reached 10cm/second). We then calculated our dependent measure at each of the 450 samples between the points corresponding to 100ms before movement onset and 1700ms after movement onset. It was important to include the 100ms leading up to movement onset so as to ensure we considered the very start of the reaching response on each trial. For any trials on which the participant touched a response panel less than 1700ms after their movement began, we simply repeated the xyz coordinates from the final sample to make up the full 450 samples for that trial.

We used x-velocity as our dependent measure, defined as the finger's velocity along the left-right or x axis. Because participants indicate their sex-categorisation decision along this dimension (e.g. left for male; right for female), x-velocity reflects the finger's velocity in the correct direction. x-velocity is a signed value, in that positive values indicate the finger is moving towards the correct response panel, and negative values that the finger is heading away from the correct response panel (i.e., in the incorrect direction).

When considered as a continuous dataset, x-velocity values essentially provide a moment-to-moment index of the participant's response certainty over the course of the reaching movement. That is, the faster the finger moves in the correct direction (i.e., the higher x-velocity is), the more certain the participant must be regarding their classification decision. To understand how x-velocity reflects response certainty, consider the following example. Say participants are engaged in a lexical decision task in which they must reach left in response to pseudoword targets right in response to word targets. Just as RTs are typically shorter for high frequency words (e.g. follow) than for low frequency words (e.g. beckon), here we would expect participants' reaching movements to be more efficient (i.e., head in the correct direction sooner) in the former condition (for a detailed discussion of reaching trajectory analyses, see Finkbeiner, Coltheart, & Coltheart, 2014). We used a modified version of the Orthogonal Polynomial Trend Analysis (OPTA) procedure (Karayanidis, Provost, Brown, Paton, & Heathcote, 2011; Woestenburg, Verbaten, & Slangen, 1983) to smooth each x-velocity profile individually (for details of this procedure, see Quek & Finkbeiner, 2013; Finkbeiner et al., 2014; Quek & Finkbeiner, 2014). As a final step, we calculated a single value for each trial, termed initial x-velocity, by averaging x-velocity values across the first 200ms following target onset. These initial x-velocity values were subjected to the statistical analyses described below.

#### **4.3.7.2. Statistical Analyses.**

We analysed participants' accuracy and initial x-velocity data using custom software written in R ([www.r-project.org](http://www.r-project.org)). We conducted linear mixed-effects modelling (LMM; Baayen, Davidson, & Bates, 2008; Bates, 2005) using the lmer4 package written for R (<http://lme4.r-forge.r-project.org>; Bates, Maechler, & Bolker, 2011). Generalised LMM has been argued to be the most appropriate analysis for discrete accuracy data (Dixon, 2008). We modelled our data using an incremental model comparison procedure in which we evaluated the reliability of each effect by examining which model fit the data

better – one that included the effect of interest or one that did not. The preferred model was that which minimised the goodness-of-fit statistics AIC and BIC and maximised the Log Likelihood value (Akaike, 1974; Schwarz, 1978). Below we report the results of this Likelihood ratio test, and where appropriate, the coefficients, standard errors (SE), and *t*-values for the terms included in the final model selected. Our criterion for significance for individual fixed effects was an absolute *t* ratio of 2.0, as per Kliegl, Masson, and Richter (2010). Although the degrees of freedom are not known exactly in LMM, the very large number of observations in the datasets used here and elsewhere mean that the *t* distribution converges to the normal distribution. Thus, the criterion cutoff of two SEs corresponds well to the .05 significance criterion (see Finkbeiner et al., 2014; Kliegl et al, 2010; Masson & Kliegl, 2013; Quek & Finkbeiner, 2013; 2014).

## **4.4. Results**

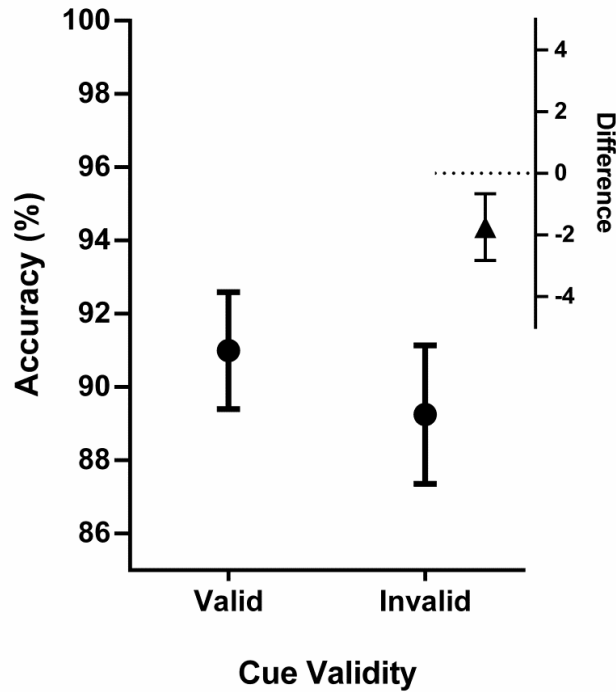
### **4.4.1. Accuracy**

The overall sex-categorisation accuracy rate following this was 90%. Accuracy rates close to ceiling are typical of the Reach-to-Touch paradigm, since unlike button press tasks, this response measure allows participants to *correct* their initial decision about the target before making their final choice (e.g. Quek & Finkbeiner, 2013; 2014). Despite these high accuracy scores, we were still able to observe experimental effects of interest in participants' accuracy rates. We analysed the binomial accuracy data using a linear mixed model which included Participant as a random factor. Using the model comparison procedure described above, we then verified that including the fixed effect of Cue Validity significantly improved the fit of the model,  $\chi^2(1) = 11.97, p < .001$ . Participants were

significantly *less likely*<sup>1</sup> to classify the target correctly on invalidly cued trials than on validly cued trials ( $b = -0.20$ ,  $SE = 0.06$ ,  $z = -3.46$ ,  $p < .001$ , see Figure 3), indicating our spatial cueing procedure was effective in manipulating participants' spatial attention ( $M_{VAL} = 91\%$ ,  $M_{INVAL} = 89\%$ ). By contrast, neither the fixed effect of Visual Field,  $\chi^2(1) = .12$ ,  $p = .729$  ( $M_{UVF} = 90\%$ ,  $M_{LVF} = 90\%$ ), nor the interaction between Visual Field and Cue Validity,  $\chi^2(1) = .00$ ,  $p = .982$ , significantly improve the model; these terms were thus excluded from the final model for accuracy data.

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<sup>1</sup> For binomial data, positive and negative coefficients obtained using LMM indicate increasing and decreasing probabilities, respectively (Baayen et al., 2008).



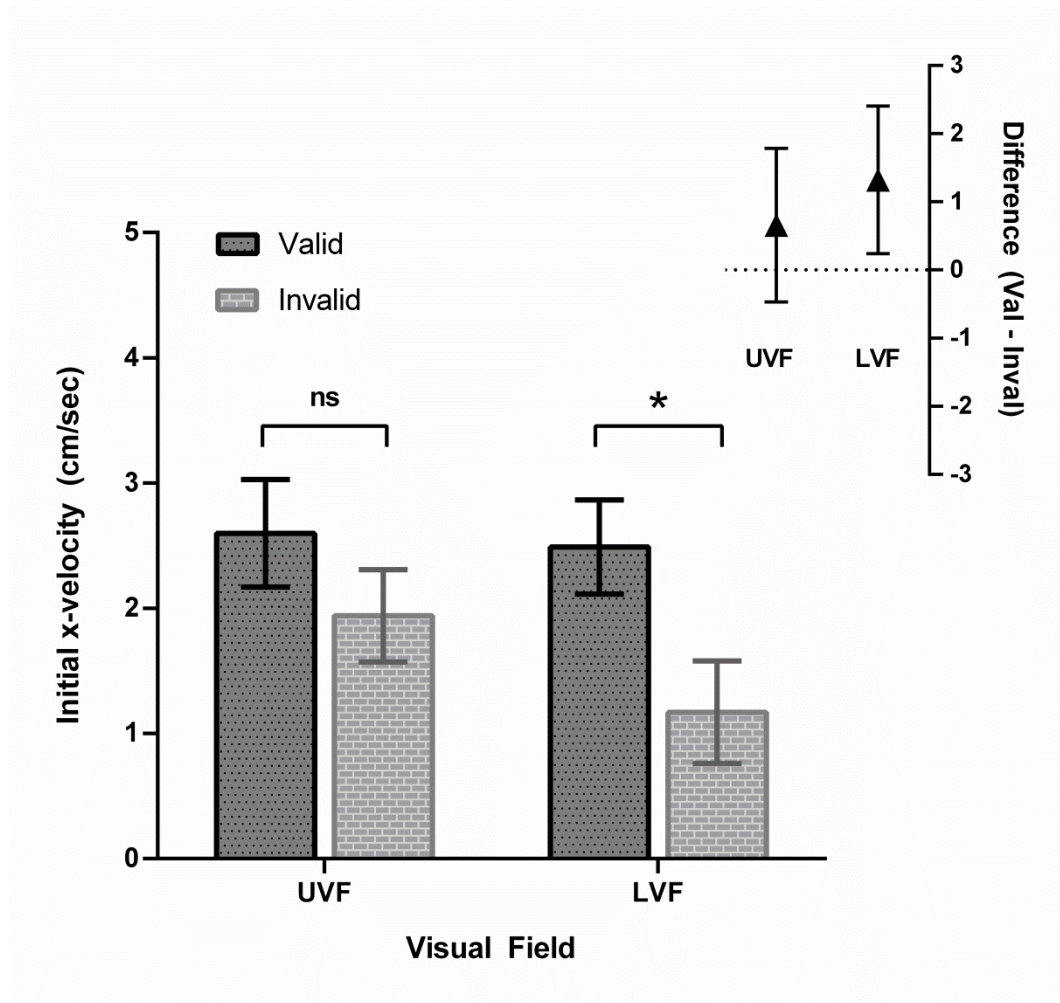
*Figure 3. Main:* Hand sex-categorisation accuracy rates as a function of Cue Validity. Binomial LMM analyses indicated participants were significantly more likely to classify the target correctly on validly cued trials than on invalidly cued trials. Error bars represent within-subjects 95% confidence intervals (WSCIs). Visual Field had no effect on accuracy rates and is not depicted here. **Inset:** Since there is no rule-of-eye for interpreting overlap between WSCIs (see Cumming & Finch, 2005), we here depict the 95% CI around the mean of the differences (valid – invalid). Since the CI around the mean difference score excludes zero, we must reject  $H_0$  and concede that accuracy rates were higher for validly cued trials compared to invalidly cued trials.

## **4.4.2. Initial x-velocity**

### **4.4.2.1. Analyses collapsed across target-viewing time**

We submitted the 11,644 initial x-velocity values to LMM analysis which included random intercepts for Participant. We used the model comparison procedure described above to verify that the inclusion of Cue Validity,  $\chi^2(1) = 141.72, p < .001$ , Visual Field,  $\chi^2(1) = 21.06, p < .001$ , and the interaction between these factors,  $\chi^2(1) = 14.48, p < .001$ , all improved the fit of the model. Thus, we included all three terms in our final model of initial x-velocity. As may be seen in Figure 4, there was a main effect of Cue Validity ( $b = -.68, SE = 0.12, t = -5.76$ ), whereby initial x-velocity was significantly higher on validly cued ( $M = 6.60$  cm/second) compared to invalidly cued trials ( $M = 5.25$  cm/second). In contrast, the main effect of Visual Field was not reliable ( $b = -.07, SE = 0.12, t = -.59$ ), however we did observe a significant interaction between the factors ( $b = -0.64, SE = 0.17, t = -3.81$ ). As may be seen in Figure 4, the cueing effect was stronger when targets appeared in the LVF compared to the UVF. Follow-up paired  $t$ -tests between the valid and invalid cue conditions within each vertical hemifield indicated the cueing effect was reliable in the lower-hemifield ( $t(33) = 2.49, p = .036$  Pearson's  $r = .40$ ), but not the upper-hemifield ( $t(33) = 1.19, p = .244$ , Pearson's  $r = .20$ ) ( $p$  values corrected using False Discovery Rate, FDR).

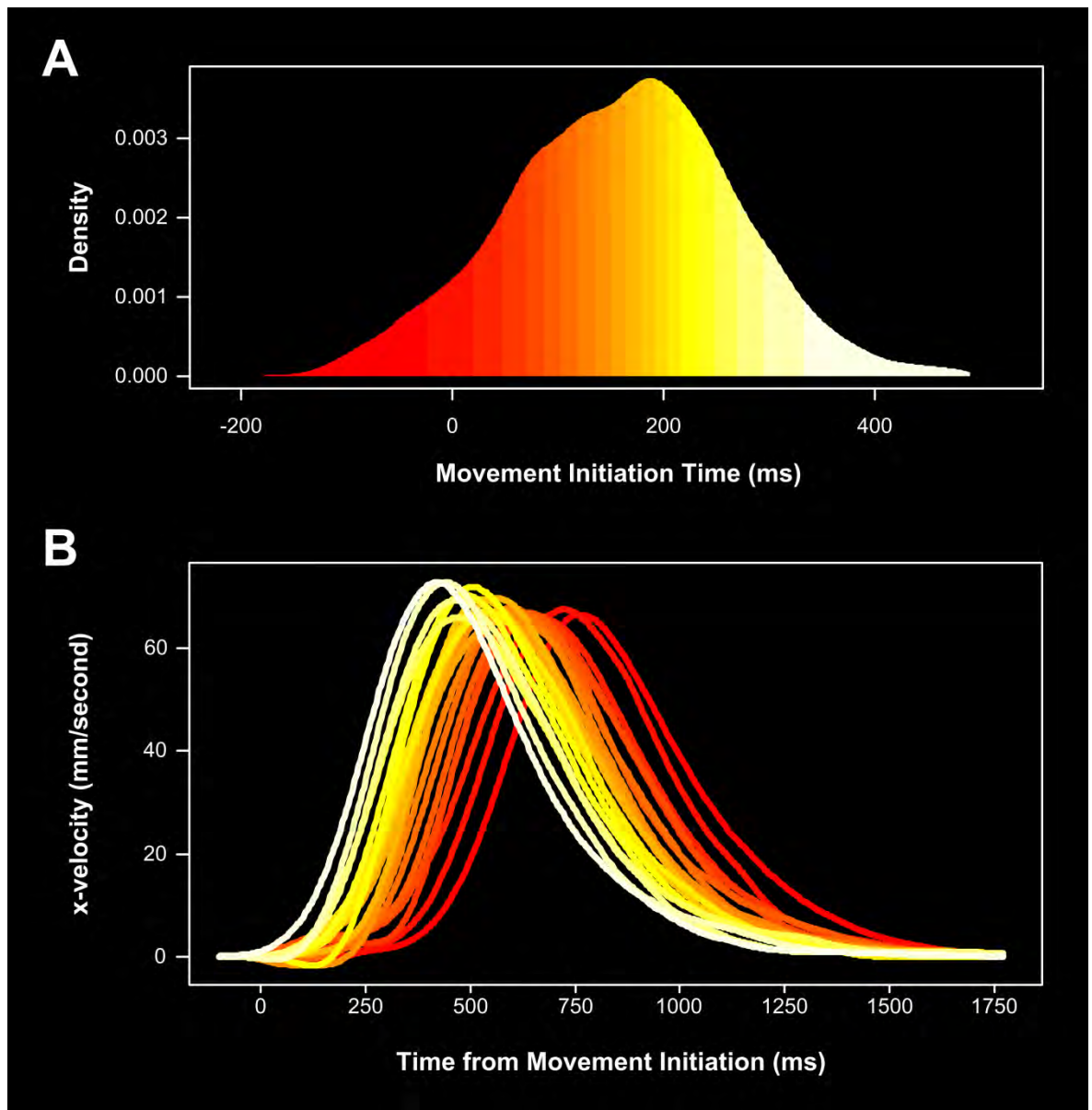




**Figure 4. Main:** Initial x-velocity as a function of Cue Validity and Visual Field. We followed up the significant interaction between these factors by conducting paired t-tests between the valid and invalid cue conditions for each visual field. The effect of Cue Validity was reliable in the LVF, but not the UVF (\* $p < .05$ ; corrected using False Discovery Rate). Error bars represent 95% WSCIs. **Inset:** 95% CIs around the mean of the differences (valid – invalid) for each visual field. The CI around the mean difference for the LVF excludes zero, indicating that initial x-velocity was significantly higher for valid compared to invalid trials in the LVF. In contrast, the CI around the mean difference for the UVF captures zero, indicating the difference between valid and invalid trials was not reliable in the UVF.

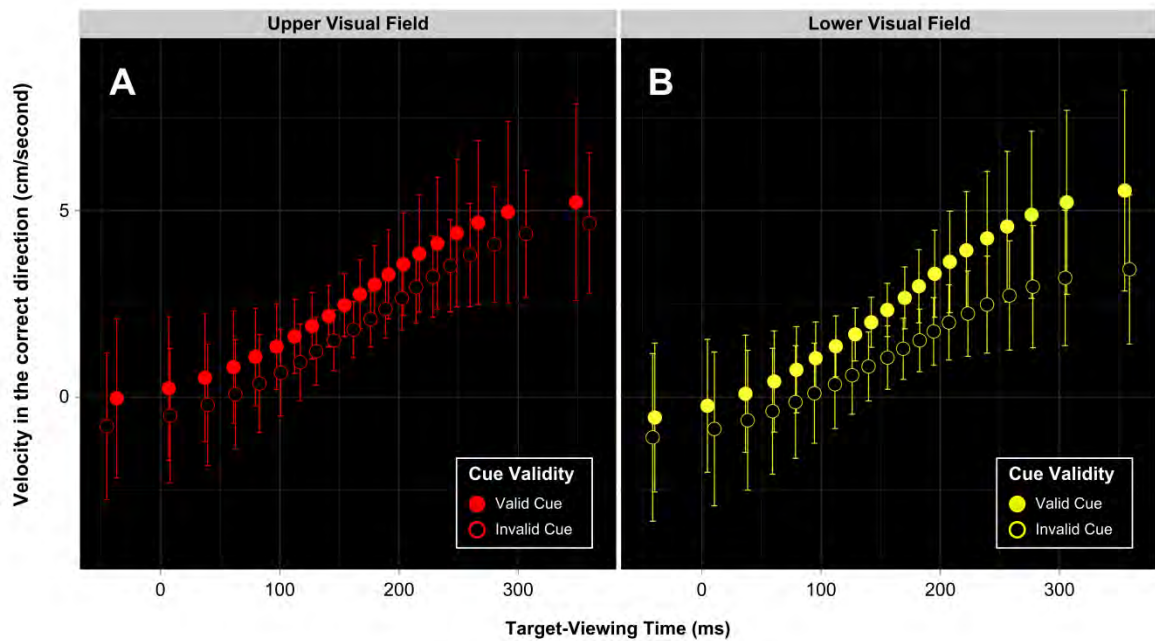
#### 4.4.2.2. *Analyses taking target-viewing time into account*

A unique advantage of the version of the Reach-to-Touch paradigm we have implemented here is that it enables the experimenter to examine not only the magnitude, but also the *timecourse*, of experimental effects. By requiring participants to initiate their classification movement in response to an auditory go-signal whose onset varied in time with respect to the target, we were able to examine how target-viewing time modulated our experimental effects reflected in initial  $x$ -velocity. The OPTA procedure discussed above (see also Finkbeiner et al., 2014; Quek & Finkbeiner, 2013; 2014) allowed us to take account of the relationship between target-viewing time and  $x$ -velocity by treating MIT latency as a covariate during data-smoothing. Figure 5 shows the strong effect target-viewing time (i.e., MIT latency) had on way the reaching response itself unfolded. Here we have grouped the MIT latencies into 20 quantiles, or semideciles (i.e., the shortest 5%, then the next shortest 5%, and so on – plotted in Figure 5a) and calculated the average  $x$ -velocity profile for each of these MIT Quantiles (plotted in Figure 5b). Looking at this figure, it is evident that the longer participants viewed the target before *initiating* their classification response (i.e., the greater their MIT latency was), the more efficient their reaching movement was when it began (i.e., the faster their finger headed in the correct direction).



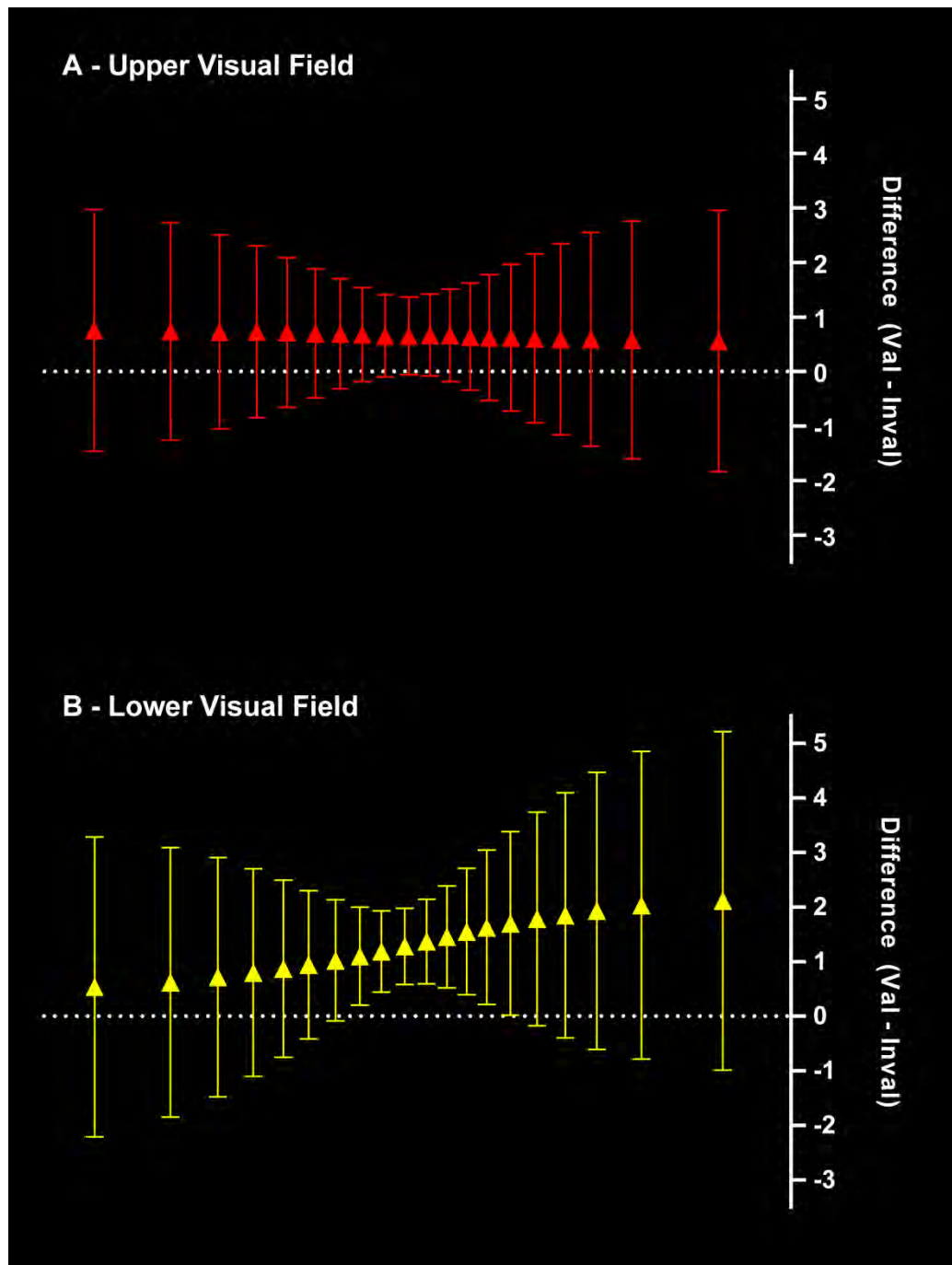
*Figure 5.* The effect of target-viewing time on initial x-velocity. (A) The MIT latency distribution. We grouped MIT latencies into 20 incremental quantiles (i.e., semideciles), represented here by the colour gradient (dark/red colours = short MIT latencies; yellow/pale colours = long MIT latencies). (B) Averaged x-velocity profiles as a function of MIT Quantile. It is clear that the x-velocity profiles of reaching trajectories initiated very soon after target onset (i.e., short MITs) tend to peak much later in time than those initiated after a long target-viewing time (i.e., long MITs). In other words, the longer participants view the target before commencing their reaching response, the more efficiently they are able to classify the target.

To analyse initial  $x$ -velocity *as a function of target-viewing time*, we conducted LMM analysis which included MIT Quantile as a factor. We began with a model which included random intercepts for Participant and random slopes between Participant and Quantile. We then used model comparison to confirm that the fixed effects of MIT Quantile,  $\chi^2(1) = 14.47, p < .001$ , Cue Validity,  $\chi^2(1) = 228.21, p < .001$ , and Visual Field,  $\chi^2(1) = 33.91, p < .001$ , all improved the model's fit. As may be seen in Figure 6, initial  $x$ -velocity tended to increase with MIT Quantile ( $b = 0.29, SE = 0.07, t = 4.12$ ). Initial  $x$ -velocity was also higher, on average, for validly cued trials than for invalidly cued trials ( $b = -0.57, SE = 0.14, t = -4.19$ ), and when the target appeared in the UVF compared to the LVF ( $b = -0.49, SE = 0.14, t = -3.58$ ). Regarding interactions, rather than evaluate each possible interaction given by our multifactorial design, we then restricted ourselves to examining the interactions which could reveal information about the *timecourse* of our experimental effects (i.e., those involving MIT Quantile). First, we verified that including the two-way interaction between Cue Validity  $\times$  MIT Quantile improved the model's fit,  $\chi^2(1) = 12.61, p < .001$ . In contrast, the interaction between Visual Field  $\times$  MIT Quantile did not improve the model,  $\chi^2(1) = 0.79, p = .375$ . Importantly, however, the critical three-way interaction between Cue Validity  $\times$  MIT Quantile  $\times$  Visual Field did significantly improved how well the model fit the data,  $\chi^2(1) = 40.20, p < .001$ .



*Figure 6.* Initial x-velocity (velocity averaged across the first 200ms of reaching movement) as a function of Visual Field, Cue Validity, and Target Viewing-Time (i.e. MIT Quantile). The slope of these profiles indicates that the longer participants view the target before commencing their reaching movement, the faster their finger heads in the correct direction during the reaching response itself. Initial x-velocity is higher on validly cued trials compared to invalidly cued trials. Error bars are 95% WSCIs – note that the overlap of these error bars should not be interpreted by eye (refer to Figure 7 for difference score plots).

To follow up the nature of this three-way interaction (depicted in Figure 6), for each Visual Field we computed a difference score (valid – invalid) at each MIT Quantile (see Figure 7). We then inspected each 95% confidence interval around this each difference score to see whether it included zero or not. Using this comparison method, we observed that the validity effect was reliable from the 8<sup>th</sup> to 14<sup>th</sup> MIT Quantile in the LVF, but not at any MIT Quantile in the UVF.



*Figure 7.* Difference scores (valid – invalid) for the (A) upper visual field and (B) lower visual field. Datapoints represent the size of the validity effect at each MIT Quantile, with a net validity effect of zero given by the dashed line. A 95% WSCI around the mean difference that excludes zero indicates initial x-velocity to be reliably higher for valid than invalid trials at that MIT Quantile. A comparison of the upper and lower panels shows that the validity effect in the UVF was not reliable at any MIT Quantile, whereas a reliable validity effect in the LVF was present from the 8<sup>th</sup> to the 14<sup>th</sup> MIT Quantile.

## 4.5. *General Discussion*

The present study set out to determine whether the upper visual field (UVF) advantage that has been observed for face-sex categorisation (Quek & Finkbeiner, 2014) would extend to the categorisation of nonface objects. To this end, we used the same task and response paradigm of Quek and Finkbeiner (2014) to examine how vertical hemifield would modulate participants' ability to categorise the sex of *human hands*. The results we report suggest that hand-sex categorisation enjoys a subtle UVF advantage similar to that we have shown for faces (albeit somewhat less robust) (Quek & Finkbeiner, 2014). Specifically, we observed no difference between the upper- and lower-hemifields in the accuracy or efficiency with which participants were able to classify the sex of visible hand targets. In contrast, hand-sex categorisation was strongly modulated by focussed spatial attention, in that participants' reaching responses were both more accurate and efficient when spatial attention was captured to the target's location. Critically, however, this effect of cue validity on categorisation efficiency was qualified by vertical hemifield, in that this manipulation of spatial attention had a larger and more reliable effect on the categorisation of targets presented in the LVF compared to the UVF. On the assumption that focussed spatial attention will provide the most aid to the least privileged locations (Carrasco et al., 2004; Carrasco & Yeshurun, 1998; Yeshurun & Carrasco, 1998; 1999), the finding that target classification responses were more sensitive to the effects of spatial attention in the LVF than the UVF suggests that sex-categorisation of human hands is less robust in the lower-hemifield. Conversely, the smaller and less reliable impact of spatial cueing on target categorisation in the UVF suggests the processes supporting hand-sex recognition are more efficient in this region of space.

Importantly, this differential benefit of attention on hand-sex categorisation in the UVF and LVF is highly consistent with our previous report that covert spatial attention

modulates sex-categorisation of *faces* differently in the upper- and lower-hemifields (Quek & Finkbeiner, 2014). In this previous work, we found that participants' ability to extract sex information carried by nonconscious faces depended on the allocation of spatial attention in the LVF, but not in the UVF. In conjunction with the present findings then, this suggests that the lower-hemifield's increased sensitivity to the effects of spatial attention in the context of sex-categorisation holds across two distinct stimulus types (i.e., faces and hands)<sup>2</sup>. That spatial attention improves the efficiency of processes supporting sex-categorisation in the LVF (but not the UVF) is particularly intriguing in light of previous work by Carrasco and colleagues which showed covert attention speeds information accrual to a greater degree at upper vertical meridian locations than lower (Carrasco et al., 2004). While the basis for these inconsistent findings is not yet clear, a potential explanation may lie in the different stimuli and tasks employed in these studies. Participants in Carrasco et al. (2004) performed an orientation discrimination task for Gabor stimuli presented in the periphery. A speed-accuracy tradeoff (SAT) analysis showed that information processing was significantly faster for LVF targets compared to UVF targets – a not unexpected finding given that performance in this task is based on contrast sensitivity, which is known to be advantaged at below-fixation locations (Cameron et al., 2002; Carrasco et al., 2001; T. Liu et al., 2006). As a result, their manipulation of focussed attention modulated the *rate* of information accrual to a greater extent in the disadvantaged UVF, where there was room to observe an attentional effect.

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<sup>2</sup> There is an important confound to be noted here. As can be seen in Figure 1, all the male stimuli were *right* hands, and all the female stimuli were *left* hands. As such, it is possible that participants performed the task by distinguishing left hands from right hands, rather than male hands from female hands. While less than ideal, it is important to note that this confound does not undermine the central finding of this study, namely that the upper visual field advantage extends to nonface stimuli. Regardless of *how* participants may have been categorising the hand stimuli, it remains the case that the magnitude of the cueing effect for these stimuli was larger in the lower visual field than the upper visual field.



In contrast to this relatively low-level visual discrimination task, sex-categorisation of hand and face images presumably depends on higher-level object recognition processes – processes which could very well exhibit a different pattern of vertical asymmetry effects in which the UVF is superior to the LVF. While on balance there have been very few investigations of vertical hemifield effects for higher level object stimuli, there is increasing evidence that face-processing is supported better in above-fixation locations compared to below (Coolican et al., 2008; Liu & Ioannides, 2010; Quek & Finkbeiner, 2014). Only a handful of studies, however, have alluded to similar findings for nonface stimuli such as novel objects (Chambers et al., 1999), letters (Schwartz & Kirsner, 1982), and words (Goldstein & Babkoff, 2001). As such, the present results represent an important contribution to the study of vertical asymmetry in higher level object recognition. Importantly, while these findings do support the notion that the upper-hemifield may enjoy an advantage for object recognition in general (i.e. not just for faces) (Previc, 1990), clearly more rigorous investigation of vertical hemifield effects for *nonhuman objects* is required before this claim can be made.

In conjunction with previous findings (e.g. Liu & Ioannides, 2010; Quek & Finkbeiner, 2014), the results presented here suggest that both face- and hand-sex recognition processes enjoy an advantage in the UVF compared to the LVF. What mechanism might account for this consistent pattern across two distinct stimulus types? We propose one such explanation here which centres on an upward bias in participants' voluntarily directed spatial attention. Specifically, a differential benefit of *exogenously captured* attention between the vertical hemifields could arise if participants' *voluntarily directed* attention was not distributed uniformly across the visual field. It could be the case, for example, that participants might have “favoured” the UVF (consciously or otherwise) by voluntarily directing spatial attention toward this hemifield even while maintaining central fixation. If this were case, then an exogenous manipulation of spatial attention

might well be expected to have little effect in the UVF, since processing in this region would already be facilitated by the allocation of voluntarily directed covert attention. Similarly, it stands to reason that if spatial attention were already directed to the UVF in some endogenous capacity, then an *exogenous* cue in the LVF should be especially effective in this relatively less attended region. Although a speculative possibility at this point, interestingly there is already some suggestion in the literature that there may indeed be an *upward bias* in spatial attention under certain conditions. For example, studies involving vertical line bisection (Bradshaw, Nettleton, Nathan, & Wilson, 1985; Drain & Reuter-Lorenz, 1996; van Vugt, Fransen, Cretten, & Paquier, 2000), object matching (Chambers et al., 1999), and mental scene representation (Drummond & Tlauka, 2012) suggest that participants may preferentially attend to the upper half of space over the lower half (but see Rezac & Dobkins, 2004). We have pursued the possibility of an upward bias in voluntarily directed spatial attention in subsequent series of experiments in which we manipulate the predictability of target location (Quek & Finkbeiner, in preparation).

#### **4.5.1. Conclusion**

The results reported here suggest that sex-categorisation of human hands exhibits a subtle upper-hemifield advantage. We found that the effects of spatial attention on this task were more pronounced in the LVF than in the UVF, just as we have reported previously for face-sex categorisation (Quek & Finkbeiner, 2014). Taken together, these data suggest that the UVF advantage for sex-categorisation extends to both face and nonface stimuli. As such, the findings provide empirical support for Previc's (1990) speculation that object recognition processes may enjoy an advantage in above-fixation locations. While it is not yet known what might underpin this superior performance in the UVF for sex-categorisation tasks, we have speculated here that a possible explanation could relate to an upward bias in participants' voluntarily directed spatial attention.



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THE UPPER-HEMIFIELD ADVANTAGE FOR

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## **5.1. Abstract**

Recent evidence suggests that face-processing may be more robust in the upper visual field (UVF) than in the lower visual field (LVF; see Quek & Finkbeiner, 2014). We asked whether this UVF advantage is due to an upward bias in participants' visuospatial attention. Participants classified the sex of a UVF or LVF target face that was preceded by a congruent or incongruent masked prime face. We manipulated spatial attention within subjects by varying the predictability of target location across sessions (UVF:LVF ratio of 50:50 on Day 1 and 20:80 on Day 2). When target location was unpredictable, priming emerged earlier in the UVF (~165ms) than the LVF (~195ms). This UVF advantage was reversed when targets were more likely to be presented in the LVF. Here priming arose earlier for LVF targets (~53ms) than UVF targets (~165ms). Critically, however, UVF primes were processed to the same degree regardless of whether spatial attention was diffuse (Day 1) or deployed elsewhere (Day 2). We conclude that, while voluntarily directed spatial attention is sufficient to modulate the processing of masked faces in the LVF, it is not sufficient to explain the UVF advantage for masked face processing.

*Keywords:* Attention, faces, vertical asymmetry, upper visual field, lower visual field

## 5.2. Introduction

Human visual perception is not uniform across the retinal field, but, rather, is characterised by perceptual asymmetries arising from the brain's preferential response to particular stimulus types at different retinal locations. Investigations of *vertical asymmetry* in visual perception have historically favoured the lower visual hemifield relative to the upper visual hemifield. For example, spatial resolution (Talgar & Carrasco, 2002) and contrast sensitivity (Carrasco, Penpeci-Talgar, & Cameron, 2001; Skrandies, 1987) are enhanced in the lower visual field (LVF) compared to the upper visual field (UVF), with this asymmetry being most pronounced at the vertical meridian (Carrasco et al., 2001; Talgar & Carrasco, 2002). Performance is also typically better in the LVF on tasks of hue discrimination (Levine & McAnany, 2005), perception of illusory contours (Rubin, Nakayama, & Shapley, 1996), motion processing (Amenedo, Pazo-Alvarez, & Cadaveira, 2007; Edwards & Badcock, 1993; Levine & McAnany, 2005), global processing (Christman, 1993), and perception of coordinate spatial relationships (Niebauer & Christman, 1998). There are select tasks which exhibit a UVF advantage, however, including visual search (Chaiken, Corbin, & Volkmann, 1962; Fecteau, Enns, & Kingstone, 2000; Previc & Blume, 1993; Previc & Naegle, 2001; Yund, Efron, & Nichols, 1990), local processing of hierarchical stimuli (Christman, 1993), perception of apparent distance (Levine & McAnany, 2005), and categorical judgements of position (Niebauer & Christman, 1998).

While such vertical asymmetries have been well-documented for a range of low-level perceptual stimuli, there has been comparatively less work done on the possibility of vertical hemifield differences in the perception of higher-level stimuli such as faces. Nevertheless, there is now a burgeoning body of work demonstrating an *upper-hemifield advantage* for tasks involving face stimuli. For example, Felisberti and McDermott (2013)



have reported that participants are able to recognise previously seen faces better when those faces are initially encoded in the upper-hemifield rather than the lower-hemifield. Within the neurophysiological literature, Liu and Ioannides (2010) have shown that magnetoencephalography (MEG) peaks elicited by emotional faces in regions such as the medial prefrontal cortex (MPFC), left fusiform face area (FFA), and left occipital face area (OFA) arise earlier for faces presented in the UVF compared to the LVF. Most recently, we used masked priming to show that the UVF exhibits a clear behavioural advantage for face-sex categorisation (Quek & Finkbeiner, 2014). Participants in our study categorised the sex of a target face by reaching to either the left or right edge of a computer monitor. The target face could appear in either the upper or lower-hemifield and was preceded by a nonconscious masked prime face of either the same or opposite sex (i.e., congruent or incongruent). Prime–target congruency had a strong effect on the efficiency of participants’ classification responses, in that the participants reached towards the correct response panel *faster* when the prime and target were associated with the same sex-categorisation response (i.e., the congruent condition). Critically however, we found that this masked congruence effect (MCE) arose earlier in time when the prime and target were presented in the UVF compared to the LVF. Moreover, we observed a differential benefit of attentional cueing between the vertical hemifields. Where the MCE elicited by faces in the lower-hemifield depended on a valid spatial cue (i.e., no priming without spatial attention), the emergence of the MCE in the upper-hemifield was unaffected by spatial cueing, suggesting that masked prime faces presented above-fixation were processed irrespective of spatial attention’s locus (see Finkbeiner & Palermo, 2009 for a similar finding with masked UVF primes).

Taken together, these studies suggest that the visual system is able to process face information *more efficiently* at above-fixation locations than at below-fixation locations. What is not yet established, however, is why this might be. One possibility, which we

explore in the present paper, is that the vertical asymmetry in face-processing is driven by an attentional bias towards the upper-hemifield. We are by no means the first to suggest that a tendency to divide attention unevenly across the visual field might explain vertical asymmetries in visual perception. Rezac and Dobkins (2004) proposed that an “attentional weighting” favouring the *lower hemifield* might explain the LVF advantage they observed using motion and orientation discrimination tasks. Interestingly, however, there is some suggestion that biases in spatial attention may depend on stimulus type. For example, studies involving vertical line bisection (Bradshaw, Nettleton, Nathan, & Wilson, 1985; Drain & Reuter-Lorenz, 1996; van Vugt, Fransen, Creten, & Paquier, 2000), object matching (Chambers, McBeath, Schiano, & Metz, 1999), and mental scene representation (Drummond & Tlauka, 2012) suggest an *upward* bias in spatial attention. Importantly for the present case, there are good reasons to think participants may be particularly prone to favouring the UVF in the context of face-perception, as this region of space often carries important face information during real world interactions. We tend to encounter human faces more frequently in the UVF, as this region corresponds to extrapersonal space. Eye gaze, a potent source of social information which guides adaptive behaviour (Hood, Willen, & Driver, 1998; Langton, Watt, & Bruce, 2000), is also typically contained within the top half of our visual field. Thus, we wondered whether participants in our previous study might have voluntarily attended to the upper hemifield even while maintaining central fixation. Such a bias would account for both the earlier emergence of priming in the UVF, and the lack of an exogenous cueing effect in this region of space (Quek & Finkbeiner, 2014).

If an upward bias in voluntarily directed spatial attention does indeed explain the UVF face-processing advantage, then manipulating participants’ endogenously oriented spatial attention *away* from the UVF (i.e., towards the LVF) should attenuate the UVF advantage evident in the timecourse of the MCE for faces. To investigate this possibility,

we adapted our previous design known to yield both robust masked priming effects and a clear UVF advantage for face-sex categorisation (Quek & Finkbeiner, 2014). We manipulated participants' endogenous attention to the vertical hemifields by varying the probability of UVF and LVF targets across days. On Day 1, the ratio of UVF targets to LVF targets was 50:50, such that target location was entirely unpredictable for participants. In contrast, on Day 2 targets appeared in the LVF on 80% of the trials (20:80 UVF to LVF ratio). We reasoned that participants would be sensitive to this increased probability of LVF targets and, after a period of learning, would voluntarily direct their spatial attention towards the lower-hemifield. Our predictions were as follows. For Day 1 (50:50 target location ratio), we expected the MCE would be superior for UVF prime–target pairs than for LVF prime–target pairs, replicating the UVF advantage for face-sex categorisation we have shown previously (Quek & Finkbeiner, 2014). For Day 2 (20:80 target location ratio), we predicted that masked face-processing below-fixation would be facilitated by participants voluntarily directing spatial attention towards this hemifield. That is, we expected the priming effect for the LVF would be equivalent to, or perhaps even superior to, the UVF priming effect from the same day. The question of critical interest was what impact our manipulation of endogenous attention on Day 2 would have on the priming effect for the *UVF*. If the documented UVF advantage for subliminal face-processing should be attributed to an upward bias in participants' spatial attention, then the MCE elicited by UVF faces should suffer when participants direct their spatial attention to a different location. That is, in the measure to which the UVF advantage is due to focused spatial attention, then the redeployment of that focused spatial attention to the LVF should yield both increased performance in the LVF and a cost to the priming effect in the UVF.

Before undertaking this planned design, however, we wanted to first take account of the fact that our manipulation of target location probability across days would not allow us to counterbalance the order of conditions across participants. All participants would

need to complete the conditions in a fixed order (50:50 on Day 1, 20:80 on Day 2), to ensure that the location probability learned during the 20:80 condition would not carry over and influence participants' approach to the 50:50 version of the task. Consequently, we are faced with the possibility of an artefact in this design: namely, participants would be highly practiced during the 20:80 condition on Day 2, and less so during the 50:50 condition on Day 1. Thus, if we were to observe the predicted enhancement of the priming effect in the 20:80 condition on Day 2, one could argue that this was due to participants' performance simply improving over time as opposed to the redeployment of spatial attention. To rule out this possible explanation of our predicted results before embarking on the experiment proper, we ran an initial experiment across two days in which the target location probability was held constant at 50:50. If the properties of the masked congruence priming in the LVF are sensitive to the effects of practice, then we would expect to see differences in either the magnitude or onset of the MCE (or both) across days. To anticipate our results of this initial control experiment, the MCE did not vary across days in either hemifield, suggesting this index of face-processing to be robust to the effects of practice.

### **5.3. Experiment 1**

Our goal in Experiment 1 was to determine whether the masked congruence priming effect (particularly in the LVF), would improve as a function of exposure to the task. Participants attended two testing sessions across a three day period; the task on each day was identical: Classify the sex of the target face by reaching out to touch a response panel at the left or right edge of the screen. We used a fully crossed factorial design with the factors Visual Field (UVF vs. LVF) and Prime Type (congruent vs. incongruent). Importantly, this design was identical to the one planned for Experiment 2 (e.g. same number of trials, etc.), save that the predictability of the target's location did not vary across days. That is, the ratio of UVF to LVF targets was 50:50 on both Day 1 and Day 2. If the MCE is indeed sensitive to the effects of practice, then we should observe a stronger priming effect on Day 2 compared to Day 1.

#### **5.3.1. Experiment 1 Methods**

##### **5.3.1.1. Participants**

A group of 14 individuals (seven males) gave informed consent to participate in Experiment 1 for financial compensation. All participants had normal or corrected-to-normal vision, and were identified as strong right handers using the Edinburgh Handedness Inventory (Oldfield, 1971). The mean age was 26.5 years.

##### **5.3.1.2. Stimuli & Apparatus**

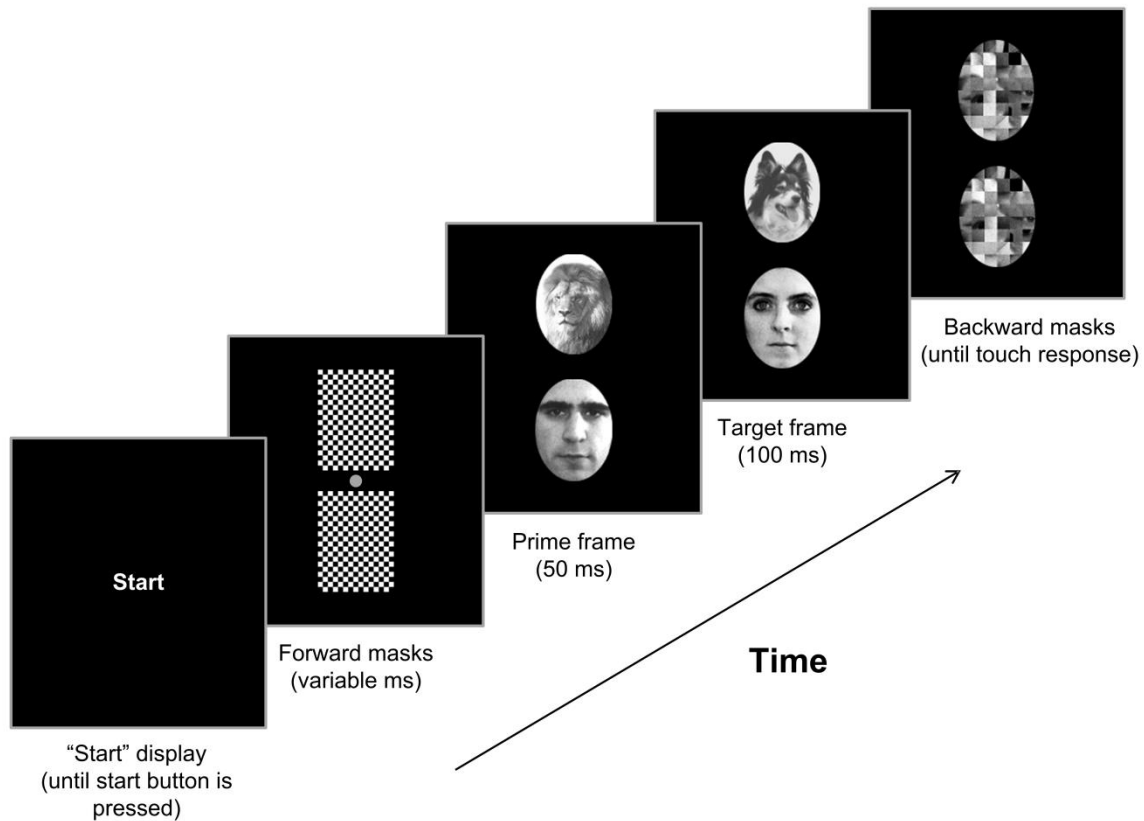
Targets were five neutral faces of each sex drawn from the Psychological Image Collection at Stirling database (PICS, <http://pics.psych.stir.ac.uk/>), cropped to exclude the facial contour. No face contained obvious sex indicators (e.g. facial hair). Distractors were 10 animal images presented within a similar cropped oval, one of which was selected at random on each trial. We used the SHINE toolbox written for Matlab to adjust the 10

target and 10 distractor items so their mean luminance and contrast values were comparable (Willenbockel, Sadr, Fiset, Horne, Hosselin, & Tanaka, 2010). We then used the same procedure to prepare an additional two faces (one male, one female) and two animal distractors to serve as novel masked primes and masked foils – stimuli which never appeared under unmasked conditions. The backward mask on each trial was randomly selected from a group of 10 possible scrambled face images of the same mean luminance and contrast. All stimuli were 75×100 pixels and subtended 3.44×4.58 degrees of visual angle from a viewing distance of 65cm. Response panels marked “M” and “F” remained at the left and right edge of the screen throughout the trial; we counterbalanced the order of these positions across participants. To record the participant’s reaching trajectories, we fitted the their right hand with two light emitting diode (LED) markers and sampled the position of these markers every 5ms using an OptotrakCertus® motion capture system (sample rate was 200Hz).

### **5.3.1.3. Procedure & Design**

Participants completed the two separate testing sessions within a three day time period. The testing procedure was identical on both days. The participant sat in a dark room before a table with a touchscreen monitor fixed 50cm from the front edge. Figure 1 presents the visual trial structure. Each trial frame consisted of two 75×100 pixel panels, vertically displaced around a central fixation dot. We instructed participants to maintain their fixation on this central dot throughout the trial and reminded them of this between each block of trials. The trial commenced when the participant used their right index finger to depress a “start button” aligned with the body midline at the front of the table. The first frame contained identical chequerboard forward masks in each panel. After a variable duration, the prime face appeared in either the upper or lower panel and was accompanied by an animal foil in the opposite location. After 50ms, the target face replaced the prime face at the same location and was accompanied by a randomly selected animal distractor in

the opposite panel. After 100ms, identical randomly selected backward masks onset in both panels and remained onscreen until the participant completed their classification by touching one of the two response panels located at the left and right. On each trial, the prime–target pair could appear in either the UVF or LVF with equal probability (50:50 UVF to LVF target location ratio). The prime was either the same sex or opposite sex as the target (i.e., congruent or incongruent). Participants completed 80 practice trials followed by 240 experimental trials on Day 1; and 40 practice trials followed by 600 experimental trials on Day 2. All practice trials were discarded from later analyses.



*Figure 1.* Visual trial structure for Experiments 1 & 2. Each trial frame consisted of two 75×100 pixel vertically displaced panels. The trial began when the participant depressed a start button aligned with the body midline at the front edge of the testing table. Participants saw an initial fixation frame containing two identical chequerboard masks and a central dot they were required to fixate on. After a variable duration, the prime face appeared in either the top or bottom panel for 50ms, accompanied by an opposite animal foil. The subsequent frame contained the to-be-categorised target face in the same location as the prime, with another animal distractor in the opposite panel. After 100ms, backward masks onset in both panels and remained onscreen until the participant completed their classification response.



On each trial, the participant had over three seconds to freely adjust their reaching trajectory and finalise their classification of the target by touching either the left or right response panel. However, although participants could complete the reaching movement in their own time, we imposed strict parameters regarding when they should *initiate* the movement. We instructed participants to begin their reaching movement on each trial in response to an auditory go-signal – the third tone in a series of three ascending beeps heard on every trial (see Finkbeiner, Coltheart, & Coltheart, 2014; Quek & Finkbeiner, 2014). The position of the auditory go-signal varied in time with respect to target onset, such that on any trial the third beep could occur at one of five randomly selected durations following target onset (0ms, 75ms, 150ms, 225ms, or 300ms). We defined Movement Initiation Time (MIT Latency) as the time in milliseconds from target onset until the finger’s velocity reached 10cm/second. We allowed MIT latencies up to 100ms before and 200ms after the beep signal. If the participant began their reaching movement outside this critical window, they received negative auditory (a loud buzz) and visual feedback (e.g. “Too Early!”), and the trial was aborted and cached for re-presentation at the end of the block. Trials with response-window failures during the re-presentation stage were removed from all subsequent analyses (11.37% of all trials).

To assess the visibility of the masked primes, participants completed a two alternative forced-choice (2AFC) prime detection task at the conclusion of the Day 2 testing session. The prime-visibility task included 160 trials which were identical to those used in the experiment proper, save that after reaching out to classify the target face, participants saw two faces (the real prime and a lure) and had to indicate which of them had been the prime on that trial. This prime-identification response was untimed, and position of the real prime and lure was counterbalanced across trials. Importantly, we instructed participants to maintain the same strategy for these prime-identification trials as they used in the experiment proper.

#### 5.3.1.4. Analysis Methods

**Data preparation.** To prepare the reaching trajectories for analysis, we selected the 450 *xyz* samples between the points corresponding to 100ms *before* movement onset, and 2150ms after movement onset<sup>1</sup>. At each sample within this epoch, we calculated *x*-velocity – a signed value which reflects the finger’s velocity along the *x*-axis. Because participants indicate their sex-categorisation decision along this left-right dimension (e.g. left for male; right for female), *x*-velocity at any given sample represents the finger’s velocity *in the correct direction*. Positive *x*-velocity values indicate the finger is moving towards the correct response panel, and negative *x*-velocity values indicate that the finger is heading *away* from the correct response panel (i.e., in the incorrect direction). We smoothed the *x*-velocity profiles using a modified version of the Orthogonal Polynomial Trend Analysis (OPTA) procedure (Karayanidis, Provost, Brown, Paton, & Heathcote, 2011; Woestenburg, Verbaten, & Slangen, 1983), the details of which have been extensively reported elsewhere (Finkbeiner, Coltheart, & Coltheart, 2014; Quek & Finkbeiner, 2013; 2014). As a final step, we averaged across the initial 300ms of the reaching movement to produce a single representative value for each trial termed initial *x*-velocity. We limited our dependent measure to the initial segment of the trajectory because this initial portion best reveals the motor plan that participants had formulated just prior to movement initiation. This is important since we are interested in comparing the way in which participants’ responses develop with stimulus-viewing time across different experimental manipulations. In the present case, the masked congruence effect (MCE) is reflected in higher initial *x*-velocities on congruent trials than incongruent trials. This

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<sup>1</sup> We included the 100ms leading up to movement onset to ensure that we considered the very start of the reaching movement on each trial. For instances in which the participant’s reaching movement concluded sooner than 2150ms after movement onset, we simply repeated the *xyz* coordinates from the final sample to make up the full number of samples for that trial.

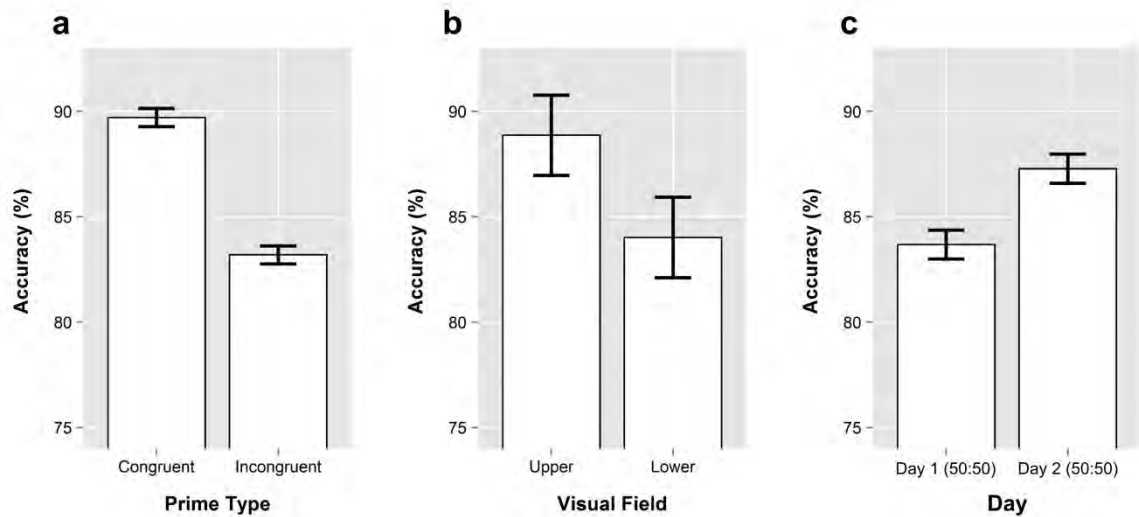
pattern is analogous to the MCE reflected in RT data (e.g. Finkbeiner & Palermo, 2009; Naccache, Blandin, & Dehaene, 2002), in that just as participants in button-press priming studies tend to press the correct button faster on congruent trials than incongruent, here participants move in the correct direction faster when the prime and target are associated with the same classification response.

***Statistical Analyses.*** We analysed all data using custom software written in R ([www.r-project.org](http://www.r-project.org)). We implemented linear mixed-effects modelling (LMM, cf. Baayen, Davidson, & Bates, 2008; Bates, 2005) using the lmer4 package (<http://lme4.r-forge.r-project.org>, Bates, Maechler, & Bolker, 2011). We evaluated the reliability of each effect of interest using an incremental model comparison procedure in which we used goodness-of-fit statistics (AIC, BIC, and Log Likelihood values, see Akaike, 1974; Schwarz, 1978) to determine which of two models fit our data better – a model which included the term under inspection, or the same model without this term. For each comparison, we selected the model which a) minimised AIC and BIC, and b) maximised the Log Likelihood. Below we report the results of this Likelihood ratio test and, where appropriate, also report the coefficients, standard errors (SE), and *t*-values for terms included in the final model selected. Our criterion for significance for individual fixed effects was an absolute *t* ratio of 2.0, as per Kliegl, Masson, and Richter (2010). Although the degrees of freedom are not known exactly in LMM, the very large number of observations in the datasets used here and elsewhere mean that the *t* distribution converges to the normal distribution. Thus, the criterion cutoff of two SEs corresponds well to the .05 significance criterion (see Finkbeiner et al., 2014; Kliegl et al, 2010; Masson & Kliegl, 2013; Quek & Finkbeiner, 2013; 2014).

### 5.3.2. Experiment 1 Results

#### 5.3.2.1. Accuracy

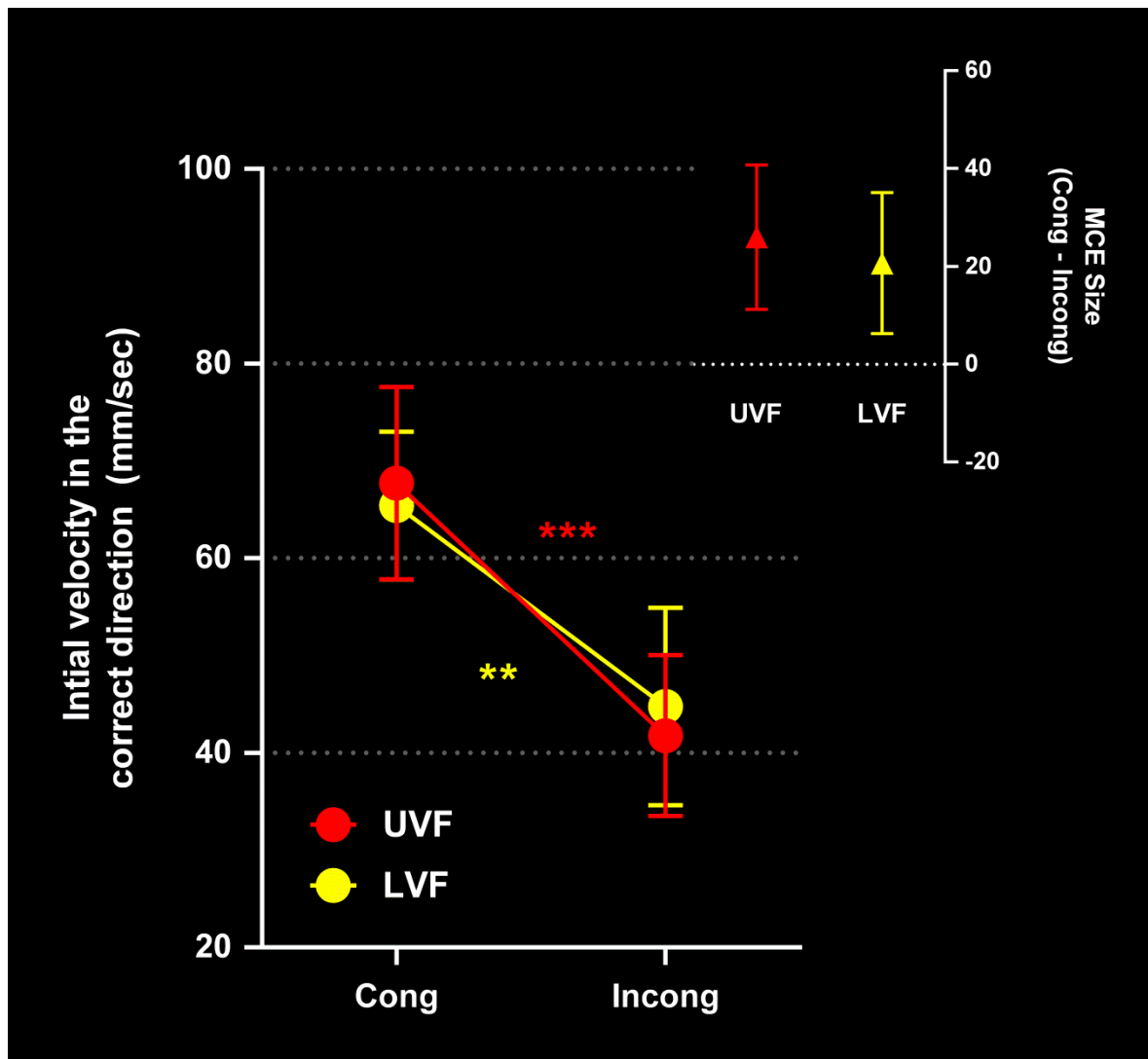
The mean classification accuracy for Experiment 1 was 85.5%. We used LMM to confirm that a model including random slopes between Participant and Prime Type fit the binomial accuracy data better than a model including only random intercepts for Participant,  $\chi^2(2) = 155.82, p < .001$ . We then verified that including the fixed effects of Prime Type,  $\chi^2(1) = 18.27, p < .001$ , Visual Field,  $\chi^2(1) = 72.74, p < .001$ , and Experiment,  $\chi^2(1) = 28.80, p < .001$  also improved the model's fit. As may be seen in Figure 2a, there was a strong MCE reflected in classification accuracy, in that participants were more likely to classify the target's sex correctly on congruent trials as compared to incongruent trials ( $b = -0.74, SE = 0.12, z = -6.06, p < .001$ ). Target classification was also more likely to be accurate for UVF trials than for LVF trials ( $b = -0.43, SE = 0.05, z = -8.48, p < .001$ ) (see Figure 2b), and on Day 2 compared to Day 1 ( $b = 0.31, SE = 0.06, z = 5.45, p < .001$ ) (see Figure 2c). Importantly, none of the two- or three-way interactions between these three experimental factors improved the model's fit ( $p > .05$  in all model comparison cases), indicating the best model of the accuracy data to be an additive one.



*Figure 2.* Experiment 1 accuracy rates as a function of a) Prime Type, b) Visual Field, and c) Day. Target classification was significantly more likely to be accurate when primes were congruent compared to incongruent; when the prime–target pair appeared in the UVF compared to the LVF; and on Day 2 compared to Day 1. No interactions between these factors were reliable. Most importantly for our purposes here, our index of nonconscious face-processing – the masked congruence effect (MCE) – did not vary significantly across the testing days. Error bars are within-subjects standard error.

### 5.3.2.2. Initial x-velocity

The analysis procedure described above yielded 11,940 initial  $x$  -velocity values from 14 participants. We used LMM to firstly compare a model with random intercepts for Participant with one that also included random slopes between Prime Type and Participant,  $\chi^2(2) = 1544.99, p < .001$ . Including the fixed effect of Prime Type significantly improved the model's fit,  $\chi^2(1) = 10.13, p < .005$ . Just as with the accuracy data, there was a strong MCE evident in initial  $x$ -velocity, which was higher on average for congruent trials than incongruent trials ( $b = -25.09, SE = 6.57, t = -3.82$ ). While the fixed effect of Visual Field did not significantly improve the fit of the model,  $\chi^2(1) = 0.40, p = .527$ , we nonetheless retained this term in the model so as to inspect its interaction with other factors. This effect was reliable in the context of the final fitted model, however, with initial  $x$ -velocity observed to be higher on UVF trials than on LVF trials ( $b = -8.41, SE = 1.87, t = -4.50$ ). Including the fixed effect of Day improved the model,  $\chi^2(1) = 91.53, p < .001$ , with the final estimates indicating that initial  $x$ -velocity was higher on Day 1 than on Day 2 ( $b = -12.13, SE = 1.63, t = -7.46$ ). Importantly for our purposes here, the interaction between Prime Type and Day did not improve the fit of the model,  $\chi^2(1) = 0.27, p = .603$ , suggesting that the MCE evident in the initial stages of participants' reaching responses did not change as a function of exposure to the task. In contrast, there was a significant interaction between Prime Type and Visual Field,  $\chi^2(1) = 9.60, p < .01$ . We followed this up by conducting a paired  $t$ -test between the congruent and incongruent conditions in each Visual Field ( $p$  values corrected using the False Discovery Rate, FDR). As can be seen in Figure 3, there was a significant MCE in both the upper-hemifield ( $t(13) = 3.80, p < .005$ , *Pearson's*  $r = .73$ ) and lower-hemifield ( $t(13) = 3.10, p < .01$ , *Pearson's*  $r = .65$ ). However, as the MCE above-fixation was *larger* than the MCE below-fixation (25.97 mm/second vs. 20.65 mm/second).



*Figure 3.* Initial x-velocity for Experiment 1 as a function of Visual Field and Prime Type. Initial x-velocity reflects the finger's velocity in the correct direction during the initial 300ms of the reaching movement. Although the MCE (evident in the slope of the lines) was reliable in both the UVF and LVF, the priming effect was larger in the UVF (red) than in the LVF (yellow). \* $p < .05$ ; \*\* $p < .01$ ; \*\*\* $p < .005$ ; \*\*\*\* $p < .001$  (two tailed paired  $t$ -tests, FDR corrected). Error bars are 95% within-subjects confidence intervals (WSCIs). **Inset:** Since there is no rule-of-eye for interpreting overlap between WSCIs (see Cumming & Finch, 2005), we here depict the 95% WSCI around the mean of the congruent – incongruent difference scores for each of the vertical hemifields. Note that the 95% WSCI for each visual field excludes zero, indicating there was a reliable MCE in both hemifields.

We also observed a significant Visual Field by Day interaction,  $\chi^2(1) = 13.40, p < .001$ . On Day 1, initial  $x$ -velocity was numerically higher for the UVF than the LVF. The reverse pattern was true on Day 2, however follow up paired  $t$ -tests (FDR corrected) of the Visual Field effect on each Day indicated that neither difference was statistically reliable ( $t < 1$  in both cases). Our final model comparison verified that including the 3-way interaction between Prime Type, Visual Field, and Day did *not* improve the model's fit of the initial  $x$ -velocity data,  $\chi^2(1) = 2.20, p = .138$  (see Figure 4). As can clearly be seen in Figure 4C, the magnitude of MCE did not change from Day 1 to Day 2 for either the UVF or LVF. This suggests that participants' ability to extract sex-information from the masked prime faces *did not* improve as a function of exposure to the task (i.e., practice).

#### **5.3.2.3. Prime Detection**

To assess prime visibility, we used the 2AFC prime detection data to calculate a hit rate, false alarm rate, and  $d'$  value for each participant. The mean  $d'$  value was 0.07. A one sample  $t$ -test confirmed that this was not significantly different from zero ( $t(13) = 0.86, p = .404, \text{Pearson's } r = .23$ ), suggesting the masked primes in Experiment 1 were below the level of conscious awareness.



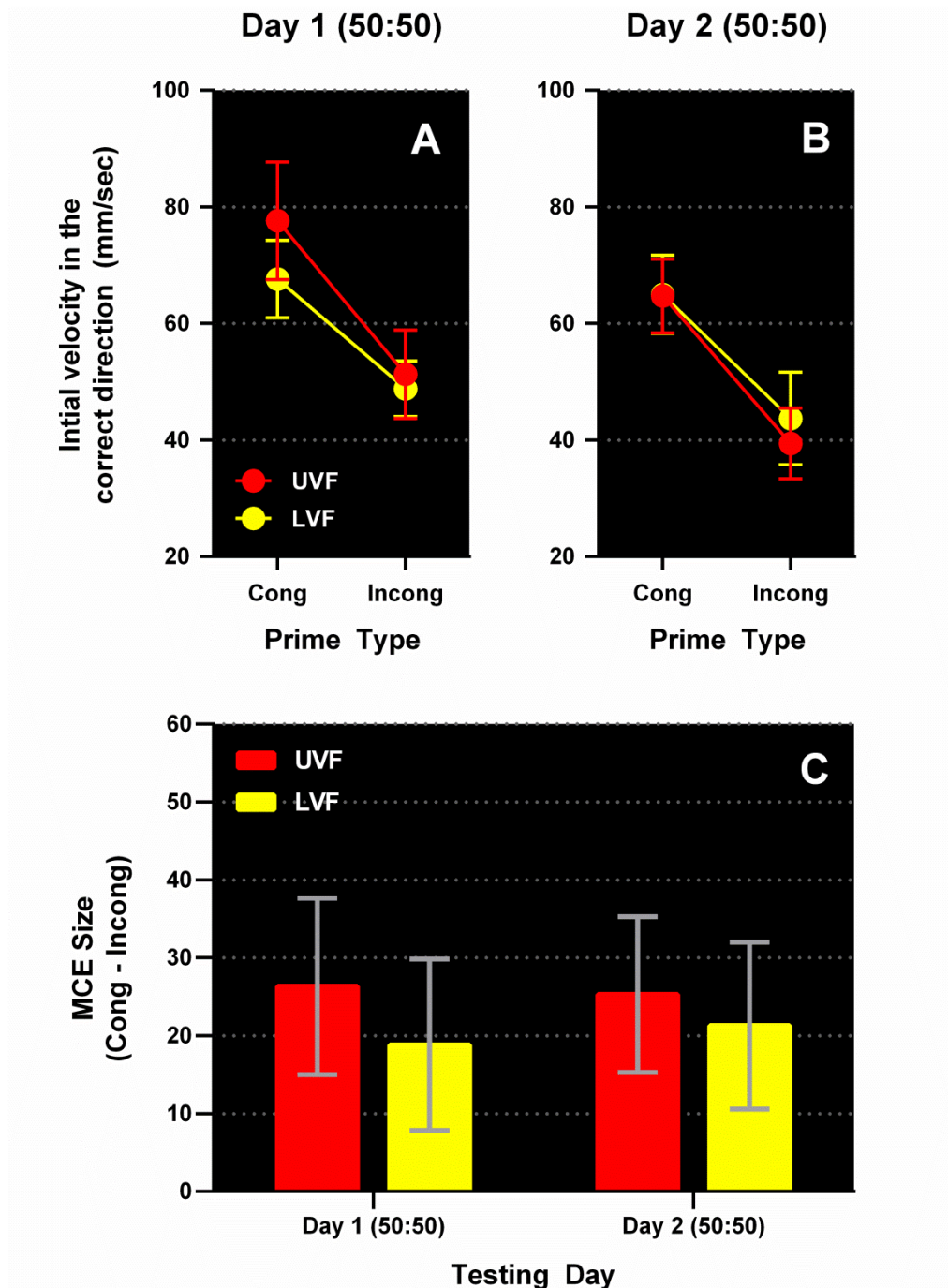


Figure 4. (A & B) Experiment 1 initial x-velocities by Prime Type, Visual Field, and Day. The ratio of UVF:LVF targets was 50:50 on both days. The 3-way interaction here was *not* significant, suggesting the priming effect in each Visual Field was similar across days. (C) The size of the MCE (congruent – incongruent) for the UVF and LVF on each testing Day. Note that all 95% WSCIs exclude zero, indicating there was a reliable MCE in all conditions. The magnitude of the MCE in each visual field was constant from Day 1 to Day 2. Error bars are 95% WSCIs, thus inter-bar overlap should not be interpreted by eye (see Cummings & Finch, 2005).

### 5.3.3. Experiment 1 Discussion

We observed a strong masked congruence effect (MCE) in Experiment 1, in that participant's classification reaching movements were both more accurate and more efficient for targets preceded by congruent primes compared to incongruent primes (i.e., same rather than opposite sex). We also found clear evidence of an upper visual field (UVF) advantage for face-sex classification, in that participants were more accurate in categorising the sex of UVF targets compared to LVF targets. Moreover, although both UVF and LVF prime–target pairs yielded a significant MCE in participants' reaching data, the magnitude of this priming effect was *reliably larger in the UVF*. This suggests participants were able to process the sex information carried by the masked prime more efficiently when the prime appeared in the upper-hemifield compared to the lower-hemifield. Taken together, these results provide strong evidence for the emerging position in the literature that face-processing, and in particular face-sex categorisation, is superior in the upper-hemifield relative to the lower-hemifield (Liu & Ioannides, 2010; Quek & Finkbeiner, 2014). In addition, and importantly for Experiment 2, we also found that the priming effect reflected in both participants' accuracy and initial reaching movements did not differ significantly between testing days for either hemifield. This suggests that participants' ability to extract the task-relevant sex information from masked faces did not improve as a function of exposure to the task (i.e., from the first to the second testing day).

## 5.4. Experiment 2

Armed with the knowledge that the MCE in our paradigm was not sensitive to the effects of practice across days, we were free to pursue the principle goal of the present study – to determine how voluntarily directed spatial attention would modulate the effect of vertical hemifield on masked face priming. Experiment 2 used an identical design to Experiment 1, save that here we manipulated target location predictability across days. On Day 1, the ratio of UVF to LVF targets was 50:50, such that target location was unpredictable to participants (just as in Experiment 1). On Day 2, however, we increased the ratio of LVF to UVF targets so that the target appeared below-fixation on 80% of trials. We reasoned that participants would be sensitive to this increased probability of LVF targets and, after a period of learning, would direct their attention to the lower-hemifield as a consequence. We predicted that covertly attending to the LVF would facilitate the priming effect in this hemifield, resulting in a stronger MCE for the LVF on Day 2 than on Day 1. Because we had already confirmed that the MCE in the LVF did not improve with task exposure in Experiment 1, we felt we would be able to attribute any improvement in the MCE in the LVF across testing days to our manipulation of target location probability, rather than simple practice effects. Of critical interest was what impact this manipulation would have on participants' ability to process masked prime faces *above-fixation*. If the UVF advantage we and others have observed for face-processing really is underpinned by an attentional bias towards the upper-hemifield, then a redeployment of spatial attention to the LVF should yield an enhanced MCE in the LVF and a diminished MCE in the UVF.

### **5.4.1. Experiment 2 Methods**

#### **5.4.1.1. Participants**

We recruited a different group of 16 Macquarie University undergraduate students (seven males) to participate in Experiment 2 for course credit. All participants had normal or corrected-to-normal vision, and were identified as strong right handers using the Edinburgh Handedness Inventory (Oldfield, 1971). The mean age was 18.81 years.

#### **5.4.1.2. Procedure & Design**

We used the same stimuli, apparatus, trial structure, and testing procedure as described for Experiment 1. As before, we required participants to initiate their reaching movement in response to an auditory go-signal (the third beep in a series) which could occur either 0ms, 75ms, 150ms, 225ms, or 300ms after target onset. Participants completed 240 trials on Day 1 in which the prime and target faces appeared with equal probability (50%) in either the upper or lower panel. On Day 2, we included the same number of UVF trials as on Day 1 (i.e., 60 UVF-congruent, 60 UVF-incongruent), and included 480 LVF trials to yield a 20:80 ratio of UVF to LVF trials. There were 80 practice trials excluded from later analyses on Day 1, and 40 on Day 2. We assessed prime visibility at the end of the experiment proper on Day 2 using the same 2AFC task described for Experiment 1, in which we maintained the 20:80 UVF to LVF target ratio.

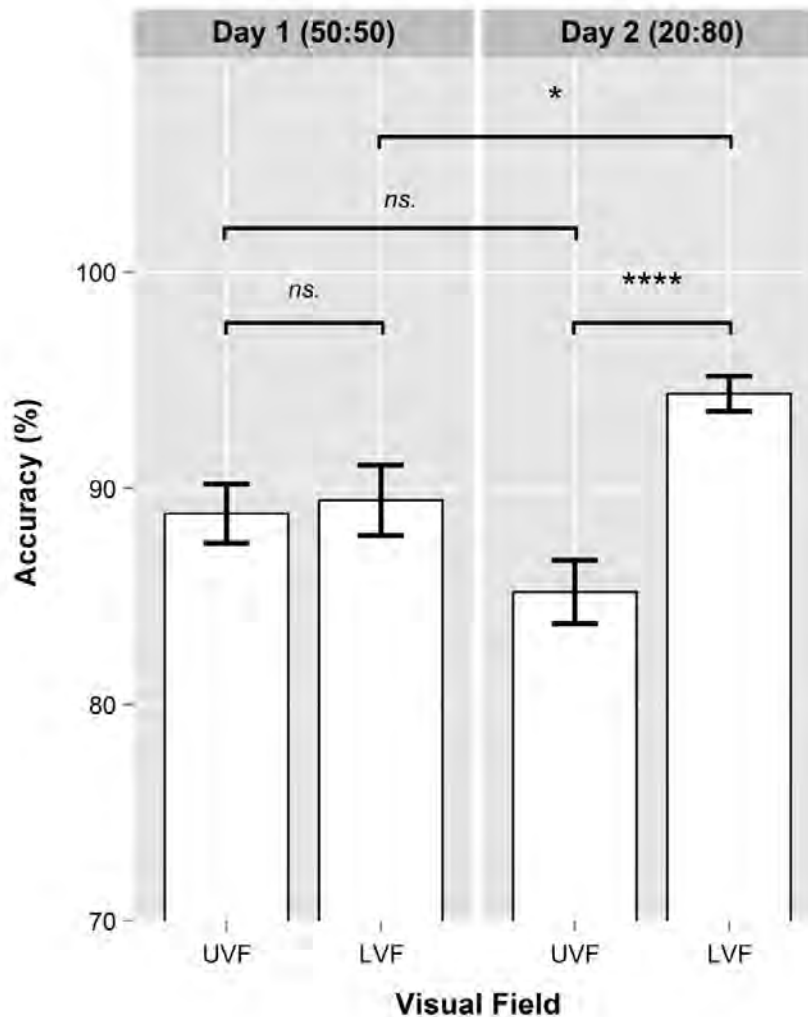
### **5.4.2. Experiment 2 Results**

#### **5.4.2.1. Accuracy**

Prior to analysis we removed all trials on which movement error occurred (11.81% of trials). Mean classification accuracy following this was 89.45%. We then used LMM to verify that a model including random intercepts for each Participant, as well as

random slopes between Participant and Prime Type, fit the binomial accuracy data better than a model with only random intercepts for each participant,  $\chi^2(2) = 414.38, p < .001$ . Including the fixed effect of Day significantly improved the model,  $\chi^2(1) = 40.96, p < .001$ , in that there was a greater likelihood of participants classifying the target incorrectly on Day 2 than on Day 1 ( $b = -0.35, SE = 0.10, z = -3.47, p < .001$ ). The inclusion of Prime Type also improved the model,  $\chi^2(1) = 27.22, p < .001$ , with a clear MCE reflected in participants' accuracy scores. Participants were significantly *less likely* to classify the target's sex correctly on incongruent trials ( $M_{\text{INCONG}} = 86.95\%$ ) compared to congruent trials ( $M_{\text{CONG}} = 96.22\%$ ) ( $b = -1.58, SE = 0.19, z = -8.32, p < .001$ ). As in Experiment 1, the interaction between Prime Type and Day did not improve the model,  $\chi^2(1) = 0.07, p = .786$ , indicating that the effect of Prime Type did not vary from Day 1 to Day 2. Visual Field improved the model,  $\chi^2(1) = 107.01, p < .001$ , however, unlike in Experiment 1, this effect was qualified by testing Day,  $\chi^2(1) = 59.78, p < .001$ . To follow up this two-way interaction we ran FDR corrected paired *t*-tests between the UVF and LVF accuracy rates, separately for Day 1 and Day 2. As can be seen in Figure 5, when target location was unpredictable (i.e., Day 1), participants' classification accuracy was comparable between the upper ( $M_{\text{UPPER}} = 88.84\%$ ) and lower visual fields ( $M_{\text{LOWER}} = 89.43\%$ ),  $t(15) = -0.24, p = .814, \text{Pearson's } r = .06$ . In contrast, when participants could reliably expect the target to appear in the LVF (i.e., Day 2), classification accuracy was significantly higher in this region compared to the upper-hemifield ( $M_{\text{LOWER}} = 94.38\%$  vs.  $M_{\text{UPPER}} = 85.24\%$ ),  $t(15) = -5.16, p < .001, \text{Pearson's } r = .80$ . To verify that the increased accuracy in the LVF on Day 2 did *not* come at a cost to target classification in the UVF, we then broke the interaction down the opposite way. FDR corrected paired *t*-tests of the effect of Day for each Visual Field indicated that accuracy in the UVF was comparable between Day 1 and Day 2,  $t(15) = 1.67, p = .155, \text{Pearson's } r = .40$  ( $M_{\text{Day1}} = 88.84\%$  vs.  $M_{\text{Day2}} = 85.24\%$ ). In

contrast, there was a significant improvement in accuracy for the LVF from Day 1 to Day 2,  $t(15) = -2.68, p = .017$ , *Pearson's*  $r = .57$  ( $M_{\text{Day1}} = 89.43\%$  vs.  $M_{\text{Day2}} = 94.38\%$ ).



*Figure 5.* Mean accuracy rates for Experiment 2 as a function of Visual Field and Day. When the ratio of UVF to LVF targets was 50:50 (Day 1), accuracy rates were comparable between the upper and lower-hemifields. In contrast, when the UVF to LVF location ratio was 20:80 (Day 2), accuracy was significantly higher in the LVF than in the UVF. This suggests our target location predictability manipulation was successful in encouraging participants to voluntarily direct spatial attention to the LVF on Day 2. Error bars are within-subjects standard error. \* $p < .05$ ; \*\* $p < .01$ ; \*\*\* $p < .005$ ; \*\*\*\* $p < .001$  (two tailed paired  $t$ - tests, FDR corrected).

#### 5.4.2.2. Initial x-velocity

*Analyses collapsed across target-viewing time.* Our analysis procedure for Experiment 2 initial x-velocity yielded 11,725 values from 16 participants. Just as in Experiment 1, we began by examining conditional mean initial x-velocity averaged *across* target-viewing times. First, we verified that a model including both random intercepts for Participant and random slopes between Participant and Prime Type fit the data better than a model with only random intercepts  $\chi^2(2) = 2354.22, p < .001$ . There was a significant fixed effect of Prime Type,  $\chi^2(1) = 13.97, p < .001$ , in that initial x-velocity was higher for congruent trials compared to incongruent trials ( $b = -27.82, SE = 7.33, t = -3.80$ ). The fixed effects of Visual Field,  $\chi^2(1) = 83.00, p < .001$ , and Day,  $\chi^2(1) = 243.48, p < .001$ , also improved the model's fit, with initial x-velocity being higher on average for UVF trials compared to LVF trials ( $b = -3.05, SE = 2.08, t = -1.46$ ), and on Day 2 compared to Day 1 ( $b = 14.67, SE = 2.10, t = 7.00$ ). Regarding 2-way interactions, including the Prime Type  $\times$  Visual Field interaction did not improve the model's fit,  $\chi^2(1) = 1.82, p = .177$ , however both the Prime Type  $\times$  Day and Visual Field  $\times$  Day interactions did,  $\chi^2(1) = 42.29, p < .001$  and  $\chi^2(1) = 5.81, p < .05$  respectively. Critically, and in contrast to Experiment 1, including the 3-way interaction between Prime Type, Visual Field, and Day also significantly improved the model of Experiment 2 initial x-velocities.

We followed up the nature of this significant 3-way interaction (presented in Figure 7) by modelling the data separately for the upper- and lower-hemifields. The model for the UVF was characterised by a significant fixed effect of Prime Type,  $\chi^2(1) = 7.51, p < .01$ , in which initial x-velocity was higher on congruent compared to incongruent trials ( $b = -27.67, SE = 10.51, t = -2.63$ ). There was also a significant fixed effect of Day,  $\chi^2(1) = 69.01, p < .001$ , in that initial x-velocity for the UVF was higher on Day 2 than on Day 1 ( $b = 15.58, SE = 1.96, t = 7.81$ ). Importantly, including the interaction between

Prime Type and Day also significantly improved our model of the initial  $x$ -velocity data for the UVF,  $\chi^2(1) = 5.83, p < .05$ . As can be seen in Figure 6C (red bars), although the MCE for the UVF was reliable on both Day 1 and Day 2 (as indicated by FDR corrected paired  $t$ -tests:  $t(15) = 2.85, p < .05$ , *Pearson's*  $r = .59$  and  $t(15) = 2.56, p < .05$ , *Pearson's*  $r = .55$  respectively), this effect was larger on Day 2 (34mm/second) than on Day 1 (28mm/second). The model for LVF initial  $x$ -velocities was similarly characterised by significant main effects of Prime Type,  $\chi^2(1) = 15.70, p < .001$ , and Day,  $\chi^2(1) = 198.83, p < .001$ . Initial  $x$ -velocity was higher on congruent trials compared to incongruent trials ( $b = -19.64, SE = 6.86, t = -2.87$ ) and on Day 2 compared to Day 1 ( $b = 24.45, SE = 1.61, t = 15.17$ ). The interaction between these factors also improved the model,  $\chi^2(1) = 48.83, p < .001$ . As can be seen in Figure 6C (yellow bars), while the MCE in the LVF was reliable on both Day 1 and Day 2 (indicated by FDR corrected paired  $t$ -tests:  $t(15) = 3.21, p < .05$ , *Pearson's*  $r = .64$  and  $t(15) = 4.97, p < .001$ , *Pearson's*  $r = .79$  respectively), the magnitude of the effect was much larger on Day 2 (36 mm/second) than on Day 1 (20 mm/second). For interest's sake, we also examined another aspect of the 3-way interaction between Prime Type, Visual Field, and Day by modelling the data separately for Day 1 (50:50) and Day 2 (20:80). To summarise these analyses briefly, when target location was unpredictable (i.e., Day 1), there was a significant interaction between Prime Type and Visual Field which indicated the MCE to be larger in the UVF than the LVF (28 mm/second vs. 20 mm/second),  $\chi^2(1) = 7.91, p < .005$ . In contrast, on Day 2 this interaction was not reliable,  $\chi^2(1) = 1.52, p = .218$ , indicating that the magnitude of the MCE did not differ significantly between the hemifields on Day 2 when participants could expect the target to appear more frequently in the LVF (34mm/second in the UVF vs. 36mm/second in the LVF).



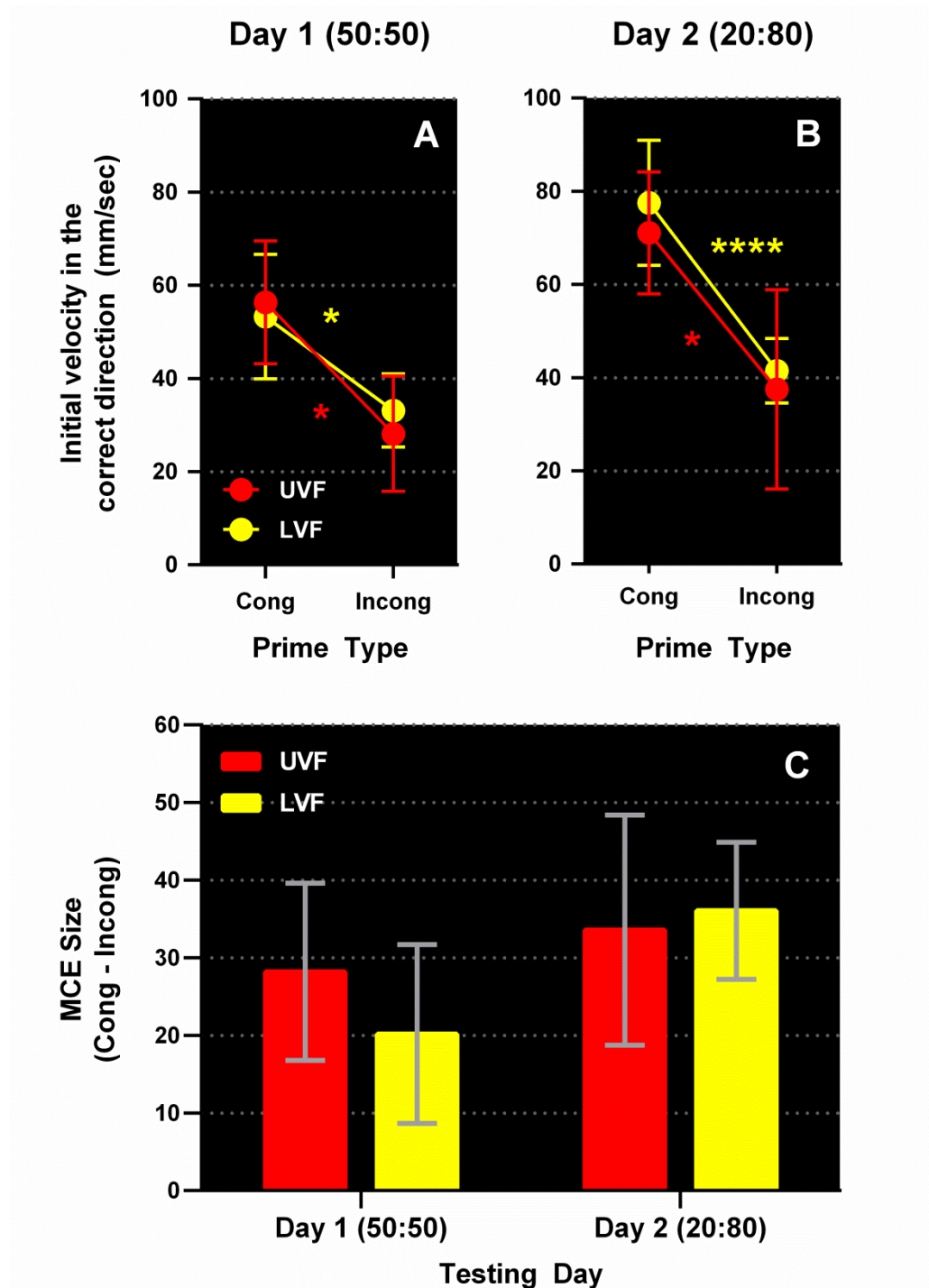
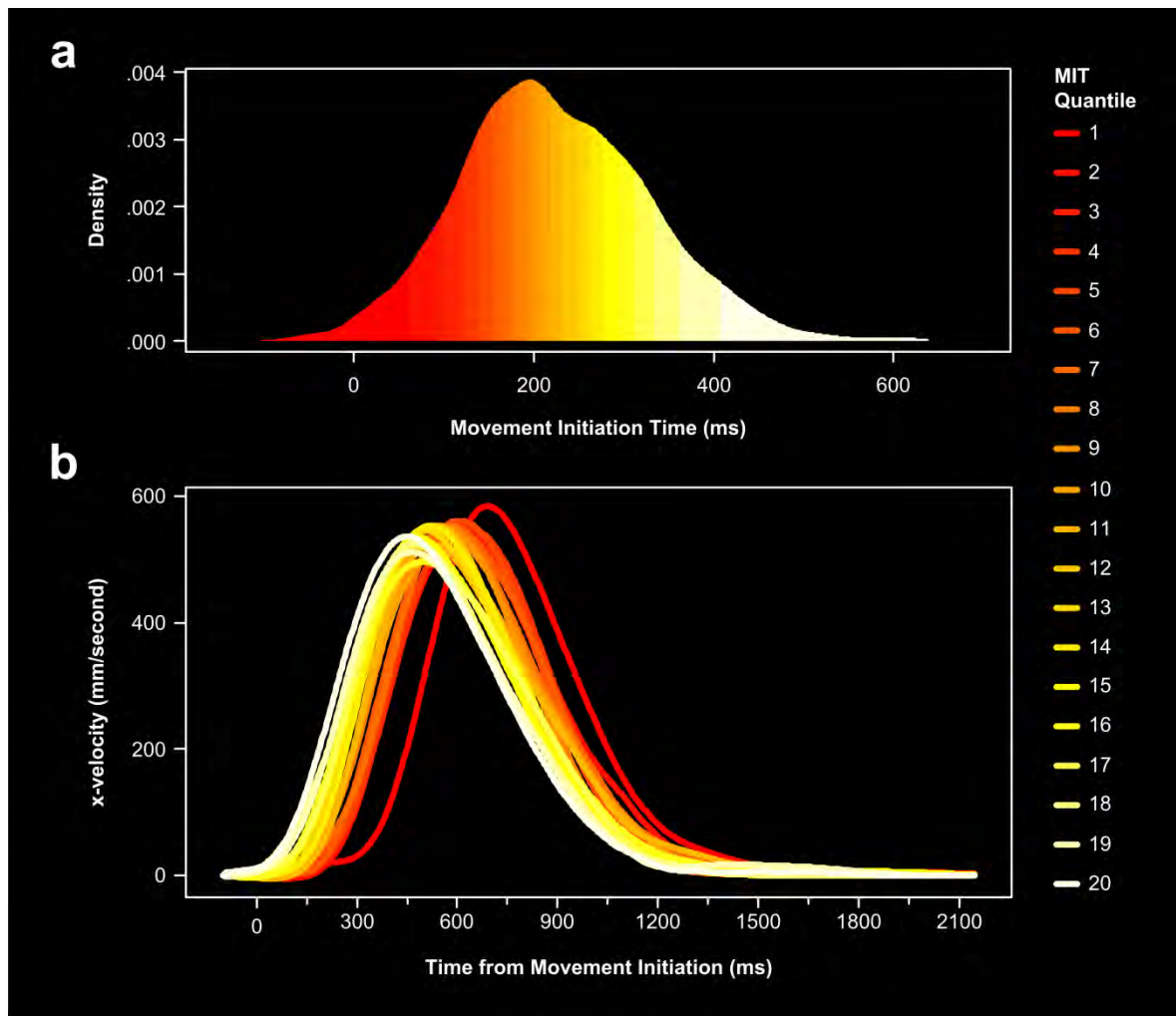


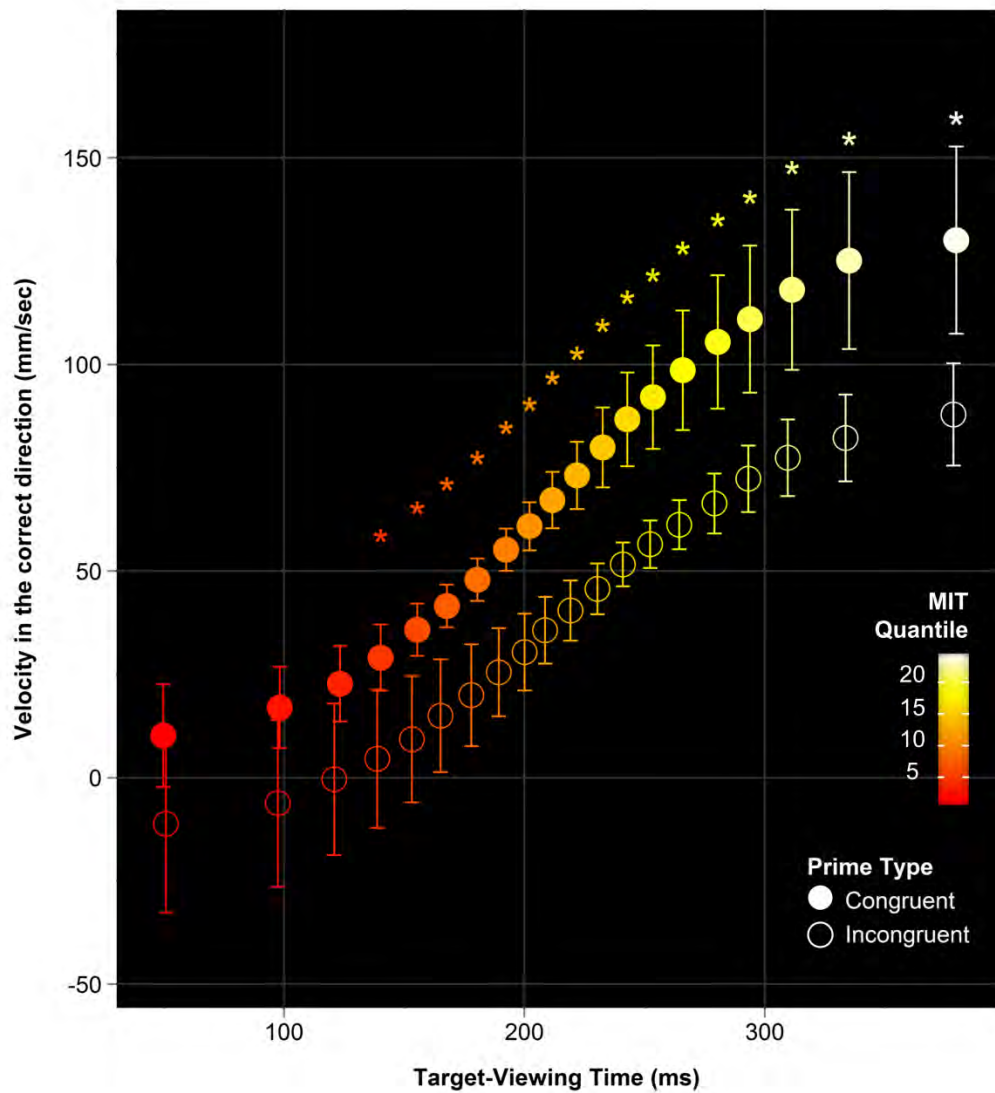
Figure 6. (A & B) Experiment 2 initial x-velocities by Prime Type, Visual Field, and Day. The ratio of UVF:LVF targets was 50:50 on Day 1, and 20:80 on Day 2. We followed up the 3-way interaction between these factors by examining the MCE in each visual field across days. \* $p < .05$ ; \*\* $p < .01$ ; \*\*\* $p < .005$ ; \*\*\*\* $p < .001$  (FDR corrected). (C) The MCE in the UVF was reliable on both testing days, and slightly larger on Day 2 than Day 1 (red bars). The LVF MCE was also reliable on both days, but much larger on Day 2 than Day 1 (yellow bars). Error bars are 95% WSCIs; inter-bar overlap should not be interpreted by eye (see Cummings & Finch, 2005).

***Analyses taking into account target-viewing time.*** In addition to comparing the magnitude of the MCE across experimental conditions, in Experiment 2 we wanted to examine whether the *timecourse* of this effect varied as a function of vertical hemifield or target location probability. To do so, we took advantage of the fact that our auditory go-signal manipulation ensured that participants' reaching trajectories would be initiated across a very wide range of MIT latencies (from -100ms before to 500ms after target onset). Since MIT latency reflects the amount of time the participant has to process the critical stimuli prior to commencing their classification response, examining initial *x*-velocity as a function of MIT latency enables us to observe the MCE as it unfolds in stimulus-processing time (i.e., at less than 500ms from target onset). The OPTA procedure we implemented to smooth our data enabled us to take account of this relationship between initial *x*-velocity and target-viewing time, depicted in Figure 7. Here we have used MIT to group the *x*-velocity profiles into 20 bins of equal proportion (i.e., semi-deciles, see Figure 7a) and calculated an average *x*-velocity profile for each of these MIT Quantiles (see Figure 7b). The effect of target-viewing time on the unfolding of the trajectory response is plain in this figure – the longer participants wait to *begin* their reaching response, the faster their finger moves in the correct direction. That is, the more time participants have to process the stimuli before initiating their movement, the more efficient the initial stages of their classification response is. As in Experiment 1, we calculated initial *x*-velocity by averaging the first 300ms of each smoothed *x*-velocity profile. Below we subject these initial *x*-velocities to statistical analysis, both a) averaged across target viewing time and then b) as a function of target-viewing time.



*Figure 7.* Examining x-velocity as a function of target-viewing time. (a) The distribution of MIT Latencies from target onset (i.e., a distribution of target-viewing-times). We then used Orthogonal Polynomial Trend Analysis (OPTA) to smooth the x-velocity profiles and grouped these into 20 bins (quantiles) ranked by MIT latency. (b) Mean x-velocity profiles by MIT Quantile. Darker colours indicate trials with short MIT Latencies (beginning at the 1<sup>st</sup> Quantile); lighter colours correspond to the longest MIT Latencies (20<sup>th</sup> Quantile). Note the clear effect of MIT Latency: the longer participants wait to begin moving, the faster the finger moves in the correct direction during the reaching response itself.

To understand the timecourse of the MCE reflected in participants' reaching trajectories, we examined initial  $x$ -velocity as a function of target-viewing time by including MIT Quantile as a factor in our LMM analyses. First, we verified that a model including random slopes between participant and Prime Type fit the initial  $x$ -velocity data better than a model with only random intercepts for each subject,  $\chi^2(2) = 10737.41, p < .001$ . Including the fixed effect of MIT Quantile further improved the model's fit,  $\chi^2(1) = 24.37, p < .001$ . As is clear in Figure 8, conditional mean initial  $x$ -velocity values increase dramatically as a function of target-viewing time (i.e., MIT latency,  $b = 4.75, SE = 0.80, t = 5.94$ ). This indicates that the longer participants viewed the target prior to commencing their classification response, the faster their finger moved in the correct direction during the initial portion of the reaching movement. We then confirmed the presence of a strong MCE, evident in the significant fixed effect of Prime Type,  $\chi^2(1) = 3815.40, p < .001$ . Initial  $x$ -velocity was significantly higher on average for congruent trials compared to incongruent trials ( $b = -20.55, SE = 0.94, t = -21.84$ ) (see Figure 8). Including the fixed effect of Day also improved the model,  $\chi^2(1) = 726.82, p < .001$ , as did the fixed effect of Visual Field,  $\chi^2(1) = 222.98, p < .001$ . Initial  $x$ -velocity was reliably higher on UVF trials compared to LVF trials ( $b = -2.51, SE = 1.12, t = -2.24$ ). To elucidate the *timecourse* over which these experimental effects emerged, we examined their interactions with MIT Quantile. We observed a significant Prime Type  $\times$  MIT Quantile interaction,  $\chi^2(1) = 199.64, p < .001$ , indicating that the magnitude of the MCE depended on target-viewing time. As may be seen in Figure 8, the longer participants have to process the prime–target pair prior to initiating their classification response, the larger the MCE evident in the initial stages of the reaching movement. In other words, the ability of the prime to influence the initial stages of the classification response grew as a function of target-viewing time.

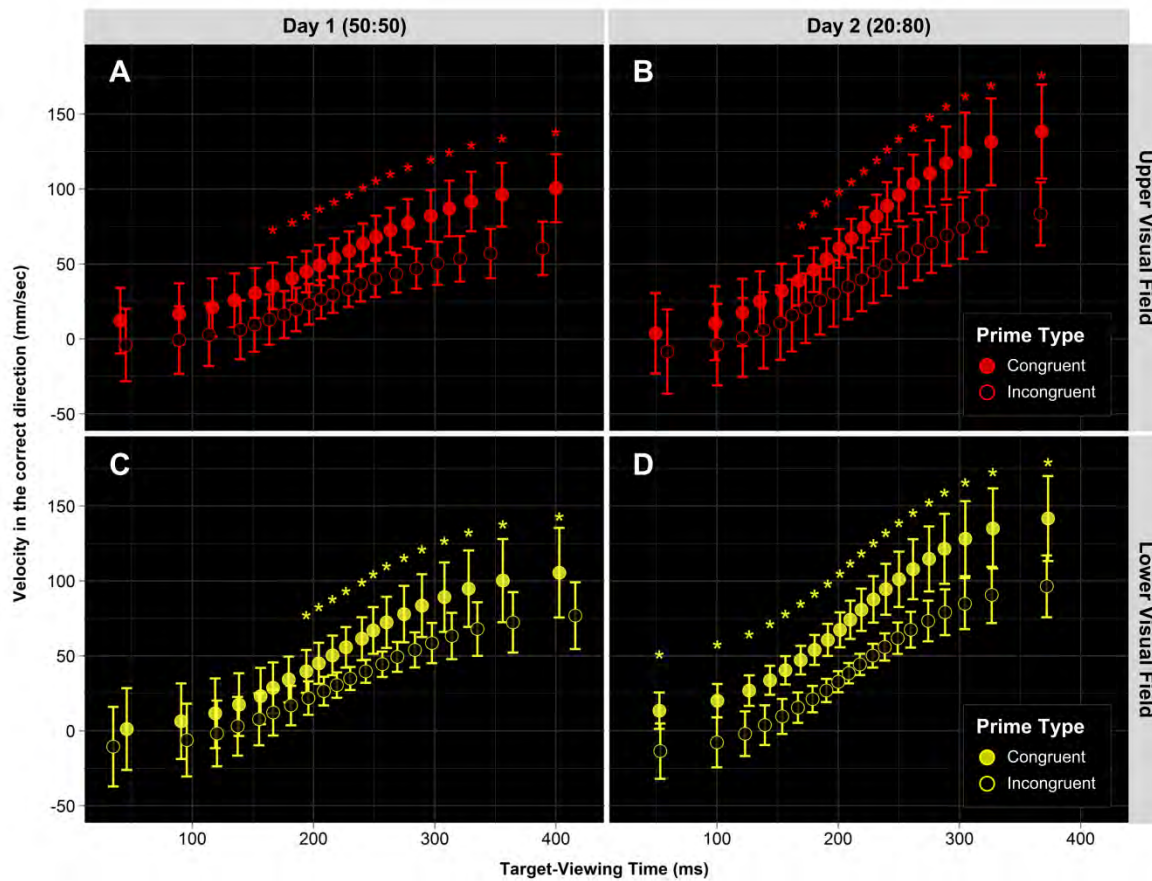


*Figure 8.* Initial x-velocities as a function of MIT Quantile and Prime Type. Initial x-velocity reflects the finger's velocity in the correct direction averaged across the first 300ms of the classification response. There was a strong effect of target-viewing time (i.e., MIT Quantile), in that the longer participants processed the prime–target pair before initiating their reaching response, the faster they moved in correct direction during its initial stages. There was also a clear MCE, with congruent trials (filled circles) producing higher initial x-velocity values than incongruent trials (open circles). As is clear in the figure above, the prime's ability to influence the response to the target appeared to grow as a function of target-viewing time. Asterisks denote .05 significant contrasts between congruent and incongruent values at each MIT Quantile (FDR corrected). Error bars are 95% WSCIs; inter-bar overlap should not be interpreted by eye (see Cummings & Finch, 2005).

Next, we verified that the effect of target-viewing time on priming was further qualified by vertical hemifield (i.e., significant Prime Type  $\times$  MIT Quantile  $\times$  Visual Field interaction,  $\chi^2(2) = 133.09, p < .001$ ). Lastly, we determined that the modulation of the MCE's timecourse by vertical hemifield depended on the ratio of UVF to LVF targets (i.e., significant Prime Type  $\times$  MIT Quantile  $\times$  Visual Field  $\times$  Location Predictability interaction,  $\chi^2(4) = 400.96, p < .001$ ). We followed up the nature of this four-way interaction (presented in Figure 9) by modelling initial  $x$ -velocity separately for each testing day.

LMM analysis for Day 1 indicated significant fixed effects of MIT Quantile and Prime Type ( $p < .001$  in both cases), but not Visual Field,  $\chi^2(1) = 0.58, p = .448$ . We nevertheless retained this factor in the model so as to inspect its interaction with other factors. Next, we verified the inclusion of the two-way interaction between Prime Type and MIT Quantile and determined that this was further qualified by Visual Field ( $p < .001$  in both cases). Because we obtained the critical Prime Type  $\times$  Quantile  $\times$  Visual Field interaction, we were able to conduct a paired  $t$ -test between the congruent and incongruent conditions at each MIT Quantile, separately for the upper and lower-hemifields. In the UVF (see Figure 9A), the FDR-corrected  $p$ -values were significant from the 6<sup>th</sup> to the 20<sup>th</sup> MIT Quantile – indicating that participant's initial reaching movements reflected a significant MCE from 165ms of target-viewing time onwards. In contrast, primes presented in the LVF did not elicit a reliable MCE until the 8<sup>th</sup> MIT Quantile; at around 195ms of target-viewing time (see Figure 9C). Thus, on Day 1, when target location was unpredictable for participants, we observed a clear UVF advantage for masked face processing, with the MCE emerging some 30ms earlier in stimulus-processing time for UVF face stimuli than for LVF face stimuli.

LMM analysis for Day 2 confirmed the same fixed effects and interactions as observed for Day 1 ( $p < .001$  in all model comparison cases). Most importantly, the significant three-way interaction indicated that emergence of the MCE across MIT Quantile depended on Visual Field. As for Day 1, we further examined this interaction by conducting a paired  $t$ -test comparison of the congruent and incongruent conditions at each MIT Quantile, separately for each hemifield. As can be seen in Figure 9B, the MCE in the UVF was reliable from the 6<sup>th</sup> to the 20<sup>th</sup> MIT Quantile, or from approximately 165ms of target-viewing time onwards. In contrast, the MCE elicited by prime–target pairs presented in the LVF was reliable at all MIT Quantiles, from around 53ms of target-viewing time onwards (see Figure 9D). Thus, on Day 2, in which participants could reliably anticipate the target’s location and direct their attention appropriately in response, we observed an LVF advantage for masked face-processing. Here primes presented in the LVF elicited a priming effect at an earlier stage of stimulus processing than primes presented in the UVF. Of critical importance here is the comparison between Day 1 and Day 2 for the UVF. Looking across Figures 9A and 9B, it is clear that face-processing efficiency in the UVF did *not* suffer when participants covertly attended to the LVF. That is, the MCE in the UVF emerged at the same stage of stimulus-processing on both Day 1 and Day 2 (i.e., around 165ms of target-processing time), suggesting that directing participants’ covert attention *away* from the upper-hemifield did not interfere with participants’ ability to process masked faces in this region.



**Figure 9.** Initial x-velocity as a function of Prime Type, MIT Quantile, Visual Field, & Day. (A) On Day 1 (50:50 target location ratio), the MCE in the UVF was significant from ~165ms of target-viewing time onwards, whereas (C) LVF primes did not elicit a reliable MCE until ~195ms of target-viewing time. The reverse was true on Day 2, in which participants could reliably expect the target to appear in the LVF more often than the UVF (80:20 ratio). Here the MCE was significant from ~53ms onwards in the LVF (D) and from ~165ms onwards in the UVF (B). A comparison of panels B) and D) suggests that directing spatial attention *away* from the UVF did not impair participants' ability to process masked faces presented in this region. Asterisks denote .05 significant contrasts between congruent and incongruent values at each MIT Quantile (FDR corrected). Error bars are 95% WSCIs; inter-bar overlap should not be interpreted by eye (see Cummings & Finch, 2005).



#### **5.4.2.3. Prime Detection**

As in Experiment 1, to assess prime visibility we calculated  $d'$  from each participant's 2AFC prime detection data. Here the mean  $d'$  value was 0.11 ( $SD = 0.13$ ), which a one sample  $t$ -test determined was significantly greater than zero ( $t(15) = 3.37, p < .01$ , *Pearson's*  $r = .66$ ). This suggests that the masked primes in Experiment 2 were not completely suppressed from conscious awareness, likely owing to our manipulation of target location predictability. That is, because participants voluntarily attended to the lower-hemifield in response to the increased probability of targets in this region, masked primes presented in the LVF were likely to have been subject to focused spatial attention.

#### **5.4.3. Experiment 2 Discussion**

Just as in Experiment 1, we observed a strong MCE in both participants' accuracy and initial reaching movements. We also replicated the UVF advantage for face-sex categorisation, in that when participants could not reliably predict the target's location (i.e., on Day 1), the magnitude of the MCE reflected in the initial stages of their reaching movement was reliably larger for UVF prime–target pairs than for LVF pairs. Moreover, the analysis that took target-viewing time into account revealed that the MCE under unpredictable target location conditions emerged *earlier* during stimulus-processing time when the face stimuli appeared in the UVF compared to the LVF (~165ms vs. ~195ms of stimulus-processing time). That masked prime items influenced the target classification response at an earlier stage of stimulus-processing when presented above- compared to below-fixation would suggest that face-sex categorisation is *more efficient* in the UVF than the LVF.

The effect of vertical hemifield on masked-face processing was very different, however, when participants could reliably expect the target to appear in the lower half of the display and could direct their spatial attention appropriately in response (i.e., on Day

2). Here accuracy was better for LVF targets than for UVF targets. Moreover, the magnitude of the MCE in the LVF was significantly larger on Day 2 than on Day 1. This suggests that voluntarily directing their spatial attention towards the LVF improved participants' ability to process masked prime faces presented in this region. This interpretation is further supported by the finding that LVF primes influenced the initial stages of target classification at a much earlier point during stimulus-processing when participants voluntarily attended to the lower-hemifield (i.e., on Day 2 compared to Day 1). By itself, this result is perhaps not altogether surprising – indeed, there is good reason to expect that attending to the prime's location should facilitate processing and increase its ability to the response to the target (see Quek & Finkbeiner, 2013). What *is* surprising, however, is that the increase in performance for LVF faces was not coupled with a commensurate decrease in performance for UVF faces. Target classification accuracy for UVF targets was comparable on Day 1 and Day 2, and the MCE for this hemifield remained consistent across days, emerging at the same time during stimulus processing on both testing days (~165ms). Taken together, these results suggest that while directing covert spatial attention to the lower-hemifield clearly confers a benefit on the processing of LVF faces, face-processing in the UVF appears to be unaffected by participants' deployment of spatial attention to the opposite hemifield.

## **5.5. General Discussion**

This paper establishes three important findings. First, we have demonstrated that under unpredictable target location conditions, face-sex categorisation exhibits a clear upper visual field (UVF) advantage. We observed this robust advantage in two separate groups of participants, in sex-categorisation accuracy, and in both the magnitude and the timecourse of the masked congruence effect (MCE). These results replicate an earlier study

(Quek & Finkbeiner, 2014) and they are also highly consistent with findings from the neurophysiological literature showing that faces presented above-fixation activate regions such as the left fusiform face area (FFA), left occipital face area (OFA), and medial prefrontal cortex (mPFC) earlier than faces presented below-fixation (Liu & Ioannides, 2010). Taken together, these findings strongly suggest that the visual system processes faces more efficiently in the upper-hemifield than in the lower-hemifield.

Second, we have shown that voluntarily directed spatial attention reliably modulates the ability of masked faces to influence the overt response to the target face. Masked primes in our study influenced the target classification response to a greater extent, and at an earlier stage of stimulus-processing, when participants could *predict* the likely location of the upcoming target and direct their attention to this location. This finding represents an important contribution to the masked priming literature, in that as far as we are aware, it is the first demonstration that *endogenously directed* spatial attention modulates the masked priming effect for faces. The finding also echoes and complements our previous demonstrations that *exogenously oriented* spatial attention facilitates the processing of masked face primes (Quek & Finkbeiner, 2013; 2014).

Third, and most importantly, the present paper dispels the possibility that the UVF advantage for face-processing is underpinned by an upward bias in voluntarily directed spatial attention. If this *were* the case, then masked face-processing in the UVF would have been negatively affected when participants voluntarily attended to the opposite hemifield, as they did on Day 2 of our second experiment. Instead, we found that participants' ability to extract the task-relevant sex information from masked faces in the upper-hemifield did not vary as a function of our manipulation of voluntarily directed spatial attention. This key finding strongly undermines the possibility that the UVF advantage for face-sex processing we report here and elsewhere (Quek & Finkbeiner, 2014) is driven by an

upward bias in spatial attentional orienting (see Bradshaw et al., 1985; Drain & Reuter-Lorenz, 1996; van Vugt et al., 2000). The implications of these findings for the masked priming, face-perception, and broader object recognition literatures are discussed below.

### ***5.5.1. The upper-hemifield advantage for face-processing:***

#### ***Not a product of attentional bias***

In contrast to the wide interest in laterality effects for face-processing, comparatively few studies have examined vertical asymmetry in face-perception (for a discussion, see Quek & Finkbeiner, 2014). This limited literature has thus far only hinted at the possibility that face-processing may be superior in the upper-hemifield relative to the lower-hemifield (Coolican, Eskes, McMullen, & Lecky, 2008; Kessler & Tipper, 2004; Liu & Ioannides, 2010). We recently provided what might be considered the strongest evidence to date for a UVF advantage in face-perception, demonstrating that masked faces affect the sex-categorisation of a target face at an *earlier* stage of stimulus-processing when presented in the UVF compared to the LVF (Quek & Finkbeiner, 2014). We have replicated these findings here in two separate groups of individuals, evidence that we feel conclusively establishes the existence of an upper-hemifield advantage in face-sex processing. The discovery has significant implications for the face-perception literature, as where researchers have long tried to take account of laterality artefacts in their designs, thus far there appears to have been little consideration given to the impact of vertical anisotropy in face-perception tasks. The finding also qualifies the characterisation of sex-categorisation as highly robust instance of object-recognition (Bruce & Young, 1998; Wild et al., 2000). While this process is unquestionably efficient, we have highlighted that this aspect of face-perception is nevertheless still subject to modulation by factors such as spatial location and spatial attention. A natural extension of this finding, and one that is already hinted at in the literature, would be to examine whether other aspects of face-

perception, such as identity or emotion recognition, exhibit a similar upper-hemifield advantage (Felisberti & McDermott, 2013; Kessler & Tipper, 2004; Liu & Ioannides, 2010).

Importantly, although the mechanism underlying this vertical asymmetry for faces remains unclear, we have provided strong evidence here to discredit the possibility that the upper-hemifield advantage for face-processing is driven by an *upward bias in voluntarily directed spatial attention*. When participants' directed their spatial attention away from the upper-hemifield, as they did when targets appeared in the lower visual field on 80% of the trials, their ability to process faces presented in the UVF was unaffected. It is worth noting, however, that voluntarily directed spatial attention is not the only top-down process capable of modulating basic perceptual processing. Where endogenously directed spatial attention prioritises stimulus processing on the basis of task demands, *expectation* can constrain visual interpretation on the basis of prior knowledge (Summerfield & Egner, 2009) by sharpening sensory representations (Kok, Jehee, & de Lange, 2012). It is well established, for example, that object detection is facilitated by a congruent context (e.g. a coffee cup in a kitchen scene will be found faster than the same cup in a beach scene) (Davenport, 2007; Fize, Cauchois, & Fabre-Thorpe, 2011). Moreover, Biederman has singled out both probability and spatial position as important relations which affect object recognition in scenes (Biederman, Mezzanotte, & Rabinowitz, 1982). Thus, it is reasonable to think that our wealth of experience encountering faces in extrapersonal space could well have engendered in us a very strong expectation that face stimuli are more likely to appear above-fixation than below. Just as expectation of object category is known to increase the efficiency with which category exemplars are processed (Puri & Wojciulik, 2008), presumably a perceptual 'prior' which also encompasses spatial location might be expected to facilitate exemplar processing in an anisotropic manner. Importantly, while attention and expectation are often intertwined, it could be the case a perceptual prior for faces is

overlearned and thus relatively less flexible. On this possibility, the probabilistic manipulation of target location used in our second experiment might have effectively guided participants' voluntarily directed spatial attention, while simultaneously having no effect on their pre-existing *expectation*. The possibility of a relatively inflexible prior expectation about face location could explain the UVF advantage observed when participants have no cause to preferentially direct their spatial attention to either hemifield (i.e., when target location is unpredictable). This possibility could also explain why face processing remains unaffected in the UVF in experimental contexts in which participants voluntarily direct their attention to the lower visual field. That is, whereas spatial attention can be flexibly controlled and directed to facilitate stimulus processing in predicted target regions, perhaps the well-learned perceptual prior regarding faces remains unchanged, allowing face-processing in the expected region to proceed similarly with or without spatial attention. We note that, while we think the possibility of a relatively inflexible expectation for faces to appear in particular locations is reasonable, it is speculative at this point.

In yet another possibility, it could be that a structural explanation is best equipped to account for the upper visual field advantage in face-processing. Given that the UVF and LVF are over-represented in the ventral and dorsal regions of visual cortex respectively (Sereno et al., 1995; Zeki, 1969), it may be that presenting faces above-fixation enables more efficient information processing within the ventral object recognition systems contained in the temporal lobe (Ishai, Ungerleider, Martin, Schouten, & Haxby, 1999; Martin, Wiggs, Ungerleider, & Haxby, 1996). Conversely, transfer of information to object recognition areas may take slightly longer from the dorsal regions of striate and extrastriate cortex, where information presented to the LVF is initially projected. We note again that, while the possibility of a structural explanation strikes us as reasonable, it is a highly speculative account of the upper-hemifield advantage for face-perception at this point. It is

clear that there are important steps that need to be taken to guide our understanding of vertical asymmetries in object-recognition.

### ***5.5.2. Endogenous attention modulates masked face-processing***

Where the modulatory effects of voluntarily directed spatial attention on the *neural response* to face stimuli are well-described in the neurophysiological literature (Holmes, Kiss, & Eimer, 2006; Holmes, Vuilleumier, & Eimer, 2003; Pessoa, McKenna, Gutierrez, & Ungerleider, 2002; Vuilleumier, Armony, Driver, & Dolan, 2001; Wojciulik, Kanwisher, & Driver, 1998), behavioural investigations to date have often failed to observe an impairment in task performance resulting from directing spatial attention away from a face's location. For example, Reddy and colleagues showed that neither face identification nor face-sex classification of peripheral masked faces suffer when spatial attention is engaged centrally by a demanding discrimination task (Reddy, Reddy, & Koch, 2006; Reddy, Wilken, & Koch, 2004). At first glance, it may appear that our findings do not support the conclusions of Reddy and colleagues. This is because we have shown that face-perception does indeed benefit from endogenously directed spatial attention, just as it does from exogenously captured attention (Quek & Finkbeiner, 2013). But we suggest, in fact, that our results are consistent with those of Reddy and colleagues. Just as participants in their studies were able to reliably identify both identity and sex even when attention was directed elsewhere, participants in our study remained perfectly able to extract the sex-information from masked face primes in the UVF when attention was directed the LVF.

### ***5.5.3. Conclusion***

There is increasing evidence to suggest that face-perception is supported better at above-fixation locations than at below-fixation locations. The present study further establishes this finding by showing that face-sex categorisation is more efficient in the upper visual field (UVF) than the lower visual field (LVF). It has been suggested that the

UVF advantage might be due to participants possessing a strong upward attentional bias in categorisation tasks. The purpose of this study was to test this possibility. Our primary conclusion is that the UVF advantage is *not* due to an upward bias in voluntarily directed spatial attention. Specifically, masked faces presented in the upper-hemifield engaged cognitive processes to the same degree even when spatial attention had been successfully deployed elsewhere.



## 5.6. References

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## CHAPTER SIX

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### GENERAL DISCUSSION

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## 6.1. Thesis Overview

The purpose of this thesis was to examine how manipulations of attention and vertical hemifield presentation modulate the visual system's ability to process information presented below the level of conscious awareness. To shed light on these questions, I have exploited a unique characteristic of human faces; that they elicit observable masked priming effects under both attended and unattended conditions (Finkbeiner & Palermo, 2009; Harry, Davis, & Kim, 2012; Khalid, Finkbeiner, Konig, & Ansorge, 2013). Using the masked congruence effect (MCE) as an index of nonconscious face perception, I have explored the manner in which nonconscious information processing is modulated by different forms of *focused attention* (Studies 1, 2, & 4). Studies 2-4 extended this work by examining how the relationship between attention and awareness is qualified by *vertical hemifield presentation*. Taken together, the results of these four empirical studies establish three key findings. First, while nonconscious perception of nonface stimuli (e.g. letters/numbers/words) appears to *depend* on attentional allocation (e.g. Fabre, Lemaire, & Grainger, 2007; Kiefer & Brendel, 2006; Lachter, Forster, & Ruthruff, 2004; Marzouki, Grainger, & Theeuwes, 2007; Naccache, Blandin, & Dehaene, 2002), I have shown that **nonconscious face-processing proceeds even when attention is focused elsewhere** in time or space. Second, I have demonstrated that although nonconscious face perception does not *depend* on attention, this cognitive process is nevertheless **still sensitive to the modulatory effects of spatial and temporal attention**. Third, I have established that **face-processing is sensitive to placement along the vertical meridian**, enjoying an advantage in the upper-hemifield relative to the lower-hemifield. In this final chapter, I will reprise these three key findings in detail; discuss their implications within a broader research context; and highlight a number of outstanding issues that present avenues for future research.

## 6.2. *Key Finding 1: Nonconscious face-processing does not depend on attention*

Attention and awareness have been characterised as functionally distinct cognitive phenomena which, although indisputably intertwined, should not be equated (Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006; Koch & Tsuchiya, 2007; Tsuchiya & Koch, 2008; van Boxtel, Tsuchiya, & Koch, 2010). In the quest to disentangle these two aspects of cognition, researchers have sought to establish the role of attention in nonconscious information processing. In the introductory chapter of this thesis, I contrasted two opposing perspectives on this issue. The widely held classical view posits that nonconscious processing proceeds in an *automatic* fashion, independent of top down factors such as attention, intention, or conscious strategy (Eysenck, 1984; Posner & Snyder, 1975; Schneider & Shiffrin, 1977). Recent masked priming research has convincingly undermined this claim, however, by establishing that attention is necessary for subliminally presented letters, numbers, and words to engage cognitive processes (Fabre et al., 2007; Kiefer & Brendel, 2006; Lachter et al., 2004; Lien, Ruthruff, Kouchi, & Lachter, 2010; Marzouki et al., 2007; Marzouki, Midgley, Holcomb, & Grainger, 2008; Naccache et al., 2002). The research presented in this thesis contributes to a *third* perspective in this debate, one that stands in contrast to both the “complete-independence” and “complete-dependence” views. This third account holds that **the influence of attention on nonconscious perception is modulated by information type** (Finkbeiner & Palermo, 2009). More specifically, the visual system processes **nonconscious face information** regardless of attentional allocation (Finkbeiner & Palermo, 2009; Harry et al., 2012; Khalid et al., 2013), whereas nonconscious processing of many other stimulus types appears contingent on the allocation of attention (see Fabre et al., 2007; Lachter et al.,

2004; Lien et al., 2010; Marzouki et al., 2007; Marzouki et al., 2008; Naccache et al., 2002).

In Studies 1 and 2, I used exogenous spatial cueing to manipulate the degree to which participants attended to the **location** of a subliminal face. In both studies, I observed that task relevant sex-information carried by the masked face influenced the participant's classification of the subsequent visible target face even when spatial attention was captured away from the prime's location. This result is in line with previous reports that masked priming effects in face-sex categorisation and face fame judgement tasks arise in the context of both valid and invalid spatial cueing (Finkbeiner & Palermo, 2009; Harry et al., 2012; Khalid et al., 2013). Importantly, the data reported in Study 1 *extend* this claim beyond spatial cueing by providing the first demonstration that masked face-processing does not rely on the allocation of **temporal attention**. That is, in contrast to the typical finding for number and word primes (Fabre et al., 2007; Kiefer & Brendel, 2006; Naccache et al., 2002), I observed that masked faces elicited reliable congruence priming effects regardless of how well participants' attention was focused in time. Taken together, these results provide strong evidence for the suggestion that nonconscious information processing of some stimuli, namely faces, can proceed in the absence of attentional allocation (Finkbeiner & Palermo, 2009).

### ***6.2.1. Evidence of leakage: A challenge to the Selective Filter Theory***

The suggestion that face-recognition processes can proceed *outside* the focus of attention represents a significant challenge to the claim that stimuli in unattended channels are not processed to the level of 'identification' (Lachter et al., 2004). According to Lachter and others (Lien et al., 2010), only **physical features** (e.g. colour, motion, orientation) of unattended objects are processed in the absence of attention (Broadbent, 1958). Yet in conjunction with previous work (Finkbeiner & Palermo, 2009; Harry et al.,

2012; Khalid et al., 2013), the findings presented here suggest that sex information carried by masked faces can “leak” through this attentional filter in a way that produces observable repetition and categorical priming effects (Finkbeiner & Palermo, 2009; Harry et al., 2012; Khalid et al., 2013). It is important to note, however, that these findings can only challenge the selective filter theory of attention insofar as the priming effect in the unattended condition(s) here can be attributed to attentional “**leakage**” rather than “**slippage**” (Lachter et al., 2004, p. 886). Leakage is defined as when attentional resources are *not* allocated to a stimulus, yet some semantic processing of this item “leaks” through the attentional filter, leading to stimulus identification. In contrast, attentional slippage refers to the situation in which inadequate control of attention results in attentional resources momentarily “slipping” (perhaps involuntarily) to the supposedly unattended channel of information. As Lachter et al. have suggested, only evidence of *attentional leakage* can challenge the central claim of the Selective Filter Theory of attention. Obtaining evidence of leakage is not straightforward, however. Indeed, many findings that have claimed to represent identification of ‘unattended’ stimuli (see Cherry, 1953; Moray, 1959) have, on closer inspection, been revealed to reflect identification arising in the context of attentional slippage.

As such, in order to claim the “unattended” priming effects reported in this thesis as attentional leakage, we must firstly verify that these effects cannot be due to attentional slippage. Given the known attentional salience of faces (Langton, Law, Burton, & Schweinberger, 2008; Theeuwes & Van der Stigchel, 2006; Vuilleumier, 2000), as well as the high degree of overlap in task-relevant features between the prime and target items (Folk & Remington, 2006; Folk, Remington, & Johnston, 1992; 1993), it would not be unreasonable to think that the masked prime faces used in our studies could well have briefly attracted attentional resources even when attention was supposedly elsewhere (i.e., slippage). Nevertheless, there are good reasons for believing this was not the case. This is

particularly true of Study 1 (Expt 1A), which was actively designed to minimise any chance of attention slipping to the ‘unattended’ prime’s location. Here the prime and target always appeared in fixed, vertically displaced positions (prime above, target below). As a result, participants knew exactly where to expect the target and could voluntarily attend to this location (and away from the prime’s location) ahead of time. In fact, we actively encouraged participants to adopt this strategy by presenting targets for only a short duration (300ms). Moreover, the very brief prime presentation (50ms) strongly minimises the chance that participants could have allocated attention to the prime *except* when its location was explicitly cued. The rationale here is straightforward. Given that exogenous shifts of attention have been estimated to take between 50-120ms (Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989; Tsal, 1983), even if the masked prime itself *did* capture attentional resources (an unlikely possibility, see Experiment 4, Finkbeiner & Palermo, 2009), on all trials the prime would have been replaced by the backward mask before attention could be reallocated to its location (see Lachter et al., 2004). Given the strict measures Study 1 imposed to minimise attentional slippage<sup>1</sup>, the priming effects observed in the unattended condition seem more likely to reflect task-relevant face-sex information ‘leaking’ through the attentional filter. In this way, this finding undermines the central claim of the Selective Filter Theory of attention, in that it suggests that information carried

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<sup>1</sup> Although the results of Study 2 also suggest priming can occur when attention is captured elsewhere, I have limited my claim of true attentional leakage to just the findings of Study 1. This is because the design of Study 2 was arguably *less robust* to slips of attention than that of Study 1. Participants in Study 1 knew where the target would appear on each trial, and could thus attend to this location (and away from the prime’s location) ahead of time. In contrast, participants in Study 2 could not reliably predict the upcoming target’s location and thus are likely to have maintained a more diffuse spread of spatial attention across the display. As such, where Study 1 combined both voluntary-directed and exogenously-captured spatial attention to minimise the likelihood of attention slipping to the ‘unattended’ prime’s location, Study 2 relied solely on the latter to prevent attentional slippage.

by nonconscious can indeed reach the level of ‘identification’ even in the absence of attention.

### **6.2.2. *A proposed mechanism for leakage***

An important caveat to note at this juncture is that the reported instances of attentional leakage appear limited to demonstrations involving face-recognition (Study 1 here, see also Finkbeiner & Palermo, 2009). Neither the work presented here nor any previous research of which we are aware has demonstrated that *nonface* stimuli can be processed outside the focus of attention. Thus, it may be the case that the central claim of the Selective Filter Theory of attention holds for most stimulus types, with faces as a notable exception. If this is the case, an outstanding question is why face-processing should be less sensitive to attentional modulation than other stimulus types. One promising line of enquiry in this regard centres on the possibility of a subcortical face-processing route that may be less vulnerable to attentional modulation than cortical pathways (Johnson, 2005; Jolij & Lamme, 2005; Vuilleumier, Armony, Driver, & Dolan, 2003). This parallel subcortical route has been suggested to provide a rapid processing path for coarse analysis via the superior colliculus and pulvinar thalamus (de Gelder, Frissen, Barton, & Hadjikhani, 2003; Palermo & Rhodes, 2007). This route is thought to be supported predominantly by magnocellular channels which carry lower spatial frequencies associated with global face configuration information (Schiller, Malpeli, & Schein, 1979; Vuilleumier et al., 2003). Historically, the subcortical face-processing route has been characterised as a rapid detection system for threatening stimuli, such as fearful faces (e.g. LeDoux, 1996; Morris, de Gelder, Weiskrantz, & Dolan, 2001; but see Palermo & Rhodes, 2007). However, since face-sex information is also thought to be predominantly carried by low spatial frequency information (Deruelle & Fagot, 2005; Goffaux, Jemel, Jacques, Rossion, & Schyns, 2003), it may be that face-sex information processing can also proceed via this



route. Indeed, early work in this area suggests that masked priming effects in face-sex categorisation tasks may be driven entirely by low spatial frequency information carried along the subcortical pathway (de Gardelle & Kouider, 2010; Khalid et al., 2013). While the ability of *attention* to modulate face-perception carried out along this subcortical route remains largely unknown, the use of transcranial magnetic stimulation (TMS) to suppress cortical processing in normal observers could represent a promising avenue of investigation in this regard. TMS applied over occipital cortex is thought to block access to the cortical visual processing route by interfering with V1 activity (Corthout, Uttl, Ziemann, Cowey, & Hallett, 1999; Cowey & Walsh, 2000). Jolji and Lamme (2005) have used these methods to show that participants can make affective discriminations of schematic faces even when occipital TMS renders these stimuli invisible. The authors propose that this “affective blindsight” is most likely to be mediated by a subcortical route that proceeds via the midbrain and thalamus to the amygdala. Coupled with an exogenous or endogenous spatial cueing paradigm, such a design could be used to determine the sensitivity of this parallel face-processing route to attentional modulation.

## **6.3. Key Finding 2: Spatial and temporal attention can modulate nonconscious face-processing**

### **6.3.1. The role of attention in nonconscious information processing**

The fact that nonconscious face-perception does not *depend* on attention does not necessarily suggest that this process should be *invulnerable* to the effects of attention. In fact, a primary goal of this thesis was to demonstrate attentional modulation of masked face priming, so as to shed light on the role attention plays in nonconscious perception. To date, the finding that attention *categorically* modulates masked priming effects for letter, number, and word stimuli has led some researchers to characterise the effect of attention on nonconscious perception as binary or categorical (Lachter et al., 2004). An alternative possibility, however, is that attention facilitates nonconscious processing in a graded fashion, in much the same way as it has been shown to influence information processing of visible stimuli (Cameron, Tai, & Carrasco, 2002; Carrasco & McElree, 2001; Carrasco, Penpeci-Talgar, & Eckstein, 2000; Carrasco, Williams, & Yeshurun, 2002; Doshier & Lu, 2000; Lu & Doshier, 1998; Yeshurun & Carrasco, 1998). The breakthrough results reported in this thesis provide clear evidence for this second possibility. Taking the MCE for faces as an index of nonconscious information processing, I have shown that although nonconscious face perception proceeds under both attended and unattended conditions, **attentional allocation nonetheless still facilitates unconscious processing**. The findings here establish that nonconscious face-processing is sensitive to endogenous and exogenous manipulations of attention, in both the temporal and spatial domains.

The influence of **exogenously-captured spatial attention** on nonconscious information processing is clear in Studies 1 and 2. The results of these studies indicate that the provision of a valid spatial cue at the masked prime's location facilitates the extent to which information carried by the subliminal face influences the response to the target. In

both studies, congruence priming effects were stronger and emerged earlier during stimulus-processing time when spatial attention was involuntarily captured to the masked prime's location. This finding is nicely complemented by the results of Study 4, which suggest that **endogenously directed spatial attention** enhances nonconscious information processing in much the same way. In this study, the masked congruence effect for faces was larger and emerged earlier when participants could reliably *predict* the location of the upcoming prime-target pair and could covertly attend to this location in anticipation of the target. Finally, the data presented in Experiment 1B of Study 1 suggest that **nonconscious information processing is also facilitated by focused *temporal* attention**. While participants in this study always knew the location of the target ahead of time, the onset of the target *in time* varied trial to trial. We employed a 'hazard function' manipulation of temporal attention (see Ghose & Maunsell, 2002) by having target onset occur after one of four randomly selected durations. In this manipulation, temporal attention to the masked prime is optimally focused when participants are most certain that the target is *about to appear* (i.e., at the longest durations). Conversely, temporal attention is minimally focused when target onset is least predictable (at the shortest durations). Consistent with our findings in the spatial domain, the results of this experiment indicated that allocating focused temporal attention to the masked prime facilitated the extent to which the prime-target relationship modulated the target classification response. Although masked primes in this study *always* elicited a reliable congruence priming effect, this MCE was larger and arose earlier when participants were most prepared for the onset of the critical stimuli (and temporal attention was thus maximally focussed).

Taken together, the results of Studies 1, 2, and 4 suggest that directing spatial or temporal attention to a subliminal face *strengthens perceptual processing of this stimulus* in a way that facilitates both the magnitude and the timecourse of observable masked priming effects. These results represent a breakthrough in the quest to understand how

attention and awareness interact: where previous masked priming investigations have observed *categorical* modulation of nonconscious perception by attention (e.g. Finkbeiner & Palermo, 2009; Lachter et al., 2004; Naccache et al., 2002), the data reported here suggest that the influence of attention on nonconscious information processing is graded (Cameron et al., 2002; Carrasco, 2011; Carrasco, Penpeci-Talgar, & Cameron, 2001; Doshier & Lu, 2000; Lu & Doshier, 1998; Luck, Hillyard, Mouloua, & Hawkins, 1996; Yeshurun & Carrasco, 1998).

Importantly, while these findings represent the first such demonstration using masked priming techniques, they are nevertheless consistent with the fledgling literature that has sought to observe a graded effect of attention on nonconscious perception using other paradigms. For example, Tapia, Breitmeyer, Jacob, and Broyles (2013) have characterised the gradient of spatial attention by examining how the strength of the flanker congruency effect decays with increasing separation between the target and flanker items. They found the rate of decay to be near-identical for visible and metacontrast masked flankers, suggesting that spatial attention modulates both conscious and nonconscious processing in a similarly graded way. Elsewhere, other researchers have shown that directing spatial attention to sinusoidal gratings rendered invisible using interocular suppression increases the magnitude of the contrast threshold elevation aftereffect produced by these stimuli (Bahrami, Carmel, Walsh, Rees, & Lavie, 2008; Shin, Stolte, & Chong, 2009), in much the same way as it does for visible adaptor stimuli (Carrasco, 2011; Ling & Carrasco, 2006; Pestilli & Carrasco, 2005; Pestilli, Viera, & Carrasco, 2007). Together with these existing findings, the results presented in this thesis contribute to the emerging view in the literature that suggests attention facilitates unconscious processing in a *graded*, rather than categorical fashion.

### **6.3.2. Consistencies with the neurophysiological face-perception literature**

The finding that attention is capable of modulating nonconscious face perception is highly consistent with neurophysiological studies that have demonstrated that spatial attention modulates sensory processing of *visible* faces. For example, Jacques and Rossion (2007) showed that focussed spatial attention modulates the evoked neural response to faces as early as 80ms after stimulus onset. The same authors reported attentional enhancement of the face-sensitive N170 component (see also Holmes, Vuilleumier, & Eimer, 2003), with similar findings reported for task-based attention (i.e., attend to faces or scenes, Sreenivasan, Goldstein, Lustig, Rivas, & Jha, 2009). ERP investigation has also indicated that attention modulates the early P1 and N1 components for face-stimuli (Wijers & Banis, 2012), although we note that it is not possible to dissociate the effects of spatial and task-based attention in this latter study. Lastly, ERP studies have also suggested that emotional expression effects evident around 100ms following face-presentation are also dependent on spatial attention (Holmes et al., 2003). Taken together, these neurophysiological findings suggest that attention modulates the *early sensory processing of faces*. The results reported in this thesis are very much in line with this possibility, in that they reveal attentional modulation of nonconscious face-processing at a similarly early stage of stimulus processing, less than 300ms following target onset.

Importantly, where the modulatory effect of attention on face perception has been relatively well documented in the neuroimaging literature, to date there has been very little *behavioural evidence* that attention is capable of modulating face-perception at all (Finkbeiner & Palermo, 2009; Harry et al., 2012; Khalid et al., 2013; Reddy, Moradi, & Koch, 2007; Reddy, Reddy, & Koch, 2006; Reddy, Wilken, & Koch, 2004). This discrepancy has represented something of a problem for clarifying the role of attention in

face-perception – after all, it is difficult to interpret the behavioural relevance of even the most reliable neurophysiological results in the absence of corresponding effects on human behaviour. As such, the findings of this thesis represent an important contribution to this debate within the face-perception literature, in that they constitute clear *behavioural evidence* that the allocation of both spatial and temporal attention modulates the degree to which the visual system processes nonconscious face information. In this way, the research presented in this thesis contributes to a more coherent understanding of the relationship between face processing and attention.

### **6.3.3. *Contrasting behavioural indices of cognition***

A key reflection to consider at this point is why the studies in this thesis observed attentional modulation of face-processing where previous behavioural investigations have failed to find such effects (Finkbeiner & Palermo, 2009; Harry et al., 2012; Khalid et al., 2013; Reddy et al., 2007; Reddy et al., 2006; Reddy et al., 2004). I would suggest that the principle factor underlying the different pattern of results is the use of differing behavioural measures. In this thesis, I was careful to employ a behavioural measure capable of revealing experimental effects in the same early stage of stimulus-processing during which attention has been shown to modulate the neural response to faces (see Holmes et al., 2003; Jacques & Rossion, 2007; Wijers & Banis, 2012). In the version of the Reach-to-Touch paradigm used here, I analysed kinematic properties of participants' reaching movements as a function of how long the participant viewed the target on each trial. As a result, I was able to observe attentional effects as they unfolded during the early stages of stimulus-processing time (less than 300ms from target onset). By contrast, previous behavioural investigations of the role of attention in face perception have typically employed button-press response paradigms, in which experimental effects are reflected in a comparison of mean response times (RTs) and/or accuracy rates. Since most

evidence accumulation processes have reached asymptote by the time participants are able to execute a button press response (e.g. 400-600ms after stimulus onset), experimental effects reflected in RT provide a *cumulative* index of preceding cognitive processes. On the assumption that face recognition is a highly efficient process (Bruce & Young, 1998; Purcell & Stewart, 1988), it may be the case that it is only possible to observe attentional modulation of face-processing if the system is probed at a point in time while evidence accumulation is still ongoing. If this were true, then we would expect measures that can index cognitive processing during *stimulus-processing time* (e.g. ERP or the Reach-to-Touch paradigm) to reveal attentional modulation of face processing, where comparatively ‘later’ indices of underlying cognitive processing may not.

#### **6.4. Key Finding 3: Nonconscious face-processing is supported better in the upper-hemifield compared to the lower-hemifield**

A third goal of this thesis was to examine **the influence of spatial location on face-processing**. In contrast to the well-documented laterality effects for face-perception (Gainotti, 2013; Yovel, Levy, Grabowecky, & Paller, 2003), in this thesis I sought to clarify how placement along the *vertical meridian* modulates the way the visual system processes faces. A guiding influence for this line of enquiry was Previc's (1990) functional specialisation account of vertical asymmetries in vision. According to this theory, the differences in visual perception between the upper visual field (UVF) and lower visual field (LVF) (e.g. Carrasco et al., 2001; Fecteau, Enns, & Kingstone, 2000; Karim & Kojima, 2010; Levine & McAnany, 2005; T. Liu, Heeger, & Carrasco, 2006; Previc & Blume, 1993; Talgar & Carrasco, 2002; Thomas & Elias, 2011) reflect specialisation of the visual capabilities associated with far and near space. Specifically, the LVF has become specialised to support motion and global information processing (Amenedo, Pazo-Alvarez, & Cadaveira, 2007; Christman, 1993; Edwards & Badcock, 1993; Levine & McAnany, 2005; Rezec & Dobkins, 2004) that facilitates visuomotor coordination required in near or peripersonal space (i.e., the region in which we reach toward and grasp objects). Conversely, the UVF is linked with the visual search and recognition mechanisms most often required in far or extrapersonal space; the region in which we typically search for and discriminate objects and people (Chaiken, Corbin, & Volkmann, 1962; Chambers, McBeath, Schiano, & Metz, 1999; Previc & Blume, 1993; Previc & Naegele, 2001; Yund, Efron, & Nichols, 1990). In this thesis, I sought to determine whether face-perception, as a critical form of object-recognition, might exhibit an upper-hemifield advantage – an intuitive possibility for which the evidence to date has been largely equivocal (Fecteau et



al., 2000; Hagenbeek & Van Strien, 2002; Kessler & Tipper, 2004; L. Liu & Ioannides, 2010; Schwarzlose, Swisher, Dang, & Kanwisher, 2008). To maximise the likelihood of observing a UVF advantage for face-perception, I examined how vertical hemifield placement modulated visual perception of *degraded* faces using the masked priming paradigm.

#### **6.4.1. Establishing the upper-hemifield advantage for faces**

A breakthrough finding reported in this thesis is that **nonconscious face-processing enjoys an advantage in the upper-hemifield relative to the lower hemifield**. In support of this claim are two key results. First, we have reported a UVF advantage in the timecourse of masked congruence priming effects for faces. Specifically, nonconscious face primes in Study 2 elicited a reliable priming effect around 80ms sooner when presented above-fixation compared to below-fixation. A similar UVF advantage reflected in the timecourse of the MCE was found in a different group of participants in Study 4. Taken together, these data suggest that the visual system processes masked prime faces *more efficiently* when these stimuli appeared in the UVF than the LVF, allowing the prime to be integrated into the target-classification response sooner in the UVF. Second, Study 2 revealed a differential benefit of spatial attention between the vertical hemifields. In this study, masked priming effects elicited by UVF face primes did not depend on the appropriate allocation of attention by a spatial cue, arising even when attention had been captured away from the prime's location. In contrast, when the masked prime face appeared in the lower-hemifield, congruence priming effects only arose when a valid spatial cue captured attention to the prime's location. The finding that nonconscious face-processing benefits from attention in the LVF, but not the UVF, again suggests that face-sex information is processed more efficiently in the upper-hemifield than in the lower-hemifield.

The finding that face-processing enjoys an upper-hemifield advantage represents a critical contribution to the literature concerned with vertical asymmetry in visual perception. That is, while UVF/LVF differences have been well-documented for a range of low-level perceptual stimuli (Amenedo et al., 2007; Carrasco et al., 2001; Christman & Niebauer, 1997; Edwards & Badcock, 1993; Karim & Kojima, 2010; Levine & McAnany, 2005; T. Liu et al., 2006; Niebauer & Christman, 1998; Previc & Blume, 1993; Previc & Naeyele, 2001; Skrandies, 1987; Talgar & Carrasco, 2002; Thomas & Elias, 2011), there have been comparatively few investigations of vertical hemifield differences in the object recognition literature (Chambers et al., 1999; Goldstein & Babkoff, 2001; Schwartz & Kirsner, 1982). Nevertheless, the findings reported here are consistent with recent evidence that suggests individuals are better at recognising previously-seen faces when the target face is initially encoded at an upper-hemifield location compared to a lower-hemifield location (Felisberti & McDermott, 2013). Others have shown that regions such as the medial prefrontal cortex (MPFC), left fusiform face area (FFA), and left occipital face area (OFA) are activated earlier by UVF faces than LVF faces (L. Liu & Ioannides, 2010). Lastly, there is some secondary evidence that face-processing may be supported better in the upper-hemifield than the lower-hemifield in studies of inhibition and face-comparison (Coolican, Eskes, McMullen, & Lecky, 2008; Kessler & Tipper, 2004). Importantly, although these existing studies certainly allude to the possibility of an upper-hemifield advantage for face-perception, the evidence they contribute in this regard is not particularly compelling (see Studies 2-4 for a critical review). For example, although Liu and Ioannides (2010) report earlier peak latencies for UVF faces than LVF faces in the *left* FFA, the authors observed the reverse pattern of results for the *right* FFA. In addition, the behavioural measure in this study did not correlate in any clear way with the effects observed in their electrophysiological measure, making it difficult to interpret the functional relevance of the UVF advantage reflected in the neural data. Given the limited

nature of this existing literature, the present finding that masked congruence effects for faces are superior in the UVF compared to the LVF constitutes perhaps the most compelling evidence to date for the claim that face-perception is superior in the upper-hemifield. As such, the results presented in this thesis contribute some of the strongest empirical support for Previc's (1990) proposal that vision in the UVF is specialised to support visual object recognition mechanisms.

#### **6.4.2. *Vertical asymmetry in nonface object recognition***

Where the goal of Study 2 was to establish the upper-hemifield advantage for face-processing, Studies 3 and 4 sought to examine potential mechanisms underlying this effect. I began this line of enquiry by considering Previc's suggestion that the upper-hemifield has become specialised to support object recognition processes *in general*. If this is indeed the case, then the UVF advantage should not be limited to tasks involving face-perception, but rather extend to tasks involving recognition of nonface stimuli as well. A handful of studies allude to this possibility, suggesting that recognition of novel objects (Chambers et al., 1999), letters (Schwartz & Kirsner, 1982), and words (Goldstein & Babkoff, 2001) may be advantaged above-fixation relative to below-fixation. These findings are by no means robust, however, with other researchers reporting mixed or equivocal vertical hemifield effects (Darker & Jordan, 2004; Hagenbeek & Van Strien, 2002). As such, the nature of vertical asymmetry effects for nonface objects remains unclear. Study 3 sought to clarify this ambiguity by examining how vertical hemifield would modulate sex-categorisation of **human hands**. The design for this Study was closely modelled after that of Study 2, including both a manipulation of focussed spatial attention and vertical hemifield. A key difference between the studies, however, was that

Study 3 did not employ masked priming techniques, as we reasoned that sex-categorisation of hand stimuli may not be robust to masking<sup>2</sup>.

The results of Study 3 indicated that the effect of focussed spatial attention on hand-sex categorisation was qualified by vertical hemifield. Just as we observed for face stimuli in Study 2, the provision of a valid spatial cue in Study 3 only improved the efficiency of the sex-categorisation response for hand targets that appeared in the LVF. When the target appeared in the UVF, cue validity had no effect on the efficiency with which participants could classify its sex. On the assumption that focussed spatial attention will provide the most aid to the least privileged locations (Carrasco, Giordano, & McElree, 2004; Carrasco & Yeshurun, 1998; Yeshurun & Carrasco, 1998; 1999), the finding that target classification responses were more sensitive to the effects of spatial attention in the LVF than the UVF suggests that sex-categorisation of human hands is *less robust* in the lower-hemifield than the upper-hemifield. These results for hand sex-categorisation are highly consistent with the findings reported in this thesis for face stimuli, in that both experiments indicated the lower hemifield to be more sensitive to the effects of spatial attention than the upper hemifield.

While these similar findings for faces and hands provide good reason to think that the UVF advantage may not be limited to tasks involving face-perception, some caution is needed in interpreting the combined findings of Studies 2 and 3 as evidence for a *stimulus general* UVF advantage in object recognition (as per Previc, 1990). Given that faces and hands represent a subset of a particular stimulus class (i.e., human body parts), there is a

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<sup>2</sup> To the best of the author's knowledge, although hand stimuli have been employed in both sex-categorisation tasks (Gaetano, van der Zwan, Blair, & Brooks, 2014; Kovács et al., 2006) and masked priming tasks (e.g. Di Luca & Pesenti, 2008), no study has combined the two to date. The ability of masked hand stimuli to elicit congruence priming effects in a sex-categorisation task is thus unknown.

clear need to validate this finding across other subcategories of object-recognition before making any strong claims about a UVF advantage for object recognition *in general*. Recent advancements in our understanding of the temporal dynamics of object categorisation in the brain offer a novel approach in pursuit of this possibility. Pattern analysis methods applied to neural data have described a representational space for objects in human inferior temporal cortex in which object exemplars are both discriminable from one another and clustered by category (e.g. faces vs. animals). A recent MEG study by Carlson, Tovar, Alink, and Kriegeskorte (2013) employed this approach to detail the emergence of such a representational structure over the first 1000ms of visual processing. The authors reported that both exemplar identity and category membership could be decoded from around 100ms following stimulus onset. In light of the findings reported here, an interesting question is whether characteristics of this representational structure might differ for UVF and LVF objects. Given the *temporal advantage* for UVF information processing we have shown in Studies 2 and 4, it might be the case that object category membership can be decoded from neuromagnetic recordings at a slightly earlier point in time when objects are presented in the UVF as compared to the LVF.

#### ***6.4.3. Exploring underlying mechanisms of the upper-hemifield advantage in face- and hand-sex categorisation***

Given that the UVF advantage for face and hand recognition reported here appears to resonate with Previc's functional specialisation account of vision, it is interesting to consider what possible *mechanism* might underlie this upper-hemifield superiority in object recognition. It is clear at the outset that the direction of vertical asymmetry reported in this thesis is not readily explained by underlying physiological differences between the upper and lower retinae and subsequent visual pathways. For example, better task performance in the *lower hemifield* (Abrams, Nizam, & Carrasco,

2012; Carrasco et al., 2001; T. Liu et al., 2006; Talgar & Carrasco, 2002) is often related to the greater cone and ganglion cell densities in the superior part of the retina on which information presented in the LVF falls (Perry & Cowey, 1985). Similarly, studies with non-human primates have suggested that slightly more neural tissue in lateral geniculate nucleus corresponds to representations of the LVF than the UVF (Connolly & Van Essen, 1984), V1 (Tootell, Switkes, Silverman, & Hamilton, 1988; Van Essen, Newsome, & Maunsell, 1984), and MT (Maunsell & Van Essen, 1987). In humans, the same Gabor stimuli have been shown to evoke a larger volume of activity in early visual cortex when presented in the LVF compared to the UVF (T. Liu et al., 2006). While these findings appear nicely consistent with the various instances of lower-hemifield advantages (Abrams et al., 2012; Carrasco et al., 2001; T. Liu et al., 2006; Talgar & Carrasco, 2002), they do not offer much explanatory power for the UVF advantage reported here.

#### **6.4.3.1. Dispelling the ‘attentional bias’ account**

An alternative account, proposed and tested in the final empirical study of this thesis, is that the UVF advantage observed for both face and hand recognition might relate to a generalised **upward bias in participants’ voluntarily directed spatial attention** (see Bradshaw, Nettleton, Nathan, & Wilson, 1985; Drain & Reuter-Lorenz, 1996; Drummond & Tlauka, 2012; van Vugt, Fransen, Creten, & Paquier, 2000). On this account, the UVF might be less sensitive than the LVF to the effects of exogenously captured spatial attention (as was found in Studies 2 and 3) due to the fact that participants are *already attending*, consciously or otherwise, to the upper-hemifield. To pursue this possibility, Study 4 manipulated the focus of participants’ voluntary spatial attention by varying target location probability. On day 1, targets appeared with equal probability in the UVF and LVF, encouraging a diffuse spread of spatial attention. By contrast, on Day 2 80% of targets appeared in the LVF – a manipulation designed to encourage participants to *voluntarily attend* to the lower-hemifield. I reasoned that if the UVF advantage observed in

Studies 2 and 3 did indeed arise as a result of an upward bias in participants' voluntarily directed attention, then encouraging participants to voluntarily attend *away* from this location should attenuate the UVF advantage evident in the timecourse of masked face-processing. Importantly, the results obtained in Study 4 did not support such an interpretation. Although directing voluntary attention to the LVF clearly facilitated masked congruence priming in this region of space, there was no commensurate decrease in priming in the UVF under these conditions. Nonconscious face-processing in the upper-hemifield *did not vary* as a function of our manipulation of voluntarily directed spatial attention, suggesting that a bias in the allocation of this attentional resource is unlikely to explain the UVF advantage for face and hand sex-recognition reported in this thesis.

#### **6.4.3.2. A second alternative: An expectation-based account**

While the results presented in this thesis strongly undermine the likelihood that the upper-hemifield advantage for face-processing is driven by an upward bias in voluntarily directed spatial attention, it is worth noting that attention is not the only top-down process capable of modulating basic perceptual processing. Where endogenously directed attention prioritises stimulus processing on the basis of task demands, *expectation* can constrain visual interpretation on the basis of prior knowledge (Summerfield & Egner, 2009) by sharpening sensory representations (Kok, Jehee, & de Lange, 2012). It is well established, for example, that object detection is facilitated by a congruent context (e.g. a coffee cup in a kitchen scene will be found faster than the same cup in a beach scene) (Davenport, 2007; Fize, Cauchois, & Fabre-Thorpe, 2011). Moreover, Biederman has singled out both probability and spatial position as important relations which affect object recognition in scenes (Biederman, Mezzanotte, & Rabinowitz, 1982). Thus, it is reasonable to think that our wealth of experience encountering faces in extrapersonal space could well have engendered in us a very strong expectation that face stimuli are more likely to appear above-fixation than below. Indeed, there is some evidence that long term experience can

modulate the degree of position-dependence inherent in representation (Kravitz, Vinson, & Baker, 2008). For example, neurons in monkey IT exhibit highly position-dependent responses in the context of extensive practice discriminating small stimuli presented in a limited number of positions in the visual field (DiCarlo & Maunsell, 2003). Just as expectation of object category is known to increase the efficiency with which category exemplars are processed (Puri & Wojciulik, 2008), presumably a perceptual prior which also encompasses spatial location might be expected to facilitate exemplar processing in an anisotropic manner. In this way, a relatively inflexible prior expectation about where faces usually appear could explain the UVF advantage observed when target location is unpredictable (i.e., Study 2, and Study 4, Experiment 1). This possibility remains speculative at this juncture, however, particularly since it provides less explanatory power for our additional finding that sex-categorisation of hand stimuli is also subtly advantaged in the upper- compared to the lower-hemifield.

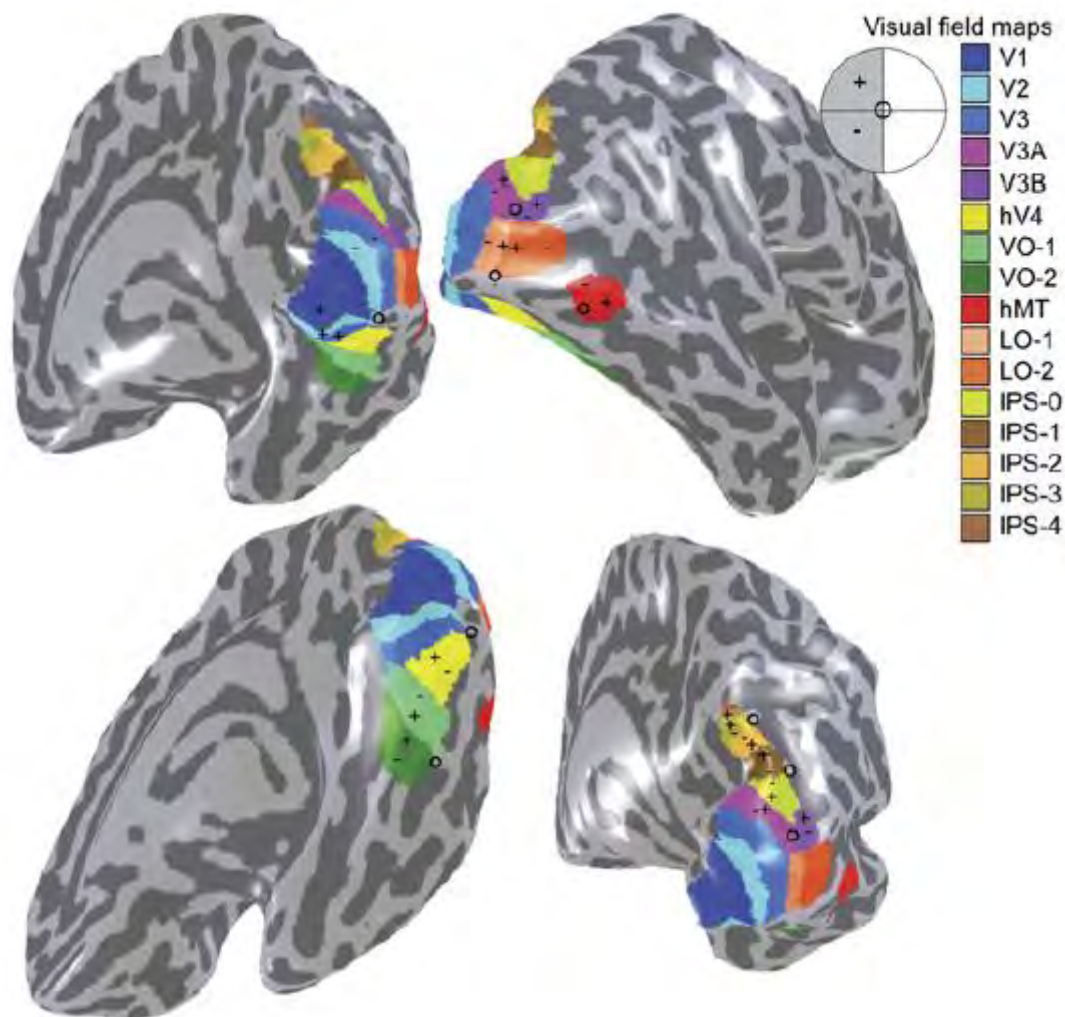
#### **6.4.3.3. A third alternative: A neuroanatomical layout account**

In yet another possibility, it may be that there is a *neuroanatomical* explanation for why recognition of both faces and hands should be advantaged in the UVF over the LVF. This speculative possibility draws on the dual-pathway account of visual perception (Goodale & Milner, 1992; Ungerleider & Mishkin, 1982), in which object recognition is proposed to proceed along a ventral visual pathway beginning at primary visual cortex (V1). From here, information processing proceeds through a series of hierarchical stages (V2-V4) to the anterior regions of inferior temporal cortex (IT) considered critical for object recognition (Grill-Spector & Malach, 2004), including face- and hand-sex categorisation (Andreasen et al., 1996; Freeman, Rule, Adams, & Ambady, 2010; Sergent, Ohta, & Macdonald, 1992). Importantly, it is well established that early visual areas are characterised by a retinotopic layout such that visual information presented to the upper and lower visual fields is initially represented in the ventral and dorsal regions of V1



respectively (i.e., below and above the calcarine fissure) (Felleman & Van Essen, 1991; Horton & Hoyt, 1991; Sereno et al., 1995; Van Essen et al., 1984; Zeki, 1969). Interestingly, we now also know that this retinotopy proceeds beyond V1 (Grill-Spector & Malach, 2004; Sereno et al., 1995; Ungerleider & Mishkin, 1982; Wandell, Dumoulin, & Brewer, 2007; Zeki, 1969). In Figure 1 below (adapted from Wandell et al, 2007), it can be seen that the segregation of upper and lower hemifield representation is maintained throughout V1, V2, and V3.

Also clear in Figure 1 is the adjacent layout of early visual areas. Tusa and Ungerleider (1985) have suggested that object recognition processes are subserved by an occipito-temporal projection system which passes visual signals from one area to the next in a hierarchical fashion. Information is passed via a series of white matter short-association U-shaped fibres (also called “autochthonous fibres”) which connect striate, pre-striate, and inferior temporal cortex (Vergani, Mahmood, Morris, Mitchell, & Forkel, 2014). Tractography studies using diffusor tensor MRI have provided support for such an occipito-temporal projection system, revealing this chain of U-shaped fibres in exquisite visual detail (see Catani, Jones, Donato, & Ffytche, 2003; Catani & Thiebaut de Schotten, 2012). Since the ventral regions of V1, V2, and V3 are situated in closer proximity to ventral occipital object recognition areas than their dorsal counterparts (Catani & Thiebaut de Schotten, 2012; Grill-Spector & Malach, 2004), it may be that visual signals carrying UVF representations (initially projected below the calcarine fissure) traverse a relatively short pathway to object recognition areas along this U-fibre network. Conversely, LVF information is initially projected to the dorsal regions of V1, V2, V3, from which transfer of information to object recognition areas may take slightly longer. Very recent dissection work has suggested that this transfer may be mediated by a white matter tract connecting the cuneus to the lingual gyrus (Vergani et al., 2014).



*Figure 1.* Visual field maps as described by Wandell et al. (2007), shown on an inflated rendering of the cortical surface of the right hemisphere. Colours represent hierarchical processing visual areas based on measurements of one participant in the Wandell et al. study. The fovea and upper and lower visual field representations given by the 'o', '+', and '-' signs, respectively. Adapted from Wandell, B. A., Dumoulin, S. O., & Brewer, A. A. (2007). Visual field maps in human cortex. *Neuron*, 56(2), 366-383. Copyright 2007, under the "Fair Dealing" provision of the Copyright Act.

The possibility that signals carrying information about the UVF traverse a shorter pathway from early striate cortex to ventral object recognition areas would fit well with our suggestion that the visual system accrues information *more efficiently* from face and hand stimuli presented in the UVF compared to the LVF. In Study 2, for example, probing the system at the same early point in stimulus processing time revealed more task-relevant information when the masked face appeared in the UVF than in the LVF. A differential speed-of-information-transfer for the UVF and LVF could also explain the increased sensitivity of the LVF to our manipulations of spatial attention (see Studies 2 & 3). That is, if information transfer to object recognition areas is slower for LVF targets than for UVF targets, then we might expect attention to benefit this comparatively less efficient processing for the LVF to a greater extent.

## **6.5. *Concluding Remarks***

The research presented in this thesis provides insight into the temporal dynamics of nonconscious information processing and the factors which modulate this hidden cognitive process. Using congruence priming effects for masked faces as an index of nonconscious perception, I have examined how information processing below our level of conscious awareness is affected by manipulations of spatial and temporal attention. The results reported here reveal a unique characteristic of nonconscious face-processing: that it proceeds even outside the focus of attention, whereas nonconscious perception of stimuli such as words and letters does not. Moreover, the results of this thesis establish that attention modulates nonconscious information processing in a *graded* fashion that mirrors attention's influence on the perception of consciously presented stimuli. This finding represents a breakthrough in the study of how attention and awareness interact, insofar as previous investigations have often characterised the influence of attention on nonconscious

perception as purely categorical. A parallel goal of this thesis was to examine the impact of vertical hemifield presentation on nonconscious face-processing. I have shown here that nonconscious faces are processed more efficiently in the upper-hemifield than the lower-hemifield, suggesting that human face-perception enjoys an advantage in the upper visual field. The findings of this thesis further suggest that this UVF advantage may extend to recognition of at least one type of nonface object (human hands), and verify that the upper-hemifield superiority for face-perception is not readily explained by an upward bias in participants voluntarily directed spatial attention. These findings represent an important contribution to the literature concerned with vertical asymmetry in vision, particularly as the impact of vertical hemifield presentation on the perception of *higher-level objects* remains relatively unexplored. In this way, the findings presented in this thesis provide some of the first empirical support for Previc's (1990) functional specialisation account of vertical asymmetries in visual perception.

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## APPENDIX ONE

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### ETHICAL APPROVALS

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----- Original Message -----

Subject: ethics amendment approved

Date: Mon, 08 Feb 2010 10:55:06 +1100

From: ethics secretariat <>

To: <>

Dear Matthew

Re: Attention, intention and automaticity (HE22FEB2008-R05671).

Thank you for your recent email. The following amendment has been approved:

1. The addition of **Ms Genevieve Quek** as a Co-Investigator on the project. Ms Quek will be conducting the research for a PhD.
2. The information and consent form has been amended to reflect the above change.

Please do not hesitate to contact me if you have any questions or concerns.

Regards

Fran Thorp

Ethics Officer (human Research)

\*\*\*\*\*

Office of the Deputy Vice Chancellor (Research)

Ethics Secretariat

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----- Original Message -----

Subject: HS Ethics Application - Approved (5201300060)(Con/Met)

Date: 30 April 2013 15:36

From: Fhs Ethics <f>

To: <>, <>

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Dear Dr Finkbeiner,

Re: "Attention, Intention and Automaticity"(5201300060)

Thank you for your recent correspondence. Your response has addressed the issues raised by the Faculty of Human Sciences Human Research Ethics Sub-Committee, effective 30th April 2013. This email constitutes ethical approval only.

This research meets the requirements of the National Statement on Ethical Conduct in Human Research (2007). The National Statement is available at the following web site:

[http://www.nhmrc.gov.au/files\\_nhmrc/publications/attachments/e72.pdf](http://www.nhmrc.gov.au/files_nhmrc/publications/attachments/e72.pdf).

The following personnel are authorised to conduct this research:

Dr Brenda Ocampo  
Dr Matthew Finkbeiner  
Miss Shahd Al-Janabi  
Mr Anthony Espinosa  
Mr Manjunath Narra  
**Ms Genevieve Lauren Yu Jing Quek**  
Ms Lucy Shi  
Ms Marina Butko

Please note the following standard requirements of approval:

1. The approval of this project is conditional upon your continuing compliance with the National Statement on Ethical Conduct in Human Research (2007).
2. Approval will be for a period of five (5) years subject to the provision of annual reports.

Progress Report 1 Due: 30th April 2014  
Progress Report 2 Due: 30th April 2015  
Progress Report 3 Due: 30th April 2016  
Progress Report 4 Due: 30th April 2017  
Final Report Due: 30th April 2018

NB. If you complete the work earlier than you had planned you must submit a Final Report as soon as the work is completed. If the project has been discontinued or not commenced for any reason, you are also required to submit a Final Report for the project.



Progress reports and Final Reports are available at the following website:

[http://www.research.mq.edu.au/for/researchers/how\\_to\\_obtain\\_ethics\\_approval/human\\_research\\_ethics/forms](http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics/forms)

3. If the project has run for more than five (5) years you cannot renew approval for the project. You will need to complete and submit a Final Report and submit a new application for the project. (The five year limit on renewal of approvals allows the Sub-Committee to fully re-review research in an environment where legislation, guidelines and requirements are continually changing, for example, new child protection and privacy laws).

4. All amendments to the project must be reviewed and approved by the Sub-Committee before implementation. Please complete and submit a Request for Amendment Form available at the following website:

[http://www.research.mq.edu.au/for/researchers/how\\_to\\_obtain\\_ethics\\_approval/human\\_research\\_ethics/forms](http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics/forms)

5. Please notify the Sub-Committee immediately in the event of any adverse effects on participants or of any unforeseen events that affect the continued ethical acceptability of the project.

6. At all times you are responsible for the ethical conduct of your research in accordance with the guidelines established by the University. This information is available at the following websites:

<http://www.mq.edu.au/policy>

[http://www.research.mq.edu.au/for/researchers/how\\_to\\_obtain\\_ethics\\_approval/human\\_research\\_ethics/policy](http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics/policy)

If you will be applying for or have applied for internal or external funding for the above project it is your responsibility to provide the Macquarie University's Research Grants Management Assistant with a copy of this email as soon as possible. Internal and External funding agencies will not be informed that you have approval for your project and funds will not be released until the Research Grants Management Assistant has received a copy of this email.

If you need to provide a hard copy letter of approval to an external organisation as evidence that you have approval, please do not hesitate to contact the Ethics Secretariat at the address below.

Please retain a copy of this email as this is your official notification of ethics approval.

Yours sincerely,

Dr Peter Roger  
Chair  
Faculty of Human Sciences Ethics Review Sub-Committee  
Human Research Ethics Committee

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## APPENDIX TWO

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### PUBLISHED MANUSCRIPTS

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