The Effects of Eye Gaze and Head Orientation On Covert Attention Capture

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners. I understand that my thesis may be made electronically available to the public.

Abstract

The direction of someone's eye gaze plays a fundamental role during social interactions and may function to capture and engage attention in the environment. Research has shown that direct eye gaze can preferentially attract visuospatial attention compared to averted gaze, while other research has shown that the congruency between head orientation and gaze direction plays a central role in determining where a person is looking. The majority of previous research examining the perception of gaze direction has predominantly measured *overt* attention, either through visual search paradigms, or other gaze judgment tasks when targets are directly fixated. However, it is unknown whether gaze direction can be accurately discriminated using *covert* attention, when stimuli are located outside the focus of attention. This thesis presents a series of studies examining whether and to what extent gaze direction and head orientation capture covert attention in the periphery. Chapter 2 contained four experiments examining gaze detection in the horizontal periphery. Individual faces with a direct- or an averted gaze were flashed for 150 ms across various horizontal eccentricities along the visual field while participants judged whether the face was looking straight or to the side. Fixation on a centred cross was enforced using an eye-tracker, ensuring the use of covert attention. Gaze detection speed and accuracy varied with stimulus type and eccentricity. Accurate gaze detection was achieved all the way to ±10.5° eccentricity when face photographs were highly symmetrical and controlled for visual contrast and luminance (Experiment 1a), but only to ±4.5° eccentricity when using natural face photographs (Experiments 1b, 1c, and 1d). By ±3º of eccentricity, head orientation started biasing gaze judgments, and this bias increased with eccentricity so that beyond central vision gaze judgment was primarily made on the basis of head orientation. However, when presented at the fovea, direct gaze was generally detected faster than averted gaze. Results also suggested a

facilitated processing of frontal heads with direct gaze in both central and peripheral vision. Chapter 3 contained three experiments that examined gaze detection in the vertical periphery. These experiments used the same paradigm as in Chapter 2, except with presenting stimuli across various vertical eccentricities (only natural face photographs were used). Gaze was detected above chance level up to ±3° eccentricity when using frontal heads (Experiment 2a), but over ±6° eccentricity when using deviated heads (Experiment 2b); Experiment 2b also showed that head orientation did not play a strong role in biasing gaze judgments. However, it was demonstrated that, beyond foveal vision, head orientation influenced gaze judgments when both head orientations were tested together (Experiment 2c), and that gaze was discriminated accurately only within central vision (~3°-4.5° eccentricity). Again, there was a special processing of frontal heads with direct gaze. Chapter 4 contained two experiments that investigated how gaze direction and head orientation influenced attention capture using an inhibition of return (IOR) spatial cueing paradigm. Target response time (RT) was measured after the presentation of a stimulus cue (150 ms situated 4.5° horizontally to either left or right of fixation), which was either a face (with direct- or averted gaze) or a house (control). Participants fixated on a centred cross at all times and responded via button press to a peripheral target after a variable stimulus onset asynchrony (SOA) from the stimulus cue. At the shortest SOA (150 ms), RTs were shorter for faces than houses, independent of an IOR response, suggesting a priming effect elicited by faces. At the longest SOA (2400 ms), a larger IOR magnitude was found for faces compared to houses. Both the priming effect and later IOR responses were modulated by gaze-head congruency; these effects were strongest for direct gaze faces with frontal heads (Experiment 3a), and for averted gaze faces with deviated heads (Experiment 3b). Overall, the series of studies in this thesis indicate that gaze direction and head orientation can be powerful social cues for capturing and engaging attention, and both contribute to gaze detection in the environment, but their roles differ with eccentricity.

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Table of Contents

List of Figures

Chapter 1: General Introduction

"The eyes are the window of the soul."

—English Proverb

The meaning of this familiar proverb implies that by looking into the eyes of a person, one can see their true emotions, attitudes, and thoughts. Eye contact is a major medium in nonverbal interaction through which we communicate our intentions and desires. The direct eye gaze of another person may be so powerful that it even captures our attention when we are not looking at the gazing individual. For example, you may have had the feeling of someone looking at you from across a room even when you were not paying attention or making direct eye contact with them. In this case, you might have been able to detect their gaze by means of a cognitive mechanism vigilant to whether someone is looking at you or not. This makes sense since human eyes play such a fundamental role during social interactions. By accurately detecting another person's gaze direction, you are able to rapidly decipher their intentions, which may also affect you, the observer. However, research is lacking on whether this hypothetical cognitive mechanism exists, and whether we can detect gaze using just our peripheral vision, when we are not directly fixated on the eyes of the target. In fact, another social cue, such as the orientation of one's head, and whether it is facing toward you or not, may also contribute to the feeling of being looked at or not, especially in the periphery. The following PhD thesis investigated whether and to what extent gaze direction and head orientation captures our covert attention in the environment. Chapter 1 reviews literature on human face perception and eye gaze processing, and on the attention capture by these stimuli. Chapter 2 examines gaze detection across horizontal eccentricities, when faces are presented in the left or right visual fields. Chapter 3 examines gaze detection across vertical eccentricities, when faces are presented in the upper or lower visual fields. Chapter 4 examines how gaze direction and head orientation modulate attention capture using an inhibition of return (IOR) spatial cueing paradigm. Finally, Chapter 5 presents an overview of the findings and the implications of the present research.

1.1 The Importance of Human Faces and Human Eyes

Human faces reveal a great deal of social information to a perceiver, including identity, gender, age, race, attractiveness, and emotions (e.g., Cunningham, 1986; Ekman & Oster, 1979; Hall et al., 2005; Schyns et al., 2002). A face is the most distinctive and widely used key to a person's identity and personal characteristics (Bruce & Young, 1986). During the free-viewing of visual scenes, attention is strongly drawn toward faces, even when presented with entire bodies (Fletcher-Watson et al., 2008; Hewig et al., 2008; Palanica & Itier, 2012). The human brain is known to have a neural network specialized for processing facial stimuli (Allison et al., 1999; Haxby et al., 2000, 2002; Hoffman & Haxby 2000; McCarthy et al., 1999; Puce et al., 1999), and very early in life, human infants start to fixate on faces and respond to different facial expressions (Johnson et al., 1991; Morton & Johnson, 1991). Newborns will also visually track a schematic face farther into the periphery than a scrambled face (Goren et al., 1975), and prefer to look at upright rather than inverted schematic faces (Mondloch et al., 1999). Because human faces are biologically and socially significant, the brain may have evolved to be more responsive to faces which can preferentially capture and engage attention compared to other stimuli (Bindemann et al., 2005; Langton et al., 2008; Palermo & Rhodes, 2007; Ro et al., 2001).

When viewing complex social scenes, faces capture more attention than any other body part, and observers tend to look preferentially toward the eyes relative to other facial areas (Birmingham et al., 2008a, 2008b, 2009; Smilek et al., 2006). The eyes are even the most attended facial feature when faces are presented in isolation (e.g., Walker-Smith et al., 1977; Pelphrey et al., 2002; Itier et al., 2007b). The activity of specific neurons in the monkey brain has also been shown to be modulated by the presence and position of the eyes (Perrett et al., 1985, 1990). The eyes of humans are very unique among other species in the animal kingdom. For instance, the ratio of exposed sclera to iris in the eye outline is largest in the human species, and is white only in humans (Kobayashi & Kohshima, 1997). Evolutionary hypotheses claim that human eyes evolved from a necessity to communicate emotional and mental states, and information about the environment. The importance of social interaction may have been driven by morphological changes to the face and eyes of primates (e.g., a flattening of the snout and a more prominent front-facing eye socket) so that these facial features can precisely focus attention to objects or other people in the environment (Emery, 2000). Human eyes are important because they are used to detect and discriminate gaze direction. The eye morphology in humans seems to have evolved from a necessity for complex social interactions (Emery, 2000), and the large ratio of exposed sclera in human eyes seems to be an adaptation to enhance the gaze signal (Kobayashi & Kohshima, 1997). By contrast, other animals, like many predators (e.g., alligators, tigers, owls), do not have an easily detectable gaze because their prey should not know when they are staring at them. Thus, human faces and eyes can be unique and powerful social-communicative stimuli for summoning visual attention. The basis of this thesis is to investigate how facial stimuli capture our attention to discriminate gaze direction.

1.2 The Power of Gaze Direction

Gaze direction in humans clearly shows others where their attention lies, and is essential to nonverbal communication and human social cognition, specifically for engaging and orienting attention (for reviews, see George & Conty, 2008, and Itier & Batty, 2009). It has also been shown that the human brain contains a complex network of areas involved in processing gaze, including the fusiform gyrus, amygdala, medial prefrontal cortex, orbitofrontal cortex, and intraparietal sulcus (for reviews, see Itier & Batty, 2009, Senju & Johnson, 2009, and Nummenmaa & Calder, 2009), with one of the most vital areas being the anterior and posterior regions of the superior temporal sulcus (STS; Allison et al., 2000; Bristow et al., 2007; Calder et al., 2002; Hoffman & Haxby, 2000; Hooker et al., 2003; Pelphrey et al., 2004b; Schilbach et al., 2006; Wicker et al., 2003). In everyday life, gaze signals play a fundamental role to capture and orient attention, where direct- and averted eye gaze seem to support different functions.

Eye contact, also called direct or mutual gaze, is defined as another person looking into your eyes, and this direct gaze serves many functions in life. We use eye contact to regulate conversation and intimacy level, to communicate interest or disinterest, to influence others, and to express emotions and intentions (for a review, see Kleinke, 1986). Furthermore, eye contact usually plays the first role when initiating a social encounter, even before interpersonal distance, touch, body language, or verbal speech. Direct gaze, relative to averted gaze, can also improve face recognition (Hood et al., 2003; Vuilleumier et al., 2005), facilitate gender categorization (Macrae et al., 2002), and increase attractiveness ratings (Conway et al., 2008; Ewing et al., 2010; Kampe et al., 2001, Palanica & Itier, 2012). Research has also shown that direct gaze can capture and engage visual attention better than averted gaze. For example, visual search paradigms have shown that direct gaze is detected faster overall than averted gaze in a crowd of opposite-gaze distractors (i.e., a direct gaze target among several averted gaze distractors, or vice versa)—a phenomenon known as the “stare-in-the-crowd effect” (Conty et al., 2006; Doi & Ueda, 2007; Doi et al., 2009; Palanica & Itier, 2011; Senju et al., 2005; Shirama, 2012; von

Grünau & Anston, 1995; but see Cooper et al., 2013 for the suggestion that the search efficiency for direct gaze is likely a result of a failure to control for similarity among distractor stimuli). Direct gaze is also very effective at engaging and holding visual attention longer than averted gaze during the presentation of faces (Miyazaki et al., 2012; Mojzisch et al., 2006; Palanica & Itier, 2012; Senju & Hasegawa, 2005; Vuilleumier, 2002; Wieser et al., 2009), and even newborns prefer to look at direct gaze than averted gaze faces (Farroni et al., 2002). Direct gaze also seems to be processed unconsciously (Burra et al., 2013; Chen & Yeh, 2012; Stein et al., 2011). For example, in continuous flash suppression paradigms—where a target image presented to one eye is suppressed by flashing distractor images presented to the other eye—faces with direct gaze overcome such suppression more rapidly and are detected faster than faces with averted gaze (Chen & Yeh, 2012; Stein et al., 2011). Direct gaze can also facilitate the detection of a target face in a visual scene even when gaze discrimination is not the primary task at hand (Doi & Shinohara, 2013), which suggests an automatic and rapid detection of eye contact. Taken together, these studies suggest that direct gaze is very attention-grabbing. Direct gaze tells us that we are the focus of the viewer's attention, and any other nonverbal communicative behavior is intended toward us (the observer).

In contrast to direct gaze, averted gaze is defined as another person looking away from your eyes, which may also influence you to look in the same area that the eyes are looking (also known as gaze following or gaze orienting; Baron-Cohen et al., 1997). Averted gaze can orient one's attention toward specific places or people (also known as joint attention), which is thought to play an important role in theory of mind—the ability to understand and attribute mental states to oneself and others (Baron-Cohen et al., 1997). The phenomenon of the gaze orienting effect has been shown by numerous studies using Posner-like attention paradigms in which a face cue is centrally presented prior to the onset of a lateral target; target detection is faster when the gaze of the face is directed toward the side where the target later appears (i.e., congruent targets) and slower when the gaze is looking in the opposite direction (i.e., incongruent targets; Driver et al., 1999; Friesen & Kingstone 1998; Langton & Bruce 1999; Ricciardelli et al., 2009; for a review, see Frischen et al., 2007a). Eye-tracking studies have also shown that averted gaze influences eye movements of the viewer to look in the same direction signaled by the gaze of the character (Castelhano et al., 2007; Itier et al., 2007b; Palanica & Itier, 2011; Zwickel & Võ, 2010). People usually want to see what another person is looking at since averted gaze may signal a potential reward or threat to the viewer. Overall, this implies that the human eye region is an extremely important facial feature for extracting (both direct and averted) gaze information and using this social cue information for directing subsequent attention. Thus, although averted gaze is efficient at orienting the attention of the viewer *away* from the looker's face, the eye region itself may *initially* capture the attention of the viewer to then signal another specific place or person. In sum, we are usually alert to the gaze direction of others in our environment since these social cues play an important role in nonverbal communication.

Being able to rapidly and accurately detect gaze direction is important for survival and social interactions, and is essential for navigating our social world. Furthermore, since gaze discrimination is already seen in neonates (Batki et al., 2000; Farroni et al., 2002), and monkey cell recordings indicate that face selective neurons in the STS are sensitive to gaze information (Perrett et al., 1985, 1990), an innate neurocognitive mechanism has been proposed, known as the Eye Direction Detector (EDD; Baron-Cohen, 1994). This mechanism would be specialized in detecting eyes and their gaze direction in the environment, and especially whether someone is looking at, or away from, the observer. This detector would compute individuals' focus of attention using local information from the eyes, based on the geometry created by the circular dark iris relative to the white sclera (Kobayashi & Kohshima, 1997; Emery, 2000). This idea is supported by studies showing that inverting the contrast information of the eye region induces the perception that the face is looking in the direction of the darkened sclera (Sinha, 2000; Ricciardelli et al., 2000). This thesis helps examine how a potential cognitive mechanism would function to detect and discriminate gaze direction in our environment.

1.3 Using Head Orientation to Infer Gaze Direction

Although behavioural and electrophysiological evidence suggests that the eye region alone is important for discriminating gaze, head orientation may also influence gaze judgments. For example, a direct gaze is usually associated with a front-facing head, and similarly, an averted gaze is usually accompanied by an averted-facing head; most individuals move their head and eyes together when looking at specific locations. Moreover, it has been shown that neurons in the monkey STS that are sensitive to gaze information are also sensitive to head orientation and even body position (Perrett et al., 1982, 1985). This led to the proposition of a more general Direction of Attention Detector (DAD; Perrett & Emery, 1994) that would infer others' attention based on the integration of directional information coming from the eyes (iris eccentricity), but also from the head and body positions.

Many behavioural studies in humans have shown that gaze judgments can be affected by the orientation of the head (Anstis et al., 1969; Kluttz et al., 2009; Langton, 2000; Langton et al., 2004; Ricciardelli & Driver, 2008; Seyama & Nagayama, 2005; Shirama, 2012; Todorović, 2006, 2009; Wollaston, 1824), thus supporting the DAD hypothesis. One of the earliest examples of this was shown by Wollaston (1824), who demonstrated that the same eye image induced different gaze directions by embedding the eyes in images of different head angles. More recently, it has been shown that reaction times are shorter to detect gaze direction when the eyes and head are oriented in the same direction than when they are oriented in different directions (Itier et al., 2007a, 2007b; Langton, 2000; Seyama & Nagayama, 2005; Todorović, 2009), reflecting a congruency effect between eye direction cues and head direction cues. Evidence even suggests that although different, iris eccentricity and head direction cues jointly specify perceived gaze direction, and that they are dependent on one another, each alone being insufficient for gaze perception (Todorović, 2006, 2009). This theoretical framework highlights the dependence of gaze perception on head direction, but makes no assumption on a particular status for the detection of either gaze direction.

In contrast, head orientation does not seem to affect gaze discrimination during visual search tasks. For example, the stare-in-the-crowd effect has been shown using photographs of deviated faces (Doi & Ueda, 2007; Doi et al., 2009; Senju et al., 2005) and photographs of eye regions from deviated faces (Conty et al., 2006), thus supporting a special status for direct gaze. The original findings for the stare-in-the-crowd effect by von Grünau and Anston (1995) used pairs of front-view schematic eyes and demonstrated that *straight* gaze was easier to detect than averted gaze. However, the fact that this search efficiency has been shown with deviated head views suggests that attention capture by direct gaze is not just due to the visual symmetry between the dark iris and white sclera of the eyes in front-view faces, but rather to the perception that the gaze is directed at the observer (Conty et al., 2006; Doi & Ueda, 2007; Doi et al., 2009; Senju et al., 2005; but see Shirama, 2012 for the suggestion that what drives the stare-in-the-crowd effect is the frontal view of the face). Recently, Cooper et al. (2013), who also used deviated head stimuli, claimed that the stare-in-the-crowd effect is driven by the result of failures to control for similarity among distracter stimuli (i.e., so salient targets are easier to see among similar distractors) across search conditions rather than any attention-capturing property of direct gaze during visual search. However, Cooper et al. (2013) made claims on efficiency slopes (i.e., the amount of time spent searching each distractor item as display size increases) rather than on overall reaction times of target detection. In fact, the researchers still clearly demonstrate that faster overall reactions times are found when searching for direct gaze than averted gaze targets. Importantly, the stare-in-the-crowd effect is seen in visual search paradigms which are very different from typical gaze discrimination paradigms in terms of stimuli presentation (arrays versus central presentation) and task (rapid detection of a given gaze direction among distractors versus looking-at-me/looking-away judgments or judgments of actual gaze direction angles). Whether direct gaze is detected better than averted gaze (across head orientations) outside of the visual search literature, is unclear. The present thesis examines how gaze direction is discriminated using different head orientations, and when faces are individually presented in the periphery.

1.4 A Possible Subcortical Gaze Detection Mechanism

If direct/mutual gaze is so important for social interactions, then it would make sense that it also catches attention in the periphery, outside of foveal vision[1]. This would be an important aspect of the human visual system since it is not efficient to scan every minute angle of our environment, and we must be alert to socially relevant stimuli, such as gaze signals. It has been proposed that faces could be detected by a subcortical face detection system (Johnson, 2005) that

[1] Vision scientists discriminate between central vision, which encompasses foveal vision (~1° eccentricity on either side of fixation) and parafoveal vision (1-5° eccentricity), and peripheral vision, which encompasses everything beyond parafoveal vision (Calvo & Lang, 2005; Larson & Loschky, 2009). Foveal vision corresponds to the spatial focus of overt attention, whereas parafoveal and peripheral vision involve covert perception outside the focus of attention. This terminology will be used in the remainder of the thesis.

would also enable eye contact detection in the periphery (Senju & Johnson, 2009), similar to a "threat detection" mechanism in other animals for processing danger in the environment. For example, mammals appear to use one of two neuronal circuits when processing stimuli indicating predation threat. The first is an evolutionary ancient subcortical pathway where sensory information is processed in the amygdala and directly triggers behavioural fear responses; this system is fast but more prone to errors in decision-making (Trimmer et al., 2008). The second is a more recently evolved cortical system which accumulates information about predation threat more slowly but with greater accuracy (Trimmer et al., 2008). In humans, for example, Vuilleumier et al. (2003) found that when processing faces with a fearful expression, shorter subcortical pathways provided the amygdala with coarse but rapid sensory information, while longer cortical pathways provided more detailed information over a longer time-scale. However, it should be noted that this study used an fMRI paradigm, which does not provide accurate information on the timing of cognitive processes; thus, the "shorter" pathways in this study mostly refers to the fact that the visual information travels through fewer areas and less distance within the brain. Intracranial recordings in humans have shown that, when processing faces with a fearful expression, activation within the amygdala occurs around 200 ms post-stimulus (Krolak-Salmon et al., 2004), whereas the first visual responses (using faces as stimuli) occur with a latency of about 60 ms in the lateral geniculate nucleus (Krolak-Salmon et al., 2003). However, it is still unclear how fast the entire cortical or subcortical pathways process facial information, and may in fact process information in parallel to each other (Senju & Johnson, 2009).

For gaze detection in humans, it has been proposed that stimuli may be processed through both a crude subcortical stream and through a more sensitive cortical network. In the more evolved cortical pathway, visual information travels from the retina to the lateral geniculate, the early visual areas, the STS, and finally toward attention control circuitry including the lateral intraparietal area, frontal eye fields, and superior colliculus (Shepherd, 2010). On the other hand, the subcortical pathway may offer a rapid but crude route to processing faces and gaze direction in the periphery. For eye contact detection, this mechanism is thought to be based on low spatial frequencies, picking up contrast information between the circular dark iris and the white sclera of the eyes; this information is then sent to the superior colliculus, pulvinar, and amygdala, offering a "fast-track" route of visual processing (Johnson, 2005; Senju & Johnson, 2009; Shepherd, 2010). However, this subcortical route remains to be fully examined, especially since most studies that have examined gaze discrimination used face stimuli presented centrally, in the viewer's direct focus of attention. Very few studies have examined how gaze direction is discriminated covertly in the viewer's peripheral field of view, and what role head direction plays in the periphery, which was a central purpose of the current thesis.

1.5 Gaze Detection Outside of Foveal Vision

Overall, people are rather accurate at discriminating gaze direction from a wide range of distances and head orientations, at least when the targets are focused overtly (Gale & Monk, 2000; Gamer & Hecht, 2007; Gibson & Pick, 1963; Symons et al., 2004). Gaze direction can be accurately determined at 5 m away (and potentially farther) from a virtual head on a computer screen (Gamer & Hecht, 2007). However, gaze discrimination becomes considerably less accurate when the perceiver is not directly fixating the target, that is, when the stimulus is viewed covertly. For example, Loomis et al. (2008) presented face stimuli with various gaze directions at different visual eccentricities and found that participants' judgments of gaze direction were only reliable in central vision, up to 4° of horizontal eccentricity, while judgments of head orientation were reliable all the way to 90° of eccentricity. That study, however, focused on gaze judgment accuracy (participants judged lookers' facing direction using a haptic pointer) rather than on direct/averted gaze discrimination, and did not measure reaction times. In a series of six experiments, Burton et al. (2009) showed that eye gaze could not be perceived from unattended (distractor) faces presented in the vertical visual field (between 3.6° and 4.9° eccentricity above or below fixation), even when their size was adjusted to match that of centrally presented items in terms of cortical representation. These authors concluded that gaze processing requires focused attention and suggested that gaze can only be discriminated when participants actually attend to and fixate on the gaze cue. In contrast, the head direction (side profile views) of these distracter faces impacted responses to the centrally presented items, suggesting that head direction might be processed outside of focused attention (supporting Loomis et al., 2008). Burton et al. (2009) focused participants' attention on the direction indicated by the target (left or right), not on whether the face was looking straight ahead or to the side. Thus, it remains unknown whether such a gaze discrimination judgment could be done with faces presented in the periphery while no central item competes for attention, which is what Chapter 2 of this thesis addresses.

Although the implications from Burton et al. (2009) and Loomis et al. (2008) were similar (i.e., that people need to fixate relatively close to a looker's eyes to gather gaze information), an important design difference between the two studies was the position of the stimuli. Loomis et al. (2008) positioned stimuli along horizontal eccentricities, while Burton et al. (2009) positioned stimuli along vertical eccentricities. Furthermore, since the task of the two studies were so different, it is unclear whether and to what extent gaze direction can be quickly and accurately detected in the horizontal or vertical periphery when using the same type of paradigm and task. Chapter 2 of this thesis examines gaze detection in the horizontal periphery, while Chapter 3 addresses this question in the vertical periphery.

1.6 Inhibition of Return for Faces and Gaze Direction

Chapters 2 and 3 of this thesis examine how gaze direction and head orientation influence explicit gaze judgments for faces presented across a variety of eccentricities. Chapter 4, in contrast, examined the attention capture of faces and gaze direction using a paradigm known as inhibition of return (IOR; Posner & Cohen, 1984). The phenomenon of IOR refers to the finding that after attention has been exogenously cued and then withdrawn from a location, attention is inhibited to return to that region, and there is delayed responding to stimuli subsequently presented at that cued location relative to previously uncued locations (Klein, 2000). IOR is suggested to promote efficient foraging behaviour to bias searching towards novel areas relative to areas already inspected (Klein, 1988; Klein & MacInnes, 1999). It was originally shown that IOR follows an initial facilitation period (prior to ~200 ms Stimulus Onset Asynchronies—SOAs—the amount of time between the start of the stimulus cue and the start of the target presentation) where attention resides at the cued location and targets are detected *faster* than those presented at uncued locations. After the subsequent withdrawal of attention from the cued location (from ~300 ms to 3000 ms SOAs), IOR then develops (reviewed in Samuel & Kat, 2003). However, it has also been argued that IOR does not have to follow facilitation, and these two processes may be independent, as evidenced by research showing little or no significant facilitation at short SOAs (reviewed in Collie et al., 2001). That is, some studies have found early IOR effects without any facilitation, in which reaction times (RTs) to cued targets are slower than RTs to uncued targets at both short and long SOAs, with IOR being found for SOAs ranging from 0 to 4000 ms (Berlucchi et al., 1989; Tassinari et al., 1994; Tassinari & Berlucchi, 1995; Tassinari et al., 1989). It has been inferred that this inhibition occurs as a result of maintaining fixation at a central location while *covertly* orienting visual attention to a peripheral cue. Although the peripheral cue initiates the preparation of a saccade toward the cued location, a covertly orienting task requires that this saccade be inhibited. Consequently, there is a motor bias against responding to targets appearing at previously cued locations (Klein & Taylor, 1994; Rafal & Henik, 1994). It should also be noted that the majority of research examining IOR processes use low level visual stimuli (e.g., a brightened square in the periphery). Perhaps encoding or processing more meaningful stimuli, such as faces, requires more cognitive resources and thus facilitates different IOR response patterns than the traditional facilitation-IOR curve.

Few studies have examined IOR in the context of faces. Typically, these studies involve a stimulus cue presented to the left or to the right of a central fixation that participants attend to covertly while maintaining fixation on a central fixation point. Then, after a variable SOA, a target (a probe dot) is presented at the location of the stimulus cue or at the location that did not contain a stimulus cue. Participants either detect the target via button press or make a speeded saccade to the target location. If the stimulus cue captures attention in a reflexive and exogenous way, then after attention is brought back to fixation, an IOR is expected to occur for targets at the location that previously contained the stimulus cue. Given that faces are biologically and socially relevant, face cues should capture attention faster and better than other stimulus cues, leading to a greater IOR response after attention is brought back to fixation. That is, other stimuli should also capture attention when acting as a stimulus cue, but there should be faster and more thorough processing for faces, so that once attention is brought back to fixation, there is a stronger inhibition to return to that previously attended area where the face was, and instead to search novel areas (perhaps for new faces). Since faces should be processed in depth very quickly, there should not be a need to immediately re-examine a face once it has been attended to because vital social information (like eye gaze) should have been fully processed from the initial attention capture. By contrast, other stimuli should not capture as much initial attention as faces, so there should be less of an inhibition to return to that same location since that previous stimulus was not attended to the same degree as faces; thus, there should be more of a bias to re-attend or re-examine these non-facial stimuli since they were not initially processed as thoroughly as faces.

Some studies have found an IOR effect for faces compared to other stimuli (Taylor & Therrien, 2008; Theeuwes & Van der Stigchel, 2006), while others have found no difference in IOR magnitude (Taylor & Therrien, 2005). Some research has used emotional face cues and found a larger IOR response for happy and neutral faces compared to angry faces (Fox et al., 2002), while other research has found no difference in IOR magnitude for fearful, neutral, or scrambled face cues (Stoyanova et al., 2007). Yet another study found that both faces and household objects induced an IOR response for both short (200 ms) and long (700 ms) SOAs, but faces reduced saccade latencies toward subsequently presented targets (in both cued and uncued locations), independent of an IOR, only at the short SOA (Weaver et al., 2012). These authors suggested that this represented a short-lived priming effect or social facilitation effect from the mere presence of a face, due to the higher level of alertness to respond to social stimuli. Overall then, the literature is inconsistent on how and when faces actually capture attention via an IOR paradigm. Furthermore, it is currently unknown whether other facial factors, like gaze direction or head orientation, affect IOR for faces, since previous research has only used front-view faces with straight gaze as facial stimuli. Chapter 4 of this thesis helps address these questions.

1.7 The Present Thesis

In sum, the faces and eyes of humans can be very powerful for capturing attention compared to other stimuli. Additionally, since gaze direction plays such an important role in social cognition, it makes sense to be alert to the gaze signals of others around us. However, few studies have examined face and gaze processing outside of the viewer's focus of attention. Although some theories suggest that accurate gaze detection may occur covertly via a subcortical route (Johnson, 2005; Senju & Johnson, 2009) or Direction of Attention Detector (Perrett & Emery, 1994), these theories remain to be directly tested in a controlled paradigm. Furthermore, it is unknown whether direct gaze is detected better than averted gaze when viewing faces covertly, and what role head direction plays in these gaze judgments. If human faces and eyes are so powerful at capturing attention in our environment, then they should be easily detected and processed across a wide range of eccentricities in our field of view. It is surprising, then, that this issue has never been directly investigated.

This thesis presents a series of studies examining whether and to what extent gaze direction and head orientation capture covert attention across the visual field[2]. First, I examined

[2] It is important to note that this thesis did not examine extrasensory perception (ESP) of gaze detection (e.g., Schwartz & Russek, 1999; Sheldrake, 2001; Wiseman & Schlitz, 1998), which would involve detecting targets outside the entire field of view (e.g., the sense of being stared at from someone behind you). In all of the present studies, participants could "see" the target faces, albeit using covert attention.

whether gaze direction could accurately be detected[3] in the peripheral visual fields. For the experiments in Chapter 2, individual faces (both frontal- and deviated head orientations) with either a direct- or an averted gaze were briefly presented across various horizontal eccentricities (both centrally and peripherally) while participants focused on a central fixation. These studies measured the speed and accuracy of gaze detection, and the level of eccentricity at which participants were still accurate above chance level. I also examined whether there were any gaze detection asymmetries between direct and averted gaze, and to what extent head orientation affected this gaze discrimination. The experiments in Chapter 3 replicated and extended this paradigm by presenting stimuli across various vertical eccentricities (above and below fixation). Chapter 4 investigated how gaze direction and head orientation influenced attention capture using an IOR spatial cueing paradigm. Across all studies, to ensure that participants maintained central fixation (thus ensuring the use of covert rather than overt attention), an eye-tracker was used to control participants' eye movements.

In the experiments of Chapters 2 and 3, participants explicitly discriminated gaze direction. That is, participants knew that they were detecting a direct- or averted gaze target. In the experiments of Chapter 4, participants were not given any information about the meaning of the stimuli or the purpose of the study and thus gaze direction was processed implicitly. Chapters 2 and 3 set a baseline measurement to examine to what extent gaze processing occurs at a particular eccentricity in the visual field. Chapter 4 used this information to examine whether gaze processing occurs implicitly at this said eccentricity. Therefore, the studies in this thesis tested whether gaze direction and head orientation influenced both explicit and implicit gaze processing. If a possible gaze detection mechanism exists for being vigilant toward gaze signals

[3] Throughout this thesis, the term "gaze detection" means the ability to accurately perceive a gaze signal in the environment, while the term "gaze discrimination" means the ability to dissociate between different gaze directions (e.g., direct gaze vs. averted gaze).

in our environment (whether it be an EDD, DAD, or subcortical route), then it should be robust enough to detect social cues beyond the foveal region and influence visuospatial attention.

Chapter 2: Detecting Gaze in the Horizontal Periphery

The first step of this thesis was to examine whether gaze direction could actually be detected beyond foveal vision. Since most studies examining gaze processing only used centrally presented stimuli, it is unknown whether observers can actually determine gaze direction when they are not directly focused on the target. Additionally, anecdotal evidence may allow us to believe that we can quickly determine whether someone is looking at us or not from the corner of our eye, but there is a lack of scientific research directly testing this belief in a controlled laboratory setting. Loomis et al. (2008) examined this issue, but participants in that study simply estimated the lookers' gaze direction, rather than using reaction times to rapidly discriminate a direct/averted gaze judgment. Burton et al. (2009) also somewhat examined this issue, but participants were told to ignore a distractor face outside of foveal vision while they focused their attention on a central target to make a directional (left–right) gaze judgment, rather than to judge whether the face was looking straight ahead or to the side. Thus, the purpose of Chapter 2 was to fill some of the gaps in the current literature by directly measuring rapid direct/averted gaze discriminations while individual faces are viewed outside of foveal vision.

The goal of Chapter 2 was three-fold, with all objectives having equal importance. First, this study examined whether and to what extent gaze direction could be detected in the horizontal periphery above chance level, using covert attention, and with no distractor items competing for attention. Second, this study investigated whether direct gaze was faster and more accurately discriminated than averted gaze, and, if so, at what visual eccentricities. Third, this study examined to what extent head orientation affected gaze discrimination in the periphery. The speed and accuracy of gaze detection was measured when faces were presented across the visual field (between 0° and ±12° of horizontal eccentricity) while fixation was centred and enforced by an eye-tracker. Based on previous research (Burton et al., 2009; Loomis et al., 2008), it was predicted that gaze detection would be above chance only in central vision (0° to ±5°) where acuity is high, given the major reliance of gaze perception on iris position (i.e., local visual information). As eccentricity increases and visual acuity decreases, perception of gaze direction should become more difficult, and thus error rates and RTs should increase. Based on the visual search literature (Conty et al., 2006; Doi & Ueda, 2007; Doi et al., 2009; Palanica & Itier, 2011; Senju et al., 2005; Shirama, 2012; von Grünau & Anston, 1995), it was also predicted that direct gaze faces would be detected faster and more accurately than averted gaze faces (across head orientations), and this should be seen at the eccentricities at which gaze discrimination is accurate, i.e., in central vision. Based on the gaze perception literature (Itier et al., 2007a, 2007b; Langton, 2000; Seyama & Nagayama, 2005; Todorović, 2009), congruency effects were predicted between head and gaze directions in central vision, such that direct gaze detection should be fastest in frontal heads while that of averted gaze should be fastest in deviated heads. However, if gaze is accurately perceived in central vision only, while head orientation is accurately perceived in the periphery (Burton et al., 2009; Loomis et al., 2008), then a bias toward using head orientation cues to discriminate gaze should be seen in the periphery. That is, when eye gaze cues become less visible in the periphery, head orientation should serve as the main cue for gaze direction judgment (e.g., Perrett et al., 1992). Additionally, at eccentricities in which eye cues are not at all visible, the gaze discrimination judgment might be made solely on the basis of head orientation, with participants equating direct gaze with frontal head views and averted gaze with deviated head views. There is also a possibility that an asymmetry of target detection could occur between the left visual field (LVF) and the right visual field (RVF). For example, a LVF advantage has been shown for gaze processing

(Ricciardelli et al., 2002), which may be related to a right hemisphere dominance for face and gaze processing (e.g., Burt & Perrett, 1997; Calder et al., 2007). Thus, participants in the current study may either detect gaze signals better in the LVF than in the RVF, or their gaze judgments may be more biased in some way for responding to LVF targets. However, it is unknown how strong this detection asymmetry would be, or at what eccentricity this difference would occur, due to the lack of research examining covert gaze in the periphery.

Four experiments were run. Experiment 1a used frontal head views that were Photoshopped and controlled for contrast and luminance, while a natural set of faces were used in the remaining studies, with frontal head views (Experiment 1b), deviated head views (Experiment 1c), and both frontal and deviated head views (Experiment 1d). In the first three experiments, separate groups of participants were shown upright or inverted faces. Inverted faces were used as a control condition to confirm the idea that gaze judgments are made using information from the head and are thus configural, rather than purely featural and involving solely local eye cues such as iris/sclera contrast information. Face processing is sensitive to configural orientation, with upside-down faces being disproportionately more difficult to recognize than inverted versions of other types of objects. This is known as the "face inversion effect" (Yin, 1969; for a review, see Valentine, 1988). It was expected that by disrupting the configural information, face inversion would disrupt gaze processing—a phenomenon known as the "gaze inversion effect" (Jenkins & Langton, 2003; Schwaninger et al., 2005; see also Senju et al., 2005; Senju & Hasegawa, 2006). Thus, it was predicted that the detection advantage of direct gaze should be diminished in inverted faces, and this impact might be more pronounced with eccentricity, as visual acuity diminishes. It was not expected that face inversion would completely eliminate gaze discrimination, but rather decrease the efficiency of detecting direct gaze over averted gaze, since face inversion is suggested to lead to quantitative rather than qualitative changes in face processing (e.g., McKone & Yovel, 2009; Sekuler et al., 2004).

2.1 Experiment 1a: Frontal View Faces Controlled for Contrast and Luminance

Experiment 1a used faces that were cut into oval-shaped stimuli so as to remove all external features. Faces were also controlled so mean contrast and mean luminance did not vary significantly across faces and gaze conditions. Finally, gaze direction was computer manipulated.

2.1.1 Experiment 1a Methods

Participants. A total of 26 participants performed the Upright Face condition, and 25 different participants performed the Inverted Face condition. Three participants were rejected in the Upright Face condition, and 4 in the Inverted Face condition, due to eye-tracking calibration issues or participant tiredness/fatigue. This left a total of 23 participants in the Upright Face condition (13 female, 10 male; 21 right-handed; age range 17-25 years, $M = 19.8$), and 21 participants in the Inverted Face condition (11 female, 10 male; 20 right-handed; age range 18-23 years, $M = 19.8$). Participants were undergraduate students from the University of Waterloo (UW), with normal or corrected-to-normal vision, who took part in the study for course credit. All samples of participants were different in every experiment of this thesis (i.e., no participant completed more than one experiment). The study received full ethics clearance from the UW Office of Research Ethics and all participants signed informed written consents.

Stimuli. Photographs of eight individuals (four men, four women) with neutral expressions were selected from the NimStim Face Stimulus Set[4] (Tottenham et al., 2009). For each face, eye gaze was manipulated using Adobe Photoshop to produce a leftward and rightward gaze (approximately 30º angle) in addition to the original straight gaze. An elliptical mask was applied on each picture so that the hair, ears, and shoulders were not visible. The set of photographs were transformed to 8-bit greyscale images and were equated for mean Root Mean Squared (RMS) contrast and mean luminance using the SHINE toolbox (Willenbockel et al., 2010). All face photographs subtended a visual angle of 3° horizontally by 4.5° vertically. The entire eye region (including both eyes and nasion) subtended a visual angle of 2.5° horizontally, from the outer edge of one eye to the outer edge of the other eye, and 0.5° vertically, from the bottom edge to top edge of one eye (including eye lids). The iris diameter subtended 20 minutes of arc (0.33° visual angle). The average pixel luminance value for each individual eye (1° x 0.5° visual angle) was 94.26 ± 7.55 *SD*, with an RMS contrast of 0.465 ± 0.025 *SD*.

Apparatus. A Viewsonic PS790 CRT 19-inch colour monitor was used to present the stimuli (Intel Corel 2 Quad CPU Q6700; 1024 x 768 pixels; 60 Hz frame rate). We used a remote EyeLink 1000 eye-tracker from SR Research with a sampling rate of 1000 Hz to control for participants' initial fixation and record any possible eye movements during stimulus presentation. Trials in which eye movements were recorded were rejected from the analyses. Participants' viewing position and distance were maintained by chin and forehead rests. At a viewing distance of 70 cm, the monitor subtended a visual angle of 29.2° x 22.2°.

Procedure. Participants were randomly assigned to either the Upright- or Inverted Face condition. All aspects of both face configuration conditions were identical except for the

[4] Development of the MacBrain Face Stimulus Set was overseen by Nim Tottenham and supported by the John D. and Catherine T. MacArthur Foundation Research Network on Early Experience and Brain Development. Please contact Nim Tottenham at nimtottenham@ucla.edu for more information concerning the stimulus set.

orientation of the face stimuli. Participants were instructed to focus on a central fixation cross at all times (see Figure 1.1). Before each trial, a fixation cross (1° x 1°) was presented for 1200 ms, and then became a fixation trigger that participants must have focused on for 300 ms to activate the next trial. For each trial, an individual face was presented for 150 ms randomly in one of 17 possible locations aligned horizontally across the screen. Each face centre was positioned from –12° (left of fixation) to +12° (right of fixation) visual angle horizontally (the widest limit achievable with the computer screen). The distance between the centres of each adjacent face position was separated by 1.5° of visual angle horizontally. Following stimulus presentation, participants were required to detect whether the target face had a direct or an averted gaze as quickly and as accurately as possible, using a two-button press with their index and middle fingers of their dominant hand. Buttons were counterbalanced across participants. The next trial started 1000 ms after the end of stimulus presentation, regardless of whether a response was made or not. Before each study session, 17 practice trials (one for each possible stimulus location) were presented to familiarize participants with the stimuli and task.

Half of the stimulus trials consisted of direct gaze (DG) faces that looked straight ahead while the other half of trials consisted of averted gaze (AG) faces (half looking to the left and half looking to the right). It may be argued that straight gaze in the periphery would be perceived as non-mutual gaze, and similarly, averted gaze in the periphery in the direction of the observer may be perceived as mutual gaze contact However, at debriefing, all participants confirmed that they were aware of the difference between gaze directions across all eccentricities and did not perceive an averted gaze as a mutual gaze or a direct gaze as an averted gaze in the periphery.

A total of 8 blocks of 136 trials were presented, for a total of 1088 trials. Within each block, between 3 and 5 trials were presented for each gaze direction at each eccentricity, resulting in a total of 32 DG trials and 32 AG trials (16 left- and 16 right-averted) per eccentricity across the entire experiment. Gaze and eccentricity trials were randomized within each block. Stimulus presentation was random within each block. A rest was given between blocks. The experiment lasted about 70 minutes.

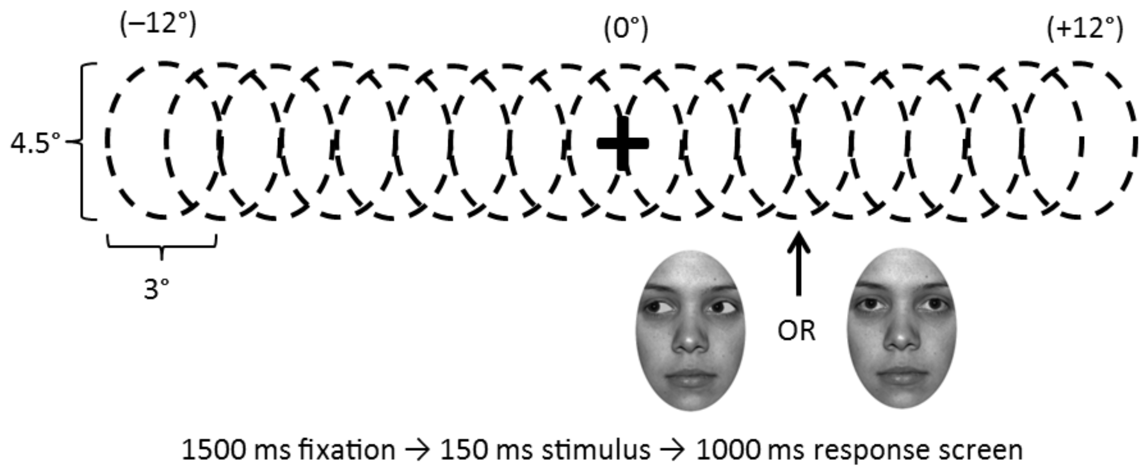

Figure 1.1. Stimulus presentation in Experiment 1a. The dotted ovals are shown to represent all of the 17 possible locations of stimuli presentation, but were invisible during trials. Negative (–) eccentricities represent target positions to the left of fixation, while positive (+) eccentricities represent those to the right of fixation. The fixation cross was shown during the entire duration of each trial to keep participants' fixation focused. Faces were shown inverted in the Inverted Face condition. Please also note that for averted gaze faces, both left- and right-looking faces were used (in equal proportions).

2.1.2 Experiment 1a Data Analysis

Left- and right-averted gaze directions were combined and averaged for each target position. Preliminary analyses revealed no significant differences between left- and right-averted gaze targets across eccentricities. Mean RT data were computed using only correct responses. For each subject, RTs that were below 150 ms or exceeded 2.5 standard deviations from the mean of each gaze condition per eccentricity were discarded. This was to remove any anticipatory responses or outliers from the data (Van Selst & Jolicoeur, 1994), which eliminated

8.9% of the data in Experiment 1a, 6.9% in Experiment 1b, 6.8% in Experiment 1c, and 6.4% in Experiment 1d. All trials where more than one fixation was made (i.e., when participants moved their eyes away from the central fixation) were eliminated (2.6% in Experiment 1a; 3.5% in Experiment 1b; 3.2% in Experiment 1c; 2.8% in Experiment 1d). RTs exceeding 1000 ms were recorded as a miss (4.6% in Experiment 1a; 4.3% in Experiment 1b; 6% in Experiment 1c; 4% in Experiment 1d). Miss rates did not vary significantly across gaze conditions or eccentricities for any experiment. Error rates were calculated as the number of false alarms (e.g., pressing the AG button when a DG face was presented, or vice versa) that were made out of the total amount of responses that could have been made for each individual eccentricity. As this was a two-button press, forced choice task, a 50% error rate to a particular condition is chance level performance. If a participant responded using only one button for each trial (e.g., DG button), then their error rate for DG would be 0% and their error rate for AG would be 100% (i.e., 100% false alarm rate and 0% hit rate for AG, assuming 0% misses). Preliminary analyses revealed that none of the participants followed this pattern of response. In all studies, we only reported error rates for clarity. The overall percentages of responses were also reported to each gaze condition regardless of whether participants were correct or not, indicating a possible response bias to press one button over the other. Preliminary analyses also revealed no significant effects of participant gender or stimulus gender on gaze detection.

All statistical analyses in this thesis were run using SPSS (Version 20) software. Since gaze perception should decrease as eccentricity increases (i.e., farther from centre), larger RTs and larger error rates should be found in the periphery relative to central vision and a response bias might be observed in the periphery. RTs, error rates, as well as response rates were thus analyzed using a one way ANOVA with eccentricity as a within subjects factor, for AG and DG separately. The Greenhouse-Geisser degrees of freedom correction was used when the sphericity assumption was violated (i.e., when the Mauchly's test of sphericity was significant)[5]. One main goal of the thesis was to determine the peripheral eccentricities at which gaze was discriminated above chance level. Error rates for each gaze condition were thus compared to chance level at each eccentricity using one-sample *t*-tests (two-tailed, with a test value of 50). To correct for the family-wise errors, these *t*-tests were corrected for the number of comparisons made (17 eccentricities x 2 gaze directions = 34; so the p value used was .05/34 = 0.001).

Another main goal of the thesis was to determine whether there were any gaze discrimination differences between AG and DG across eccentricities; thus, for each dependent measure (RT, error rate, response rate), planned paired sample *t*-tests (two-tailed) were performed comparing the two gaze conditions at each eccentricity. To correct for alpha inflation from the 17 eccentricities, the Bonferroni correction was used for all these planned comparison *t*-tests, making the p value significance threshold at .003 (i.e., .05/17 = .003). Upright and Inverted Face conditions were analyzed separately.

2.1.3 Experiment 1a Results

Upright Faces

For RT responses, there was a main effect of eccentricity for both AG ($F(16, 352) = 13.97$, $MSE = 2471.65$, $p < .0001$, $\eta_p^2 = .39$), and DG ($F(16, 352) = 48.19$, $MSE = 2473.78$, $p < .0001$, $\eta_p^2 = .69$; see Figure 1.2A), indicating that RTs increased with eccentricity (away from centre in each left and right direction). Planned *t*-tests revealed faster RTs for DG than AG faces from –6° to +3° (all $p < .003$), except at –4.5°.

[5] Throughout this entire thesis, for clarity, only the adjusted *p*-values were reported and the original degrees of freedom kept.

For percent error rates, a main effect of eccentricity was found for both AG ($F(16, 352) = 19.88$, $MSE = 393.68$, $p < .0001$, $\eta_p^2 = .48$), and DG ($F(16, 352) = 29.65$, $MSE = 533.28$, $p < .0001$, $\eta_p^2 = .57$; see Figure 1.2B), indicating that error rates increased with eccentricity. Planned *t*-tests revealed lower error rates for DG than AG faces at –1.5° and 0° ($p < .001$). Results also showed that participants detected both gaze directions above chance level at all eccentricities (using a one-sample *t*-test with a test value of 50, $p < .001$), except at ±12° in the DG condition.

For percent response rates (irrespective of hits or errors), there was no main effect of eccentricity for either gaze condition. Planned comparison *t*-tests revealed higher DG than AG responses at 0° ($p < .001$). This indicated that participants were equally likely to press the DG or the AG button at any eccentricity except the centred position for which they were more likely to press the DG button.

Inverted Faces

For RT responses, there was a main effect of eccentricity for both AG ($F(16, 320) = 13.91$, $MSE = 3904.93$, $p < .0001$, $\eta_p^2 = .41$), and DG ($F(16, 320) = 35.76$, $MSE = 4584.81$, $p < .0001$, $\eta_p^2 = .64$; see Figure 1.2D), indicating that RTs increased with eccentricity. Planned *t*-tests showed that RTs were faster for DG than AG faces from –6° to +4.5° (all $p < .001$), except at –3°. The gaze difference was maximal at central eccentricities.

For percent error rates, a main effect of eccentricity was found for both AG ($F(16, 320) = 27.64$, $MSE = 350.03$, $p < .0001$, $\eta_p^2 = .58$), and DG ($F(16, 320) = 31.22$, $MSE = 533.28$, $p < .0001$, $\eta_p^2 = .61$; see Figure 1.2E), indicating that error rates increased with eccentricity. Lower error rates were found for DG faces than AG faces at –1.5° and 0° (planned *t*-tests, all $p < .003$). Participants performed above chance level at all eccentricities ($p < .001$) except at ±12° in the

DG condition and at –12° in the AG condition (no difference from 50 using a one-sample *t*-test, $p > .01$).

For percent response rates, a main effect of eccentricity was found for AG ($F(16, 320) = 2.86$, $MSE = 301.23$, $p < .05$, $\eta_p^2 = .13$), but not for DG ($F(16, 320) = 2.07$, $MSE = 295.96$, $p = .076$, $\eta_p^2 = .09$; see Figure 1.2F). Planned *t*-tests failed to find any significant differences between DG and AG responses, indicating generally equal responses for both gaze conditions.

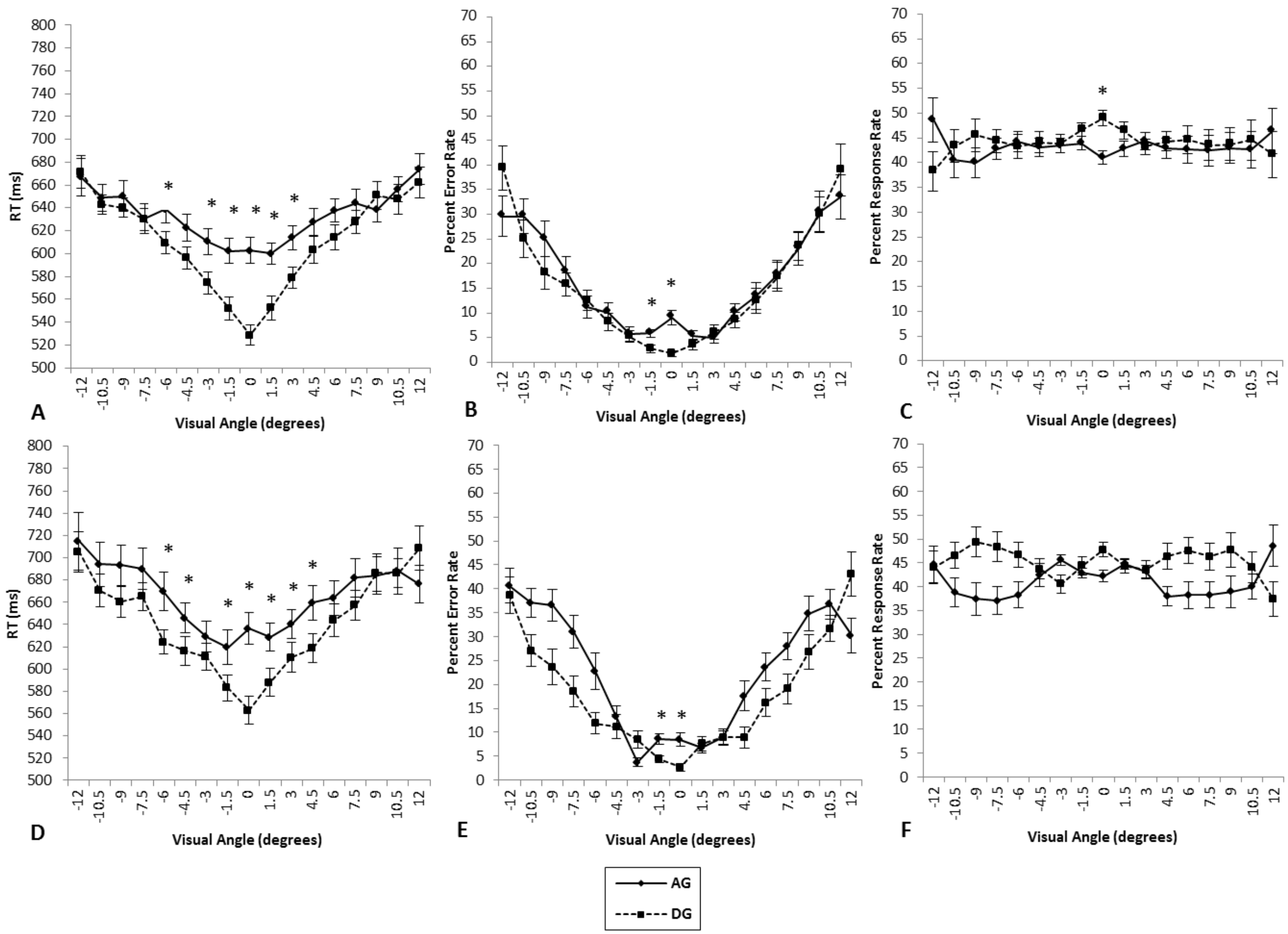

Figure 1.2. Results for Experiment 1a, as a function of gaze direction and eccentricity, for (A) RT responses in the Upright Face condition, (B) Error rates in the Upright Face condition, (C) Response presses in the Upright Face condition, (D) RT responses in the Inverted Face condition, (E) Error rates in the Inverted Face condition, and (F) Response presses in the Inverted Face condition (all shown with standard error bars). DG vs. AG paired comparisons: *p < .003.

2.1.4 Experiment 1a Discussion

In this experiment, frontal heads looking straight ahead, to the left or to the right, were presented randomly at one of 17 possible horizontal eccentricities while fixation on a centred fixation cross was enforced by an eye-tracker. In the periphery, attention was thus covert. On each trial, participants discriminated between direct and averted gaze using two response buttons. RTs and error rates increased with eccentricity as expected, given the decrease in visual acuity from central to peripheral vision (e.g., Larson & Loschky, 2009) and the importance of iris position (a local detail) in gaze perception (e.g., Ricciardelli et al., 2000; Sinha, 2000). The face size remained constant across eccentricities, so there was no compensation in cortical magnification for faces presented in the fovea versus those presented in the periphery. Across both upright and inverted orientations, gaze was discriminated above chance level up to 10.5º of eccentricity, i.e., well beyond foveal and parafoveal vision.

Visual acuity is the ability to discriminate two stimuli separated in space at high contrast compared with the background; Kniestedt & Stamper, 2003). Normal visual acuity (in foveal vision) is considered as the ability to resolve a spatial pattern separated by one minute of arc (i.e., 1/60 degree of visual angle), which is a 20/20 Snellen fraction. Visual acuity falls off rapidly with distance from the fovea (Millodot et al., 1975). For example, at approximately 5° eccentricity from the fovea centre (the limit of central vision), visual acuity is only about one third of foveal acuity (i.e., 20/60 Snellen fraction), and at 10° eccentricity, it is one fifth of foveal acuity (i.e., 20/100; Kniestedt & Stamper, 2003). This means that at 10° of eccentricity, the iris diameter of 20 minutes of arc of the faces used would be equivalent to about 4 minutes of arc at 0° (i.e., 20/5). Given that a letter on a Snellen chart subtends 5 minutes of arc, the results of the current study suggest that the size of the eye stimuli were still within the limits of normal visual acuity. Nevertheless, this finding goes against the prediction regarding the limit of accurate gaze detection, and contradicts the view that gaze can be reliably discriminated only in central vision (Burton et al., 2009; Loomis et al., 2008). Burton et al. (2009) used a competition paradigm where faces in the near vertical periphery were unattended and the task focused on the centrally presented item. Loomis et al. (2008) employed a gaze direction judgment where participants indicated as accurately as possible where the face was looking using a haptic pointer. Using a direct/averted gaze judgment task, it seems that gaze can be detected above chance beyond central vision using covert attention, and this might be achieved through the proposed Direction of Attention Detector (Perrett & Emery, 1994) or subcortical face and gaze detector picking up the iris/sclera contrast information available in the periphery (Senju & Johnson, 2009).

This paradigm also revealed a gaze detection asymmetry, as across both upright and inverted faces, DG was responded to faster than AG from about –6° to +3° eccentricity. This suggests facilitation for the processing of direct gaze beyond central vision (although the effect was maximal within central vision). In contrast to RTs, error rates were lower for DG than AG only at –1.5° and 0º of eccentricity in both upright and inverted faces. Response rates in the centred target position suggested that these errors were likely due to a bias in responding “direct gaze” more often than “averted gaze” for upright faces. Thus, contrary to the expectation that inversion would reduce gaze discrimination, similar results were found for upright and inverted faces in the current experiment. This finding could have been due to the particular stimuli that were used.

Experiment 1a employed stimuli that were unnatural. Faces were cropped to fit an oval shape, mean contrast and luminance were equated across pictures, and gaze was manipulated manually. Faces were thus very symmetrical and the position of the iris within the white sclera was very clear. These faces also had high luminance values which could help in discriminating local features of the face, such as eye gaze. Experiment 1b sought to replicate the present findings using a different set of stimuli.

2.2 Experiment 1b: Natural Faces with Frontal Head Orientation

Experiment 1b used an entirely new set of faces. The faces were in front-view against a black background and included the ears and hair. They were not equated for contrast and luminance, and gaze direction was not manipulated manually in the picture. Thus, this face set was more ecological than the faces used in Experiment 1a, but gaze direction was also less clear. Consequently, it was possible that gaze direction would not be detected as far in the periphery as the highly symmetrical and visibly clear facial stimuli used in Experiment 1a.

2.2.1 Experiment 1b Methods

Participants. A total of 22 participants performed the Upright Face condition, and 21 participants performed the Inverted Face condition. One participant was rejected in the Upright Face condition due to eye-tracking calibration issues. This left a total of 21 participants in the Upright Face condition (12 female, 9 male; 15 right-handed; age range 18-22 years, M = 19.8), and 21 participants in the Inverted Face condition (11 female, 10 male; 20 right-handed; age range 18-23 years, M = 19.7).

Stimuli. Greyscale photographs of 8 individuals (four men, four women) with neutral expression were taken from George et al. (2001)[6]. Each face was photographed against a black background with the head pointed straight towards the camera, with the eyes looking straight ahead at the camera, or 30° to the right side. These pictures were then mirror-reversed using

[6] These photographs could not be publicly shown in this thesis due to a contract signed by Roxane J. Itier authorizing the privacy of stimuli from Nathalie George.

Adobe Photoshop to avoid any bias between the left and right sides. Thus, the eye gaze direction was not manipulated in these photographs and was completely natural. The overall picture sizes subtended a visual angle of 4.4° horizontally by 6.6° vertically. However, the faces within the pictures subtended a visual angle of 3° by 4.5°, i.e., the same dimensions as the faces used in Experiment 1a, and the eye region subtended the same visual angle of 2.5° horizontally by 0.5° vertically, with the iris diameter subtending 20 minutes of arc, as in Experiment 1b. The average pixel luminance value for each individual eye was 51.72 ± 16.23 *SD*, with an RMS contrast of 0.438 ± 0.069 *SD*. This luminance and contrast were lower than the respective 94.26 and 0.465 values in Experiment 1a. For an example of the similar facial stimuli used from George et al. (2001), see Figure 1.3.

Apparatus, procedure, and data analysis were identical to Experiment 1a.

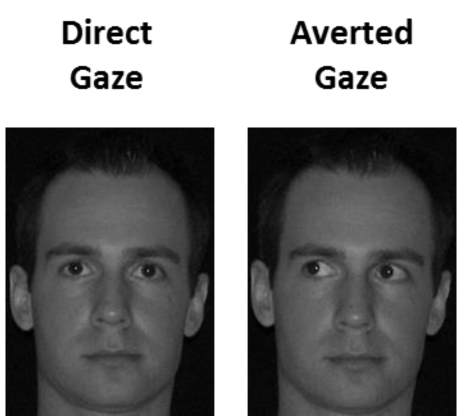

Figure 1.3. Example frontal head stimuli used in Experiment 1b, but the actual photos were taken from George et al. (2001). Faces were shown inverted in the Inverted Face conditions. Please also note that for averted gaze faces, both left- and right-looking faces were used.

2.2.2 Experiment 1b Results

Upright Faces

RTs increased with eccentricity as revealed by a main effect of eccentricity for both AG ($F(16, 320) = 5.39$, $MSE = 3993.10$, $p < .0001$, $\eta_p^2 = .21$), and DG ($F(16, 320) = 14.68$, $MSE = 2791.82$, $p < .0001$, $\eta_p^2 = .42$; see Figure 1.4A). Planned *t*-tests revealed faster RTs for DG than AG faces at all positions ($p < .003$), except at + 7.5°, +10.5°, and +12°.

Error rates increased with eccentricity as revealed by a main effect of eccentricity for both AG ($F(16, 320) = 24.61$, $MSE = 939.30$, $p < .0001$, $\eta_p^2 = .55$), and DG ($F(16, 320) = 18.94$, $MSE = 338.25$, $p < .0001$, $\eta_p^2 = .49$; see Figure 1.4B). Planned *t*-tests revealed lower error rates for DG than AG faces from –12° to –3°, and at +6° (all $p < .003$). This difference increased with eccentricity, due to a sharper increase of error rates for AG that reached a plateau by ±6°. For AG, participants performed at chance level from –12° to –4.5° and from +6° to +12° (one-sample *t*-test, $p > .001$). For DG, performances were above chance at every eccentricity (one-sample *t*-test, $p < .001$), except at +12°.

For response rates, a main effect of eccentricity was found for AG ($F(16, 320) = 4.52$, $MSE = 521.11$, $p < .01$, $\eta_p^2 = .18$), which showed decreased responses with eccentricity, while for DG ($F(16, 320) = 3.69$, $MSE = 499.38$, $p < .05$, $\eta_p^2 = .16$), responses increased with eccentricity. This response bias increased with eccentricity until around ±4.5°, at which point it plateaued. Planned *t*-tests revealed that the response difference between the two gaze directions was significant from –10.5° to –3°, and at +6° (all $p < .003$). Thus, at these eccentricities, participants pressed the direct gaze button more often than the averted gaze button, regardless of stimulus type.

Inverted Faces

RTs increased with eccentricity (main effect of eccentricity for both AG, $F(16, 320) = 3.22$, $MSE = 5101.14$, $p < .01$, $\eta_p^2 = .15$, and DG, $F(16, 320) = 4.64$, $MSE = 5363.20$, $p < .005$, $\eta_p^2 = .20$; see Figure 1.4D). Planned *t*-tests showed that RTs were faster for DG than AG faces from –1.5° to 0°, and from +4.5° to +6° (all $p < .003$).

Error rates increased with eccentricity (main effect of eccentricity for both AG ($F(16, 320) = 15.98$, $MSE = 1544.32$, $p < .0001$, $\eta_p^2 = .44$), and DG ($F(16, 320) = 8.13$, $MSE = 1637.46$, $p < .005$, $\eta_p^2 = .29$; see Figure 1.4E). Lower error rates were found for DG than AG faces, a difference that increased with eccentricity, and was more pronounced in the right than in the left visual field. Planned *t*-tests revealed that this effect was significant from +3° to +10.5° (all $p < .003$). Participants also performed at chance level in the AG condition from –12° to –4.5°, and from +3° to +12° (one-sample *t*-test, $p > .004$); additionally, participants performed at chance level in the DG condition from –10.5° to –12° ($p > .004$).

For response rates, a main effect of eccentricity was found for both AG ($F(16, 320) = 4.41$, $MSE = 1706.35$, $p < .05$, $\eta_p^2 = .18$), and DG ($F(16, 320) = 4.40$, $MSE = 1539.39$, $p < .05$, $\eta_p^2 = .18$; see Figure 1.4F). More responses were made for DG than AG, which increased with eccentricity, following the same pattern as for error rates; planned *t*-tests revealed that the response difference was significant from +3° to +12° (all $p < .003$).

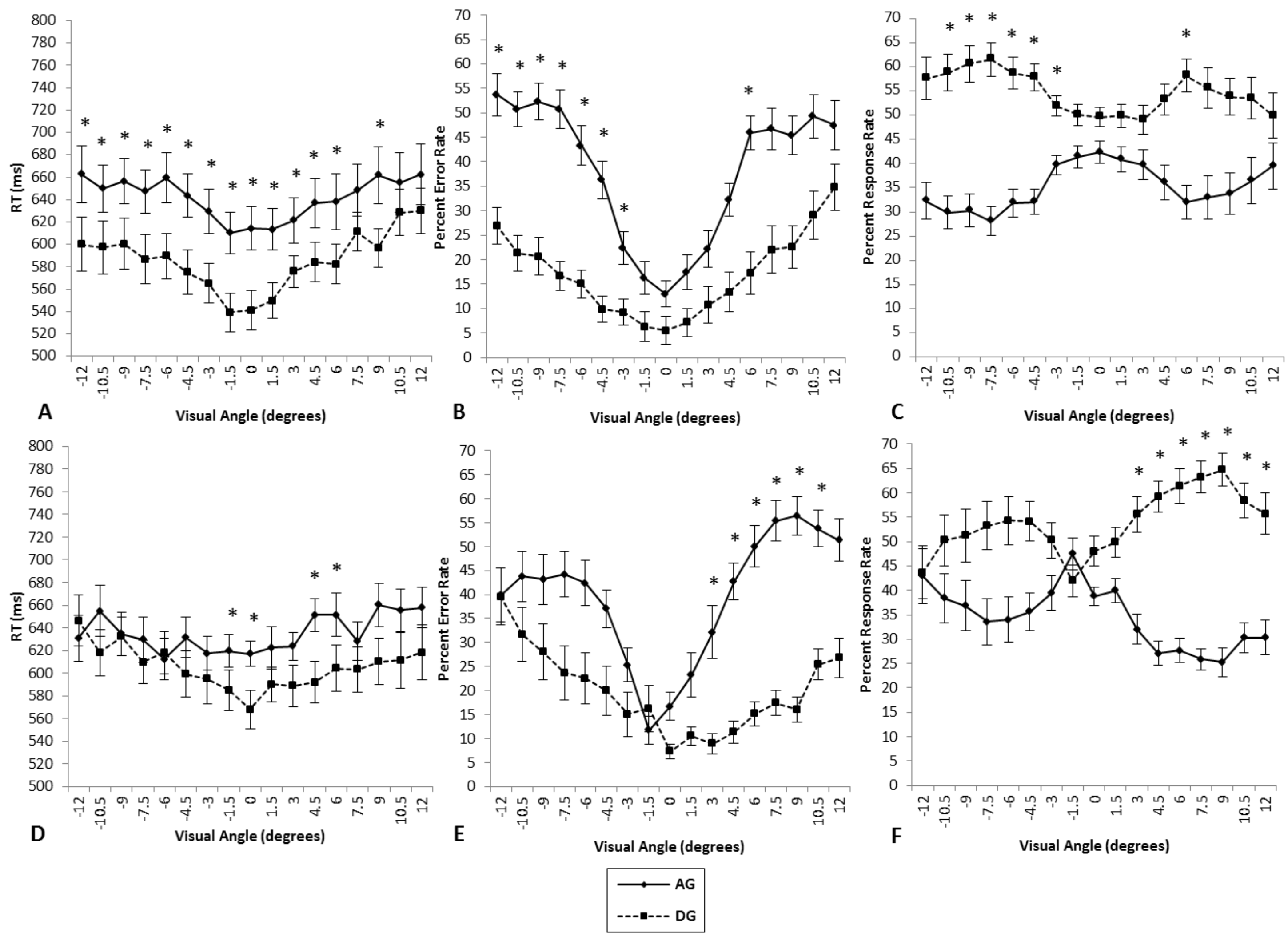

Figure 1.4. Results for Experiment 1b, as a function of gaze direction and eccentricity, for (A) RT responses in the Upright Face condition, (B) Error rates in the Upright Face condition, (C) Response presses in the Upright Face condition, (D) RT responses in the Inverted Face condition, (E) Error rates in the Inverted Face condition, and (F) Response presses in the Inverted Face condition (all shown with standard error bars). DG vs. AG paired comparisons: *$p < .003$.

2.2.3 Experiment 1b Discussion

As in Experiment 1a, for both upright and inverted faces, RTs and error rates increased with eccentricity, and performances for the DG condition were above chance level at nearly all eccentricities. In contrast to Experiment 1a in which AG was also detected above chance level at all eccentricities, in Experiment 1b, participants performed at chance level for AG faces from about ±4.5° (and even less with inverted faces) of eccentricity and beyond. The overall response rates indicated that participants were biased toward responding "direct gaze" more often than "averted gaze", and that this bias increased with eccentricity. Thus, the response bias led to overall accurate performances in the DG condition, but to chance level performances for the AG condition beyond central vision, due to too many errors.

When faces were presented within foveal and parafoveal vision (i.e., from 0º to ±4.5º), error rates were low for both gaze directions, suggesting true gaze discrimination. Thus, the limit of gaze detection in Experiment 1b was approximately 4.5° of eccentricity, similar to the 4° limit reported by Loomis et al. (2008), and to the central vision limits suggested by Burton et al. (2009). Loomis et al. (2008) used front-view natural face stimuli with visible hair and ears that were not equated for contrast and luminance, and in which the different gaze directions were also natural rather than artificially created by manipulating the image. Thus, it appears that when using natural face images in front views with natural contrast and shadows like one would see in typical real life situations, gaze direction can only be detected to about 4.5° of eccentricity; beyond this limit, participants are biased toward responding "direct gaze" more often than "averted gaze". Importantly, the iris diameter of the faces in Experiment 1b was of the same size as in Experiment 1a (20 minutes of arc). At about 5° eccentricity (i.e., one third of foveal acuity), an iris diameter of 20 minutes of arc would be equivalent to about 6.6 minutes of arc at 0° (i.e., 20/3), which is well within the threshold of normal visual acuity. However, the eye regions of the natural faces used in Experiment 1b were of lower luminance than those in Experiment 1a (51.72 versus 94.26, respectively), which most likely contributed to the gaze detection differences between the two experiments. This lower luminance presumably impacted the overall visibility of the eye region, which thus made discrimination of gaze more difficult.

In contrast to Experiment 1a where a response bias was seen only in the centred position, the response bias in Experiment 1b was more prominent in the periphery (although in different visual fields depending on the configuration of the faces). This suggests that as the gaze signal was more difficult to discriminate in the periphery, participants were more likely to press the direct gaze button regardless of the actual stimulus gaze direction. Results were similar for both upright and inverted faces, like in Experiment 1a, again suggesting that inversion did not impact response rates as much with this set of stimuli, as the eye gaze signal visibility was already poor beyond central vision in upright faces. It is possible that participants would respond “I don’t know” in the periphery if given a third button option, but the rationale for the current design was to eliminate the potentially large amount of “I don’t know” responses.

DG was discriminated faster than AG across almost all eccentricities in upright faces, which contrasts with Experiment 1a in which faster responses for DG were seen mostly centrally, and up to ~6° of eccentricity. In the periphery, this effect is probably linked to the chance level accuracy for AG. Although only correct responses were used for RTs, it is likely that participants hesitated and thus took longer to respond to AG faces if they were not sure of their response. In contrast, the faster response to DG than AG in central vision, where gaze was accurately discriminated, is in line with previous research reporting congruency effects between gaze direction and head orientation in front-view faces (e.g., Itier et al., 2007a, 2007b; Langton, 2000; Seyama & Nagayama, 2005; Todorović, 2009). One possibility for the response bias of detecting direct gaze over averted gaze is that participants responded to head orientation rather than to iris position, especially in the periphery. This seems likely if true gaze discrimination can only occur within central vision, while head direction can be accurately discriminated in the periphery (Burton et al., 2009; Loomis et al., 2008). Head orientation was thus most likely to be used as the primary source of gaze direction cues when iris position became less visible. This idea was tested in Experiment 1c which used deviated head views rather than frontal head views.

2.3 Experiment 1c: Natural Faces with Deviated Head Orientation

The literature on the stare-in-the-crowd effect supports the hypothesis that direct gaze is special and is processed faster compared to averted gaze, leading to better detection of direct gaze targets among averted gaze distractors than averted gaze targets among direct gaze distractors, even with deviated head views (Conty et al., 2006; Doi & Ueda, 2007; Doi et al., 2009; Senju et al., 2005). Experiment 1c used faces with deviated heads to investigate whether the directness of eye gaze alone was sufficient to lead to faster and more accurate responses for DG than AG in a non-visual search paradigm. If direct gaze is truly special and its processing is facilitated, then it should still be processed faster and more accurately than averted gaze in deviated head views. In contrast, if head orientation biases gaze judgments, then congruency effects should be seen such that averted gaze should be detected faster and more accurately than direct gaze. In addition, it was predicted that if participants used head orientation to respond to gaze direction, then they would equate deviated heads with averted gaze, and would thus be biased to respond “averted gaze” more often. This would lead to more errors for direct gaze than averted gaze conditions, especially in the periphery where eye cues are more difficult to see, indicating a greater reliance on head orientation with eccentricity.

2.3.1 Experiment 1c Methods

Participants. A total of 21 participants performed the Upright Face condition, and 20 participants performed the Inverted Face condition. One participant was rejected in the Upright Face condition due to fatigue, which left a total of 20 participants in the Upright Face condition (10 female, 10 male; 18 right-handed; age range 18-23 years, *M* = 19.5), and 20 participants in the Inverted Face condition (10 female, 10 male; 17 right-handed; age range 18-22 years, *M* = 19.3).

Stimuli. Greyscale photographs of the same 8 identities as in Experiment 1b were used (again from George et al., 2001). In this experiment, all faces were oriented 30° to either side (see Figure 1.5). For direct gaze faces, the eyes looked toward the observer (i.e., eyes were averted in the opposite direction as the head orientation to make mutual eye contact with the observer); for averted gaze faces, the eyes looked 30° to the side (i.e., eyes were pointed in the same direction in-line with the deviated head orientation). Gaze direction was again natural. The face photographs subtended a visual angle of 4.4° horizontally by 6.6° vertically; the eye region subtended a visual angle of 2.2° horizontally by 0.5° vertically (slightly narrower than Experiments 1a and 1b as the faces were oriented to the side). The iris diameter subtended 20 minutes of arc, as Experiments 1a and 1b. The average pixel luminance value for each individual eye was 58.64 ± 12.29 *SD*, with an RMS contrast of 0.424 ± 0.089 *SD*. This luminance was slightly greater than the 51.72 value in Experiment 1b, but much less than the 94.26 value in Experiment 1a; RMS contrast was slightly lower than the 0.438 value in Experiment 1b and

0.465 value in Experiment 1a.*Apparatus, procedure, and data analysis* were identical to Experiments 1a and 1b.

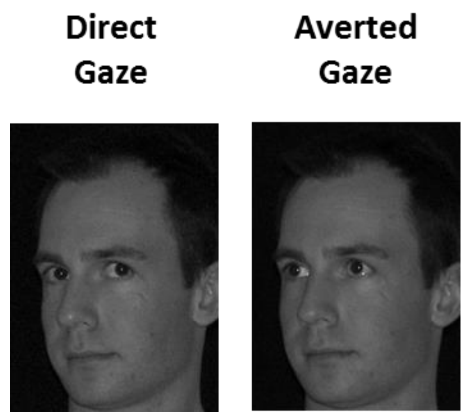

Figure 1.5. Example deviated head stimuli used in Experiment 1c, but the actual photos were taken from George et al. (2001). Faces were shown inverted in the Inverted Face conditions. Please also note that both left- and right-facing head orientations were used.

2.3.2 Experiment 1c Results

Upright Faces

For RTs, a main effect of eccentricity was found for DG ($F(16, 304) = 16.93$, MSE = 3722.56, $p < .0001$, $\eta_p^2 = .49$, but not for AG ($F(16, 304) = 2.29$, MSE = 3899.10, $p = .052$, η_p^2 = .11); see Figure 1.6A). Planned *t*-tests revealed faster RTs for AG faces than DG faces from –12° to –6° (except at –9°), and at +12° (all $p < .003$).

Error rates increased with eccentricity (main effect of eccentricity for AG, $F(16, 304)$ = 18.04, MSE = 262.21, $p < .0001$, $\eta_p^2 = .49$, and DG, $F(16, 304) = 58.69$, MSE = 413.85, $p <$ .0001, $\eta_p^2 = .76$; see Figure 1.6B). Lower error rates were found for AG than DG faces, significantly from –12° to –6° (planned *t*-tests at $p < .001$). For DG, performances were at chance level from –12° to –4.5°, and from +6° to +12° (one-sample *t*-test, $p > .001$). In contrast, performances were above chance level for AG faces at all eccentricities, and errors plateaued around ±4.5°.

Response rates increased with eccentricity for AG (main effect of eccentricity, $F(16, 304) = 6.80$, $MSE = 401.03$, $p < .001$, $\eta_p^2 = .26$), but decreased with eccentricity for DG ($F(16, 304) = 9.41$, $MSE = 220.63$, $p < .0001$, $\eta_p^2 = .33$; see Figure 1.6C). This response difference increased steadily with eccentricity (although more so in the left visual field), with *t*-tests revealing a significant difference between AG and DG responses from –12° to –6° (all $p < .001$).

Inverted Faces

For RT responses, a main effect of eccentricity was found for AG ($F(16, 304) = 5.00$, $MSE = 5541.94$, $p < .001$, $\eta_p^2 = .21$), which showed decreased RTs with eccentricity, while no effect of eccentricity was found for DG ($F(16, 304) = 1.96$, $MSE = 7647.31$, $p = .081$, $\eta_p^2 = .10$; see Figure 1.6D). Planned *t*-tests revealed no difference between gaze directions except at +10.5° with faster RTs for AG than DG ($p < .001$).

Error rates increased with eccentricity (main effect of eccentricity for both AG, $F(16, 304) = 3.26$, $MSE = 552.49$, $p < .05$, $\eta_p^2 = .15$, and DG, $F(16, 304) = 28.13$, $MSE = 480.61$, $p < .0001$, $\eta_p^2 = .60$; see Figure 1.6E). Lower error rates were found for AG than DG faces at –12°, and from +4.5° to +12° (planned *t*-tests, all $p < .003$, except at +7.5°). For DG, error rates increased almost steadily with eccentricity and were above chance level only from –1.5° to +1.5° (one-sample *t*-test, $p < .001$). Performances were above chance level for AG faces at all eccentricities and plateaued by ±4.5°.

Response rates increased with eccentricity for AG (main effect of eccentricity, $F(16, 304) = 3.85$, $MSE = 352.60$, $p < .001$, $\eta_p^2 = .17$), and decreased with eccentricity for DG ($F(16, 304) = 5.17$, $MSE = 368.32$, $p < .005$, $\eta_p^2 = .21$; see Figure 1.6F). This response difference increased steadily with eccentricity, and *t*-tests revealed that this effect was significant at –12°, and from +4.5° to +12°(all $p < .003$, except at +7.5°).

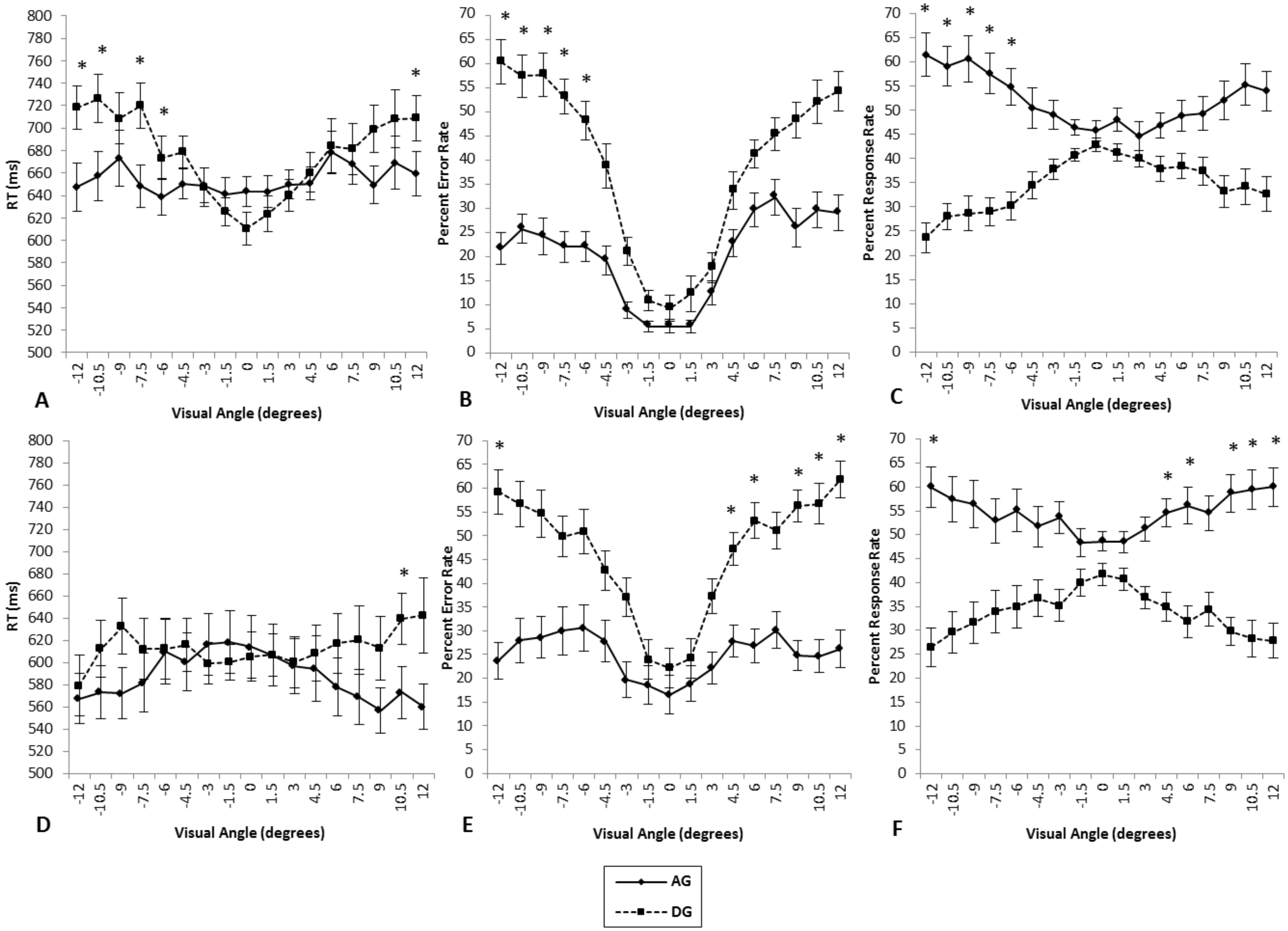

Figure 1.6. Results for Experiment 1c, as a function of gaze direction and eccentricity, for (A) RT responses in the Upright Face condition, (B) Error rates in the Upright Face condition, (C) Response presses in the Upright Face condition, (D) RT responses in the Inverted Face condition, (E) Error rates in the Inverted Face condition, and (F) Response presses in the Inverted Face condition (all shown with standard error bars). DG vs. AG paired comparisons: *p < .003.

2.3.3 Experiment 1c Discussion

As in Experiments 1a and 1b, error rates increased with eccentricity, although for RTs, only DG upright faces increased with eccentricity. A very similar pattern of results as in Experiment 1b was seen, except in the opposite direction. For both upright and inverted faces, performances for the AG condition were above chance level at all eccentricities, and error rates plateaued around 4.5° to 6º of eccentricity. In contrast, error rates increased steadily with eccentricity for direct gaze faces until chance level was reached at about 4.5° to 6° of eccentricity. This led to AG faces being detected more accurately than DG faces, increasingly so with eccentricity. The pattern of overall responses suggested that this was due to a bias in responding "averted gaze" more often than "direct gaze", thus leading to more errors for direct gaze faces in the periphery (although in different visual fields depending on the configuration of the faces). It is possible that participants were simply more confident in their averted gaze judgments when discriminating deviated faces in the far periphery, even though it was equally likely that faces could have had either direct or averted gaze in any particular trial or eccentricity. This pattern of results is the exact opposite of what occurred in Experiment 1b with frontal heads, where direct gaze responses could have been associated with higher confidence judgments. Again, it is likely that participants would have responded "I don't know" in the periphery if given a third button option, considering that RTs increased with eccentricity, reflecting the indecisiveness of responses and/or decrease in visual acuity; thus, participants were more likely to respond with a default button in the periphery (direct gaze in Experiment 1b, and averted gaze in Experiment 1c).

These results support the claim that gaze discrimination is accurate only in central vision, and that participants use head orientation to respond to gaze direction, especially in the periphery. Again, this could also be a reflection of the natural face stimuli that were used, which were not as clearly visible as the faces used in Experiment 1a, due to the decrease in luminance for natural faces. Although congruency effects between gaze direction and head orientation were found in the periphery, there were no significant differences in RTs between DG and AG faces presented centrally (i.e., fixated overtly, 0º of eccentricity) This is in contrast to Experiments 1a and 1b, where the largest RT differences between gaze conditions were found centrally. Furthermore, this does not support the stare-in-the-crowd effect with deviated-view faces (Conty et al., 2006; Doi & Ueda, 2007; Doi et al., 2009; Senju et al., 2005), which suggests a special status for direct gaze, regardless of head orientation. Overall, it appears that (deviated) head orientation plays a more prominent role in influencing gaze detection in the periphery, but not in central vision.

In sum, the results of Experiment 1c suggest that, with deviated heads, gaze discrimination seems to rely mainly on head orientation beyond foveal vision, and increasingly so with eccentricity. However, in all three experiments, head orientation was known to participants at the beginning of the study. The heavy reliance of gaze discrimination on head orientation might thus be the result of a specific strategy. To eliminate this possibility, Experiment 1d included both frontal and deviated head views.

2.4 Experiment 1d: Frontal and Deviated Heads Together

In Experiments 1b and 1c, frontal and deviated head conditions were tested in separate participant groups. It is thus possible that participants developed a strategy to detect gaze because they would only view trials with one type of head orientation. Experiment 1d addressed this possibility by using both frontal and deviated heads in the same within-subjects design. If head orientation truly impacts gaze perception beyond any specific strategy, then results should be very similar to those of Experiments 1b and 1c. In addition, this design allowed comparing directly the effects of frontal versus deviated head views on gaze perception. It has recently been suggested that when searching for a stare in a crowd, frontal faces guide overt attention independently of gaze direction (Shirama, 2012), suggesting a particular status for front-view faces in visual search. The present design allowed to test whether a similar effect of frontal heads could be seen on covert attention.

It was expected that congruency effects would be found between gaze direction and head orientation such that direct gaze would be processed faster and more accurately in frontal than deviated heads, while the opposite effect would be found for averted gaze. This pattern should be seen in the periphery given the proposed increased reliance of gaze judgments on head orientation with eccentricity suggested by Experiments 1b and 1c. For error rates, this pattern was predicted in the foveal region based on the existing congruency effects reported in the gaze literature. If head orientation always drives gaze perception beyond iris position and given the special role of frontal heads in attention (Shirama, 2012), then it was expected that a main effect of head orientation would be found in favour of frontal heads rather than the expected gaze-head interactions (congruency effects). Finally, as the inversion manipulation in the previous experiments did not have much theoretical implication, Experiment 1d only involved upright faces.

2.4.1 Experiment 1d Methods

Participants. A total of 24 participants completed Experiment 1d. Two participants were rejected due to eye-tracking calibration issues, one due to fatigue, and one due to an insufficient amount of data. This left a total of 20 participants (11 female, 9 male; 19 right-handed; age range 19-23 years, $M = 20.7$).

Stimuli and Procedure. The same upright face photographs as in Experiments 1b and 1c were used. To keep the same duration as Experiments 1a-1c (~70 min), half of the eccentricities as the other studies were used. Individual faces were presented randomly in one of 9 possible locations aligned horizontally across the screen, from –12° to +12° eccentricity. For each eccentricity, there were 32 frontal DG trials, 32 frontal AG trials, 32 deviated DG trials, and 32 deviated AG trials, totalling 1152 trials which were divided into 8 blocks of 144 trials each. Importantly, head orientation was not confounded with gaze direction (i.e., each individual face could have been either a frontal or deviated head position, with either a direct or an averted gaze). All other aspects of the design were identical to Experiments 1a-1c.

Since this experiment was different in design than the previous experiments, it was important to test for interactions between gaze and head orientation within participants. From Experiments 1b and 1c, it appears that there would be a strong interaction between DG and AG across frontal and deviated head orientations. Thus, RTs, percent error rates, and percent response rates were analyzed using a 2 (head orientations) by 2 (gaze directions) by 9 (eccentricities) repeated measures ANOVA. The Greenhouse-Geisser degrees of freedom correction was used when the sphericity assumption was violated. Subsequently, for each dependent measure (RT, error rate, response rate), planned paired sample (two-tailed) *t*-tests were performed comparing the two gaze conditions within each head orientation at each target position, as well as comparing the two head orientations within each gaze direction at each target position. The Bonferroni correction was used for these planned *t*-tests comparing the two gaze conditions and two head orientations across the 9 eccentricities (i.e., 36 comparisons), making *p* value significance thresholds at .001 (i.e., .05/36 = .001). The same significance threshold was also used for one sample *t*-tests (two-tailed) performed at each eccentricity and each condition testing error rates against chance level (test value of 50).

2.4.2 Experiment 1d Results

RT results can be found in Figure 1.7A. There were main effects of eccentricity ($F(8, 152) = 9.20$, $MSE = 5316.78$, $p < .0001$, $\eta_p^2 = .33$), gaze direction ($F(1, 19) = 9.86$, $MSE = 14278.18$, $p < .01$, $\eta_p^2 = .34$), and head orientation ($F(1, 19) = 51.13$, $MSE = 907.50$, $p < .0001$, $\eta_p^2 = .73$), which were strongly modulated by interactions between eccentricity and gaze direction ($F(8, 152) = 6.37$, $MSE = 3715.65$, $p < .001$, $\eta_p^2 = .25$), eccentricity and head orientation ($F(8, 152) = 3.30$, $MSE = 1665.40$, $p < .01$, $\eta_p^2 = .15$), gaze direction and head orientation ($F(1, 19) = 28.40$, $MSE = 5558.94$, $p < .0001$, $\eta_p^2 = .60$), and eccentricity by head orientation by gaze direction ($F(8, 152) = 2.37$, $MSE = 1897.65$, $p < .05$, $\eta_p^2 = .11$). This complex pattern reflected that RTs to averted gaze faces were the longest and were not modulated by eccentricity (effect of eccentricity at $p > .3$ for AG faces tested separately). In contrast, RTs to DG faces increased with eccentricity. These RTs increased steadily up to the extreme eccentricities for frontal heads, while for deviated heads, the increase was sharp from 0 to ±3°, and levelled off by ±6º. RTs were also faster for DG than AG for frontal heads from –6° to +6° (planned *t*-tests, all $p < .001$), while for deviated heads, RTs were faster for DG than AG faces only at 0° ($p < .001$). RTs were also faster for DG frontal than DG deviated heads from –6° to +6° (planned comparison *t*-tests, all $p < .001$). By contrast, no differences in RTs were found between AG deviated and AG frontal heads. The overall pattern suggested a clear distinction between DG frontal heads and the other three conditions.

For error rates (Figure 1.7B), main effects of eccentricity ($F(8, 152) = 117.70$, MSE = 127.50, $p < .0001$, $\eta_p^2 = .86$) and head orientation ($F(1, 19) = 36.72$, MSE = 200.63, $p < .0001$, $\eta_p^2 = .66$) were modulated by interactions between eccentricity and head orientation ($F(8, 152)$ = 3.84, MSE = 93.43, $p < .005$, $\eta_p^2 = .17$), head orientation and gaze interaction ($F(1, 19) = 80.83$, MSE = 1122.97, $p < .0001$, $\eta_p^2 = .81$), eccentricity and gaze direction ($F(8, 152) = 2.87$, MSE = 517.14, $p < .05$, $\eta_p^2 = .13$), and eccentricity by head orientation by gaze direction ($F(8, 152)$ = 14.88, MSE = 231.77, $p < .0001$, $\eta_p^2 = .44$). The overall pattern clearly showed lower error rates for frontal heads with direct gaze followed by deviated heads with averted gaze (the two congruent conditions), and then by the two incongruent conditions, which did not differ. Error rates increased steadily with eccentricity for frontal view DG faces but performances well above chance level at all eccentricities ($p < .001$). In contrast, the increase in error rates levelled off for the other three conditions by about ±6º. For the deviated view AG, errors were also well above chance level at all eccentricities ($p < .001$). For the two incongruent conditions performances reached chance level by ±6º (using a one-sample *t*-test, $p > .1$). For frontal heads, DG faces elicited lower error rates than AG faces from –9° to +9° (planned *t*-tests, all $p < .001$), except at 0°. For deviated heads, AG faces elicited lower error rates than DG faces from +9° to +12° (all $p < .001$). Additionally, lower error rates were found for DG frontal than DG deviated heads at all eccentricities (all $p < .001$), while lower error rates were found for AG deviated than AG frontal heads at all eccentricities (all $p < .001$), except between –3° and +3°.

For overall response rates (Figure 1.7C), a main effect of head orientation ($F(1, 19)$ = 8.97, MSE = 33.13, $p < .01$, $\eta_p^2 = .32$) was found, which was strongly modulated by interactions between eccentricity and head orientation ($F(8, 152) = 2.33$, MSE = 9.50, $p < .05$, $\eta_p^2 = .11$), eccentricity by gaze interaction ($F(8, 152) = 3.14$, MSE = 442.10, $p < .05$, $\eta_p^2 = .14$), head orientation and gaze direction ($F(1, 19) = 53.87$, $MSE = 1357.60$, $p < .0001$, $\eta_p^2 = .74$), and eccentricity, head orientation, and gaze direction ($F(8, 152) = 14.14$, $MSE = 174.99$, $p < .0001$, $\eta_p^2 = .43$). For frontal heads, more DG than AG responses were made from –9° to +9° (planned *t*-tests, all $p < .001$), except at 0°. For deviated heads, more AG than DG responses were made only at +9° (all $p < .001$). Additionally, the DG responses were made more often for frontal heads than for deviated heads at all eccentricities (all $p < .001$, except at +12°), while the AG responses were made more often for deviated than frontal heads at all eccentricities (all $p < .001$), except between 0° and +3°.

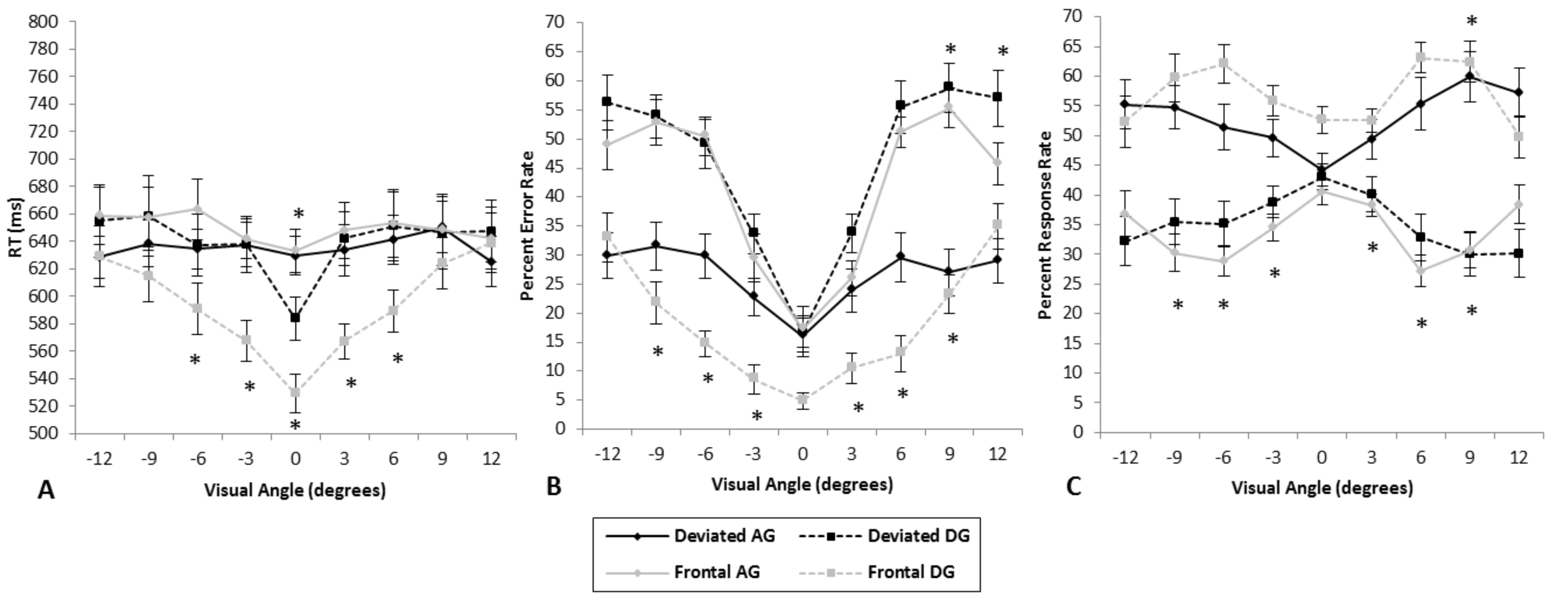

Figure 1.7. Results for Experiment 1d (upright faces only), as a function of gaze direction and eccentricity, for (A) RT responses, (B) Error rates, and (C) Response presses (all shown with standard error bars). Please note for (B) and (C), gaze direction data were computed within each head orientation (i.e., DG vs. AG for frontal heads, and DG vs. AG for deviated heads), so the scale of the graphs remain consistent with Experiments 1a-1c. DG vs. AG paired comparisons: stars above lines represent deviated heads DG vs. AG comparison; stars below lines represent frontal heads DG vs. AG comparison; *$p < .001$.

2.4.3 Experiment 1d Discussion

The pattern of errors and overall responses was remarkably similar to what was seen in Experiments 1b and 1c. Error rates increased with eccentricity, and this increase was steeper for the incongruent gaze-head conditions (i.e., AG frontal and DG deviated faces) than for the congruent conditions (i.e., DG frontal and AG deviated faces), with chance level reached at ±6° eccentricity for incongruent conditions. Again, this pattern seemed driven by the response bias, with participants making more “DG” than “AG” responses for frontal heads and more “AG” than “DG” responses for deviated heads (although this was significant for frontal heads only). This response bias was more pronounced in the periphery than in central vision, leading to more errors for the incongruent conditions with eccentricity (with a larger difference for frontal than deviated heads).

In contrast to error rates and response biases, the pattern of RTs was a little different from what was seen in Experiments 1b and 1c, and included some aspects revealed in Experiment 1a. RTs increased with eccentricity only for DG faces; this effect was more pronounced for frontal heads, while RTs for deviated heads plateaued quickly between ±3º to ±6° eccentricity. No effect of eccentricity was found for AG faces, which also elicited the longest RTs. Similar to Experiment 1a, for frontal heads, DG faces were discriminated faster than AG faces within central vision, until 6º eccentricity. This pattern contrasts with Experiment 1b in which DG faces elicited faster RTs at almost all eccentricities. However, taking into account the fact that by ±6º performances were at chance level for incongruent conditions, these results reflect truly faster (and more accurate) discrimination of the DG frontal head condition below these eccentricity limits, and thus most likely up to the limits of central vision (5º eccentricity). For deviated heads, faster RTs for DG than AG faces were seen for the centred position. However, unlike

Experiment 1c, AG deviated faces were not discriminated faster than DG deviated faces beyond the foveal position or in the periphery. Overall, the pattern of results suggest that in Experiments 1b and 1c, participants' *a priori* knowledge of head orientation might have somewhat affected the RT data.

The within-subjects design of Experiment 1d avoided any possible strategy based on this *a priori* knowledge of head orientation. DG faces were discriminated faster than AG faces across both head orientations in the foveal position, in line with the stare-in-the-crowd effect literature (Conty et al., 2006; Doi & Ueda, 2007; Doi et al., 2009; Senju et al., 2005). This result supports the idea that even in non-visual search paradigms, direct gaze processing is facilitated compared to averted gaze processing; however, this occurs only at 0º of eccentricity. A clear advantage in response speed remained for DG until the limits of central vision, but only when the face was in front view. Beyond foveal presentation, gaze discrimination judgments are biased toward head orientation, leading to strong gaze-head congruency effects that increased with eccentricity. Thus, these results are slightly different from previous research showing congruency effects on both RTs and accuracy when faces are focused overtly (Itier et al., 2007a, 2007b; Langton, 2000; Ricciardelli & Driver, 2008; Shirama, 2012). The present results demonstrate a dissociation between RTs and error rates in the centred position. RTs revealed a main effect of gaze in favour of DG in fovea while no differences were found in accuracy between DG and AG in foveal presentation, for either head orientation. The latter result argues against the idea of a general head orientation advantage in driving attention (Shimara, 2012), however, the combination between the front view of the head and the direct gaze direction facilitates processing in foveal vision and more generally in central vision. Beyond foveal vision, head orientation starts biasing gaze judgments, leading to congruency effects that increase with eccentricity. Beyond central vision, gaze judgments are no longer accurate, and are predominantly biased toward head orientation.

Overall, these results were relatively consistent with those found in Experiments 1b and 1c, in that head orientation strongly influenced the speed, accuracy, and response bias of gaze detection in the periphery. However, the direct comparison of all conditions together revealed an effect of gaze beyond head orientation on RTs within foveal vision, and a clear advantage in processing DG in frontal heads within the limits of central vision. Thus, frontal heads with DG may summon covert as well as overt attention.

2.5 General Discussion and Conclusions

Across four experiments, Chapter 2 investigated whether and to what extent gaze direction could be accurately detected in the periphery, and whether direct gaze was discriminated better than averted gaze when presented in both the central and peripheral visual fields. This study also examined to what extent head orientation affected this gaze discrimination judgment. Faces were presented randomly across many horizontal eccentricities (17 in Experiments 1a-1c, 9 in Experiment 1d) while fixation on a centred fixation cross was enforced by an eye-tracker. Faces were in front view in Experiments 1a and 1b, in deviated head view in Experiment 1c, and in both head views in Experiment 1d. Participants discriminated between direct gaze (DG) and averted gaze (AG) using two response buttons, while RTs, error rates, and response bias were recorded.

The eccentricity at which participants could accurately detect gaze direction above chance level was investigated. Experiment 1a revealed that gaze detection was accurate at nearly all eccentricities. The stimuli used in this study were cropped so that facial features were contained within the same oval shape, and hair and ears were removed. Gaze was manipulated manually, and mean luminance and contrast were equated across images, creating perfectly clear and symmetrical stimuli in which local cues, such as iris position, were clearly visible. These faces allowed easy gaze detection even when presented inverted. Under these ideal conditions (e.g., extremely clear stimuli, no other items competing for attention), covert gaze detection could be possible in the periphery, well beyond foveal or parafoveal vision, although the fact that participants knew that only frontal view faces were shown might have had an effect. This detection of gaze beyond central vision might recruit the Direction of Attention Detector (Perrett & Emery, 1994) or the subcortical face detector proposed by Johnson (2005), picking up the contrast information between the dark iris and the white sclera of the eyes available in the periphery to enable rapid eye contact detection (Senju & Johnson, 2009). It is interesting to note that these systems would work best (if not only) with frontal head views.

In contrast, Experiments 1b-1d used more natural stimuli in which gaze direction was not manually manipulated; natural shadows were also kept which decreased the visibility of the eye region. In these studies, accurate gaze detection was achieved only to about 4.5° eccentricity, which is very close to the 4° limit reported by Loomis et al. (2008), who also used natural face stimuli with visible hair and ears. It appears that when using more ecological face images, gaze direction can only be reliably discriminated within central vision, a conclusion also reached by previous studies (Burton et al., 2009; Loomis et al., 2008). In real life, these eccentricity limits are the ones most likely to be at play, given the complexity of the visual world and its constant shifts in attention demands.

Head orientation strongly influenced gaze discrimination in the current study. Experiments 1a and 1b showed better discrimination of DG than AG when using frontal heads while Experiment 1c showed better discrimination of AG than DG when using deviated heads, and this was seen in both upright and inverted faces. Experiment 1d confirmed these results and showed gaze-head congruency effects as well. Response rates also showed that beyond foveal vision participants were indeed biased to respond to the direction of the head, rather than to the direction of the eye gaze. This finding is in line with other research showing that gaze judgments can be strongly affected by head orientation (Anstis et al., 1969; Kluttz et al., 2009; Langton, 2000; Langton et al., 2004; Ricciardelli & Driver, 2008; Seyama & Nagayama, 2005; Shirama, 2012; Todorović, 2009; Wollaston, 1824). However, these previous studies only examined gaze discrimination using overt attention. This study examined gaze discrimination using covert attention, and the data showed that the effect of head orientation on gaze direction judgment increases with eccentricity.

For upright faces in Experiments 1b and 1c, head orientation seemed to bias gaze judgments more in the LVF than in the RVF, leading to larger gaze discrimination differences in the LVF than in the RVF. Overall, this demonstrates a strong visual field asymmetry in this gaze judgment task. Previously, it has been shown that during the stare-in-the-crowd visual search task, targets in the LVF are responded to faster than targets in the RVF (Conty et al., 2006; Doi et al., 2009; Palanica & Itier, 2011) indicating a trend for a leftward bias in initial spontaneous explorations of visual scenes (Ebersbach et al., 1996; Hättig, 1992). Although the current task was not a visual search, this visual field asymmetry may reflect a LVF bias for gaze perception (Ricciardelli et al., 2002), which can also be related to the right hemisphere dominance for face and gaze processing (e.g., Burt & Perrett, 1997; Calder et al., 2007). For inverted faces, gaze judgments were more biased in the RVF, suggesting that inversion disrupted any “normal” visual field asymmetries for gaze processing, although it is unclear why this effect occurred. Perhaps, if inversion disrupted normal gaze perception (Jenkins & Langton, 2003; Schwaninger et al., 2005; Senju et al., 2005; Senju & Hasegawa, 2006), then participants could have implicitly compensated for the lack of gaze signal clarity by biasing their gaze judgments in the opposite manner with which they would have if the faces were upright.

Other than the visual field asymmetries, very similar results were found for upright and inverted faces in Experiments 1a, 1b, and 1c, which support the idea that gaze judgments were made mostly on the basis of head orientation, a cue that is still clearly visible when the face is inverted. By disrupting the face configuration, and thus the general relation between the eye region and the rest of the face, inversion simply rendered the gaze signal more difficult to perceive, increasing participants' reliance on head orientation. Consequently, participants were more biased to respond to the direction of the head than the eyes. This was especially true in Experiments 1b and 1c, where the visibility of the eye region was already compromised in upright faces beyond central vision due to the type of stimuli used (natural faces with shadows), making the impact of inversion less clear. Thus, inversion decreased eye gaze perception as shown previously (Jenkins & Langton, 2003; Schwaninger et al., 2005; see also Senju et al., 2005; Senju & Hasegawa, 2006), and this in turn increased the bias of head orientation on gaze judgments.

Using head orientation as a primary indicator for gaze direction in the periphery makes sense since head direction can be seen from a much farther eccentricity than gaze direction (Loomis et al., 2008), and the two are normally highly correlated. Additionally, if the eye region is occluded (e.g., by sunglasses; Nuku & Bekkering, 2008) or obscured by shadows or low light conditions, then the head can be used to infer attention direction, an idea already suggested by research in monkeys (Perrett et al., 1992). In instances of low eye visibility, priority could be given to head direction as an indicator of social attention. These results show that this is the case in the peripheral field when eye gaze is no longer clearly visible. Electrophysiological studies in monkeys provide evidence that neurons in the Superior Temporal Sulcus (STS) integrate information from eye gaze direction, head orientation, and body position (Perrett et al., 1982, 1985). In humans, neuroimaging studies suggest that two distinct regions of the STS are involved in gaze processing. The anterior part (aSTS) has recently been shown to contain distinct neural populations sensitive to the different directions of gaze, as revealed by neural adaptation (Calder et al., 2007). The posterior part (pSTS) in contrast, has been involved in the processing of gaze (Allison et al., 2000; Hoffman & Haxby, 2000), but also in biological movements (Puce & Perrett, 2003), and recent studies suggest that it is involved in the social relevance of gaze signals and the general analysis of social intentions of human actions (e.g., Pelphrey et al., 2003, 2004a; Saxe et al., 2004) rather than in gaze direction discrimination *per se*. Although it is at present unclear how the coding of head orientation impacts the processing of gaze direction in the human brain, all of these findings support the general Direction of Attention Detector as a basis for social attention (Perrett & Emery, 1994). Future neuroimaging studies will have to investigate these links to the human brain more carefully, since the present behavioural findings can only speculate on possible cognitive mechanisms involved with these gaze detection processes, but nevertheless support previous neurophysiological research.

The present results demonstrate that in instances where eye gaze direction is not clearly visible, a response bias occurs to a more salient indicator of social attention—in this case, head orientation. Interestingly, gaze judgments in the current study were affected by head orientation within the limits of central vision, starting at ±3° eccentricity. This is likely to be from the fact that visual acuity drops very rapidly outside of fovea (Larson & Loschky, 2009). Thus, the larger size of the head compared to the eyes could account for the reliance on head orientation in gaze judgments. The larger size of the head is easier to see in the periphery compared to the eyes (Loomis et al., 2008), and may lead to a global information bias (see Navon, 1977), where global information (i.e., head orientation) receives priority over local information (i.e., eye direction) for gaze judgments. In turn, the visual salience of head orientation in the periphery could have elicited the response bias for gaze judgments, which could have also reflected higher confidence in responses. Although, considering that RTs generally increased with eccentricity, participants became more unsure of their responses in the periphery, and generally reacted with a default response that was biased toward head orientation.

In contrast, gaze judgments in the current study were not strongly affected by head orientation when the face was focused overtly (0°), contrary to previous research (Anstis et al., 1969; Kluttz et al., 2009; Langton, 2000; Langton et al., 2004; Ricciardelli & Driver, 2008; Seyama & Nagayama, 2005; Shirama, 2012; Todorović, 2009; Wollaston, 1824). In fact, results from Experiment 1d suggest that in foveal and parafoveal vision, the combination of a frontal head view with a direct gaze elicited the best response compared to the other three gaze-head combinations. In general, the typical gaze-head congruency effects on gaze judgments were seen beyond foveal vision, but the particular combination of DG with a frontal head was detected faster and more accurately than the other conditions across the majority of eccentricities (Figure 1.7). Several factors might contribute to this front-view DG effect. First, it corresponds to the innate face template for which human infants show a preference (Johnson et al., 1991; Morton & Johnson, 1991; Farroni et al., 2002). Second, parents usually direct both their head and eye gaze toward their offspring to capture their attention and also to perceive the infant’s wants and needs, making the front head with direct gaze the most prevalent visual stimulus infants are exposed to early in life. Third, in typical real-world situations, interpersonal communication usually occurs face to face. For instance, to grab another person's attention, one will tend not only to shift their gaze, but also move their face toward the person of interest. Because it is physically uncomfortable to direct one's eyes to the far side for a long period of time, people typically align their heads and eye direction to people/objects of interest. The intent in social interaction may also be perceived as stronger when both head and gaze directions are oriented toward us. Thus, the extra attention summoned by a frontal head with DG over and above the other conditions may be the result of both an innate preference for that stimulus and a learned response.

In Experiments 1a, 1b, and 1d, it is also important to note that when participants were directly fixated on the target, DG was discriminated faster than AG regardless of head orientations, in line with research supporting a facilitation of direct gaze processing (Conty et al., 2006; Doi & Ueda, 2007; Doi et al., 2009; Senju et al., 2005). This faster response to DG in the centred position using frontal heads supports previous research using a similar two-button response design to discriminate gaze direction (Itier et al., 2007b; Pageler et al., 2003); however, in the current study, people were also faster at detecting DG in the centred positions with deviated heads, contrary to these previous studies. As these studies used a very similar task (look-at-me/look away judgment), the processing of gaze seems to be affected by the specific design used, in particular, the fact that the face is always centrally presented (e.g., Itier et al., 2007b; Pageler et al., 2003) or presented randomly at different eccentricities (current study). Participants may be able to rapidly (and accurately) extract gaze information from the eye region alone (iris position) when focused overtly given the high acuity in fovea, even with a target exposure of just 150 ms. Beyond 0° eccentricity, eye and head cues are integrated for gaze judgments until the limits of central vision, at which point observers predominantly use head orientation cues for gaze judgments.

In conclusion, these findings support the notion that humans have a specialized cognitive mechanism capable of rapidly responding to important social signals in the environment. One such signal is gaze direction that gives cues to others' attention and intentions. These findings show that both head orientation and iris position contribute to gaze detection in the environment, supporting the Direction of Attention Detector that would integrate directional information from eyes, head, and body position (Perrett & Emery, 1994). While eye cues may play a more important role under focused attention, head orientation seems to drive gaze judgments beyond foveal view and especially in the periphery. Different gaze detection processes may be used depending on whether overt or covert attention is applied. The data also highlight the special role played by frontal heads with a direct gaze, the most attention-capturing stimulus during gaze detection which, under optimal conditions, can be detected quite accurately beyond central vision.

The purpose of this chapter was to directly test whether gaze direction could be rapidly and accurately detected beyond foveal vision, and to test how head orientation influenced performance. The visual field is comprised of a wide range of eccentricities that extend in all directions. Chapter 2 only examined gaze detection along the horizontal visual field, so it is unknown if these findings would be replicated across the vertical visual field as well. The goal of Chapter 3 was to address this issue.

Chapter 3: Detecting Gaze in the Vertical Periphery

The purpose of Chapter 3 was to replicate and extend the experiments of Chapter 2 by presenting faces along the vertical visual field. The same design was used for the experiments in Chapter 3, except the faces were presented above and below fixation (between 0º and ±6º of vertical eccentricity). If a Direction of Attention Detector or subcortical detection mechanism exists for processing social signals in the environment, then it would make sense to function in all directions of the visual field, including the upper and lower periphery as well as the horizontal periphery. For example, it would be beneficial to spot the eye gaze of people of different heights and across a wide field of view, especially if you were looking into a crowd of people from an elevated location (e.g., a balcony or hill top) where you would need to process social signals from all eccentricities (e.g., as if from a bird's eye view). If humans evolved with a dedicated cognitive mechanism for detecting and discriminating these social signals, then it should have evolved in all environments (whether it be desert plains, mountainous terrain, or tree-filled jungles) where noticing conspecifics was vital to survival and proper communication. The very nature of having a "specialized" mechanism for perceiving social signals inherently means that it should be vigilant for stimuli across one's *entire* surroundings.

Nevertheless, it is simply unknown whether gaze can be accurately detected along vertical eccentricities, since there is no current research that has tested this question directly. Burton et al. (2009) presented distractor facial stimuli between 3.6° and 4.9° eccentricity above or below fixation (target stimulus) to examine whether another person's gaze influenced rapid directional (left–right) gaze judgments of the target face. The researchers concluded that focused attention was required when making gaze judgments, but it remains unknown whether a direct/averted gaze discrimination judgment can be made with faces presented in the vertical periphery while no central item competes for attention. The binocular visual field in adult humans is roughly elliptical in shape and measures 200° horizontally by 130° vertically at its limits (Harrington, 1971). Although the human visual field has a wider horizontal range than vertical range, Chapter 2 and previous research (Loomis et al., 2008) found that gaze detection was only accurate to, at most, ~4.5° of horizontal eccentricity (i.e., within central vision), at least with natural faces. Since this eccentricity is still within the limits of central vision, rather than extending to the absolute range of the human visual field (i.e., 200° by 130°), it is hypothesized that accurate gaze detection would reach a similar vertical eccentricity compared to horizontal eccentricity (i.e., within central vision, where visual acuity is higher than in the periphery). Beyond this eccentricity, a bias toward using head orientation cues for gaze judgments should be seen in the vertical periphery, similar to the horizontal periphery. There is also a possibility that an asymmetry of target detection could occur between the upper and lower visual fields. It has been proposed that the visual field may be divided into peripersonal (close to the body) and extrapersonal (beyond reaching distance) space (Previc, 1990, 1998), and visual scene perception is usually carried out in extrapersonal space which may be more efficient in the upper visual field (reviewed in Danckert & Goodale, 2003). Thus, since observers may be more alert to stimuli in extrapersonal space (i.e., upper visual field), there is a possibility that participants in the current study may detect targets (i.e., gaze signals) better in the upper rather than the lower visual field. However, it is unknown how strong this detection asymmetry would be, or at what eccentricity this difference would occur. The lack of research that has directly examined gaze perception along the vertical visual field makes the current study especially important to answer some of these questions. All other predictions for Chapter 3 were the same as for Chapter 2 (substituting horizontal for vertical eccentricities), including the gaze-head congruency effects that should be seen beyond central vision, and the evidence that direct gaze faces should be detected faster than averted gaze faces (across head orientations) in foveal vision, at least when both head orientations are tested within the same design. In fact, the 0° eccentricity used in the current study effectively acted as a control baseline target position that could be directly compared with Chapter 2, since this was the direct focus of fixation.

The current study consisted of three experiments, with natural faces using frontal head views (Experiment 2a), deviated head views (Experiment 2b), and both frontal and deviated head views (Experiment 2c), replicating the design of Experiments 1b, 1c, and 1d, respectively. A primary goal was to compare gaze detection between horizontal and vertical eccentricities for each head orientation, which motivated the replication of the last three studies from Chapter 2. Furthermore, in Experiment 1c using deviated heads, head orientation strongly influenced gaze discrimination in the periphery, while Experiment 1d, using both head orientations, showed very little effect of deviated heads on gaze discrimination. Thus, it is possible that the effects of head orientation on gaze judgments would be affected by study design and also vertical eccentricities. Chapter 3 helped investigate these possibilities. This chapter also only used the natural face photographs as found in Experiments 1b, 1c, and 1d (see Figures 1.3 and 1.5). The natural face photographs allowed more ecological validity (e.g., with naturally shadowed areas, and the genuine gaze direction angles performed by the actors). In fact, all of the remaining studies in this thesis used these natural face photographs as stimuli. The faces from Experiment 1a (controlled for contrast and luminance) were not used, since gaze direction was accurately detected at nearly all levels of eccentricity tested (upwards of 12° in the horizontal periphery), so it was unknown what the limit of accurate gaze detection may have been. Since the computer screen that was used was not large enough to test targets beyond about ±7.5° vertical eccentricity, the current study only tested a maximum vertical eccentricity limit of ±6°, which was close to the tallest limit achievable with the computer screen, and from Chapter 2, it was shown that accurate gaze discrimination would only occur within central vision (i.e., ±5° eccentricity) anyway, when using natural faces. Lastly, Experiments 2a and 2b used inverted faces as a control condition to replicate Experiments 1b and 1c, respectively. Even though the inversion manipulation in these previous experiments did not strongly impact the results, it was predicted that gaze detection would be impaired, at least marginally, with inverted faces, especially with increasing eccentricity as visual acuity should diminish similarly in the vertical and horizontal periphery.

3.1 Experiment 2a: Frontal Head Orientation

3.1.1 Experiment 2a Methods

Participants. A total of 22 participants performed the Upright Face condition, and 21 participants performed the Inverted Face condition. One participant was rejected in the Inverted Face condition due to fatigue, for a final total of 22 participants in the Upright Face condition (11 female, 11 male; 20 right-handed; age range 18-24 years, $M = 20.2$), and 20 participants in the Inverted Face condition (10 female, 10 male; 18 right-handed; age range 18-23 years, $M = 20.3$).

Stimuli and Procedure. The same natural face photographs with frontal heads from Experiment 1b were used. As in Chapter 2, a centred fixation cross was presented for 1200 ms, which then became a fixation trigger that participants must have focused on for 300 ms to activate the next trial, with the use of the same eye-tracker (see Figure 2.1). For each trial, an individual face was presented for 150 ms randomly in one of 9 possible locations aligned vertically on the screen, positioned from –6° (below fixation) to +6° (above fixation). The distance between the centres of each adjacent face position was separated by 1.5° of visual angle vertically. The same two-button forced choice task was used as in Chapter 2, where participants were required to make a direct/averted gaze judgment as quickly and as accurately as possible (which again would make a 50% error rate equal to chance level accuracy). Before each study session, 9 practice trials (one for each possible stimulus location) were presented to familiarize participants with the stimuli and task. Each target position consisted of 32 DG trials and 32 AG trials (16 left- and 16 right-averted), totalling 576 trials for each study session, which were divided into 4 blocks of 144 trials each. Within each block, between 7 and 9 trials were presented for each gaze direction at each eccentricity. All other aspects of the design were identical to Experiments 1a-1c.

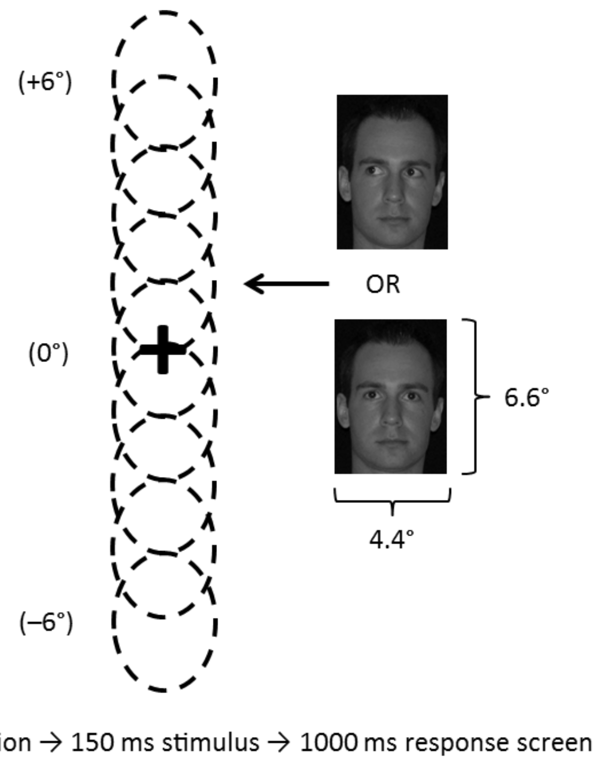

Figure 2.1. Stimulus presentation, with reproductions (i.e., not the actual photos) of the George et al. (2001) faces used in the experiments. The dotted ovals are shown to represent all of the 9 possible locations of stimuli presentation, but were invisible during trials. Negative (–) eccentricities represent target positions below fixation, while positive (+) eccentricities represent those above fixation. The fixation cross was shown during the entire duration of each trial to keep participants' fixation focused. Faces were shown inverted in the Inverted Face condition. Please also note that for averted gaze faces, both left- and right-looking faces were used (in equal proportions).

3.1.2 Experiment 2a Data Analysis

For each subject, RTs that were below 150 ms or exceeded 2.5 standard deviations from the mean of each gaze condition per eccentricity were discarded (8.1% of the data in Experiment 2a; 8.2% in Experiment 2b; 9.4% in Experiment 2c). All trials where more than one fixation was made were eliminated (3.1% in Experiment 2a; 3.2% in Experiment 2b; 2.9% in Experiment 2c). RTs exceeding 1000 ms were recorded as a miss (2.9% in Experiment 2a; 4.7% in Experiment 2b; 7.2% in Experiment 2c). Similar to Chapter 2, RTs, error rates, and response rates were analyzed using a one way ANOVA with eccentricity as a within subjects factor, for AG and DG separately. The Greenhouse-Geisser degrees of freedom correction was used when the sphericity assumption was violated. To determine the vertical eccentricity limits for gaze discrimination, error rates for each gaze condition were compared to chance level at each eccentricity using one-sample *t*-tests (two-tailed, with a test value of 50). To correct for the family-wise errors, these *t*-tests were corrected for the number of comparisons made (9 eccentricities x 2 gaze directions = 18; so the *p* value used was .05/18 = 0.002). To determine whether one gaze direction was discriminated better or faster than the other, AG and DG were also compared directly at each eccentricity using paired-sample *t*-tests (two-tailed). The Bonferroni correction was used for these tests, making *p* value significance thresholds at .005 (i.e., .05/9 = .0055). All other aspects of the data analysis were the same as for Experiments 1a-1c.

3.1.3 Experiment 2a Results

Upright Faces

RTs increased with eccentricity as revealed by a main effect of eccentricity for both AG ($F(8, 168) = 40.92$, $MSE = 1028.26$, $p < .0001$, $\eta_p^2 = .66$), and DG ($F(8, 168) = 54.88$, $MSE = 620.39$, $p < .0001$, $\eta_p^2 = .72$; see Figure 2.2A). Planned *t*-tests revealed no gaze difference at any eccentricity ($p > .005$).

Error rates increased with eccentricity (main effect of eccentricity for both AG ($F(8, 168) = 59.00$, $MSE = 172.61$, $p < .0001$, $\eta_p^2 = .74$), and DG ($F(8, 168) = 20.00$, $MSE = 102.17$, $p < .0001$, $\eta_p^2 = .49$; see Figure 2.2B). Lower error rates were found for DG than AG faces at all positions (planned *t*-tests, all $p < .005$). This difference increased with eccentricity, with a sharper increase of error rates for AG, reaching chance level at ±4.5° (with error rates being no different than 50% from –6° to –4.5°, and from +4.5° to +6°, using a one-sample *t*-test with a test value of 50, $p > .02$). For DG, performances were above chance at every eccentricity ($p < 0.001$).

For response rates, a main effect of eccentricity was found for both AG ($F(8, 168) = 12.11$, $MSE = 99.20$, $p < .0001$, $\eta_p^2 = .37$), and DG ($F(8, 168) = 7.20$, $MSE = 86.02$, $p < .0001$, $\eta_p^2 = .26$; see Figure 2.2C). Responses increased with eccentricity for DG and decreased with eccentricity for AG, sharply from ±1.5° to ±3°, where they plateaued. Larger response rates were found for DG than AG faces at all eccentricities (planned *t*-tests, all $p < .005$), except at +1.5°.

Inverted Faces

RTs increased with eccentricity (main effect of eccentricity for both AG ($F(8, 152) = 3.41$, $MSE = 4490.59$, $p < .05$, $\eta_p^2 = .15$), and DG ($F(8, 152) = 9.33$, $MSE = 1120.19$, $p < .0001$, $\eta_p^2 = .33$; see Figure 2.2D). Planned *t*-tests showed that RTs were faster for DG than AG faces at all positions (all $p < .005$), except at –6°, and at +4.5°.

Error rates increased with eccentricity (main effect of eccentricity for both AG ($F(8, 152) = 54.56$, $MSE = 208.02$, $p < .0001$, $\eta_p^2 = .74$), and DG ($F(8, 152) = 8.78$, $MSE = 78.83$, $p < .0001$, $\eta_p^2 = .32$; see Figure 2.2E). Lower error rates were found for DG than AG faces at all positions (planned *t*-tests, all $p < .005$). This difference increased with eccentricity, with a sharper increase of error rates for AG, reaching chance level by –4.5° and +3° (one-sample *t*-test, $p > .04$, from –6 to –4.5°, and from +3 to +6°). For DG, performances were above chance at every eccentricity.

For response rates, a main effect of eccentricity was found for AG ($F(8, 152) = 15.87$, $MSE = 112.47$, $p < .0001$, $\eta_p^2 = .46$), which showed that responses decreased with eccentricity, while for DG ($F(8, 152) = 11.61$, $MSE = 100.20$, $p < .0001$, $\eta_p^2 = .38$), responses increased with eccentricity (see Figure 2.2F). More DG than AG responses were made at all eccentricities (planned *t*-tests, all $p < .005$), and this difference increased sharply from ±1.5° to ±3°, after which point it plateaued.

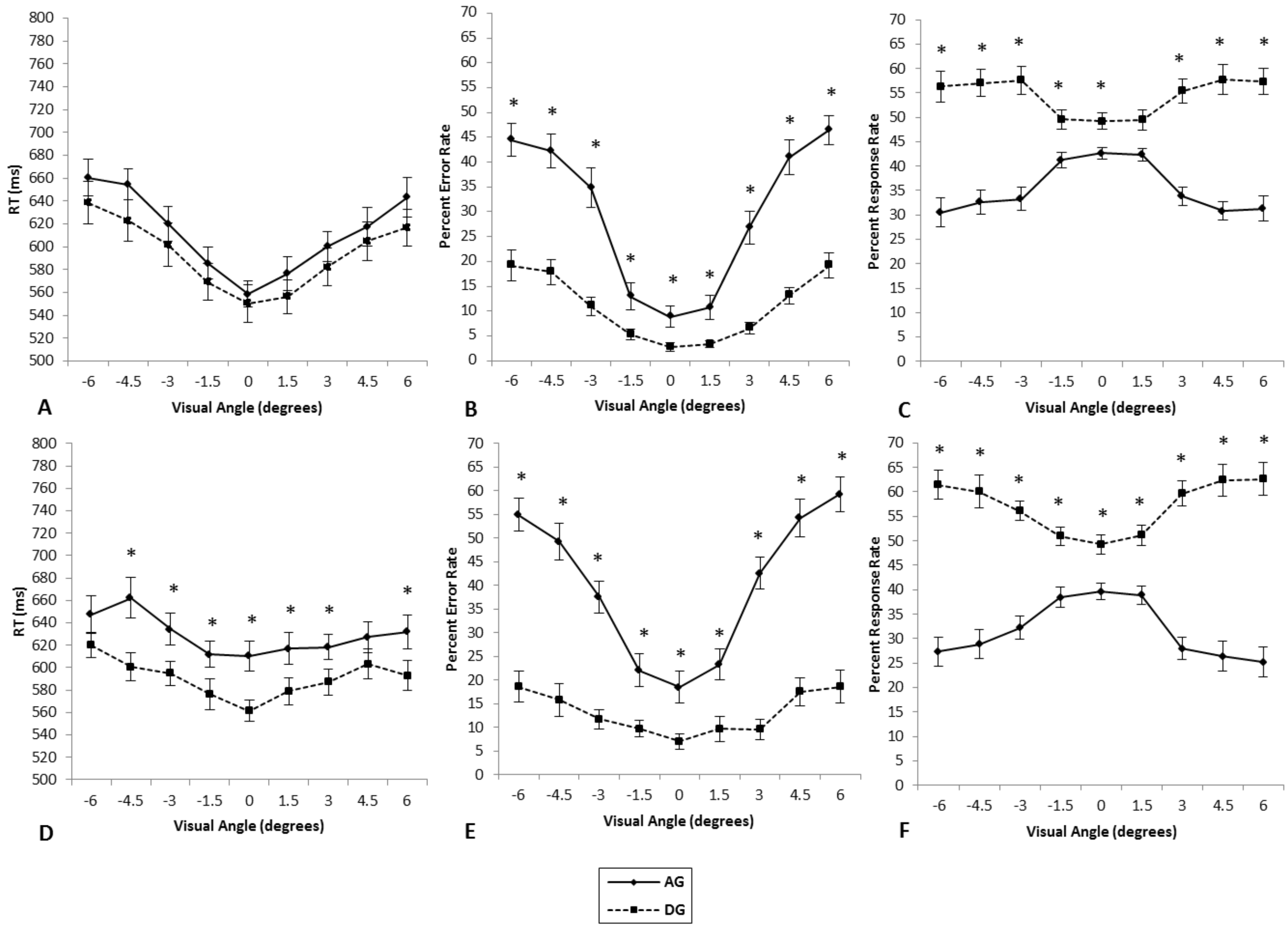

Figure 2.2. Results for Experiment 2a, as a function of gaze direction and eccentricity, for (A) RT responses in the Upright Face condition, (B) Error rates in the Upright Face condition, (C) Response presses in the Upright Face condition, (D) RT responses in the Inverted Face condition, (E) Error rates in the Inverted Face condition, and (F) Response presses in the Inverted Face condition (all shown with standard error bars). DG vs. AG paired comparisons: *$p < .006$. Note that negative visual angle positions indicate targets in the lower visual field while positive visual angle positions indicate targets in the upper visual field.

3.1.4 Experiment 2a Discussion

In this experiment, natural front-view faces with direct- or averted gaze were presented randomly at one of 9 possible vertical eccentricities while participants focused on a centred fixation cross and discriminated gaze direction using two response buttons. Overall, the pattern of these results was very similar to those in Experiment 1b, but with vertical eccentricities. For both upright and inverted faces, RTs and error rates increased with eccentricity, and DG faces were detected above chance level at all eccentricities. Participants reached chance level for AG faces at ±4.5° of vertical eccentricity, slightly less than the horizontal eccentricities of Experiment 1b. Again, for both upright and inverted faces, there was a clear response bias to press "direct gaze" more often than "averted gaze", and this bias was stronger beyond foveal vision. However, unlike in Experiment 1b, this response bias also occurred within foveal vision, and across nearly every eccentricity, which consequently led to chance level performances for AG faces due to too many errors. These findings supported the prediction that the limit of vertical eccentricity for accurate gaze discrimination (at least with natural front-view faces) would be within the limits of central vision, also supporting Burton et al. (2009) and Loomis et al. (2008).

As in Experiment 1b, inversion did not strongly affect performance, and response rates remained similar between upright and inverted conditions, likely because eye gaze visibility was only clear within central vision. In fact, beyond foveal vision, response rates were strongly biased toward DG faces, leading to a large increase in errors for AG faces beyond ±1.5° eccentricity.

For upright faces, DG was only discriminated faster than AG at one position in the left hemifield, unlike in Experiment 1b, in which faster responses were seen for DG within all eccentricities of central vision. Interestingly, DG was discriminated faster than AG at almost all positions with inverted faces, suggesting that inversion could have disrupted the clarity of gaze processing, leading to a stronger default response bias for "direct gaze" with inverted faces than upright faces, as also indicated by the response rates.

Like Experiments 1a and 1b, the overall better detection for DG over AG could have resulted from the congruency effect between gaze direction and frontal head orientation (also supporting Itier et al., 2007a, 2007b; Langton, 2000; Seyama & Nagayama, 2005; Todorović, 2009). In the current experiment, this effect occurred at both foveal and parafoveal eccentricities, unlike in Experiment 1b. If head orientation is used as a primary source of gaze judgments in both horizontal and vertical eccentricities, then using deviated head views should yield a strong detection advantage for AG over DG. This idea was tested in Experiment 2b.

3.2 Experiment 2b: Deviated Head Orientation

3.2.1 Experiment 2b Methods

Participants. A total of 21 participants performed the Upright Face condition (11 female, 10 male; 17 right-handed; age range 17-22 years, $M = 19.8$), and 21 participants performed the Inverted Face condition (12 female, 9 male; 19 right-handed; age range 18-22 years, $M = 19.7$). No participants were rejected.

Stimuli. The same natural face photographs of deviated heads from Experiment 1c were used.

Apparatus, procedure, and data analysis were identical to Experiment 2a.

3.2.2 Experiment 2b Results

Upright Faces

RTs increased with eccentricity, as revealed by a main effect of eccentricity for both AG ($F(8, 160) = 5.56$, $MSE = 2117.84$, $p < .001$, $\eta_p^2 = .22$), and DG ($F(8, 160) = 17.89$, $MSE = 1335.62$, $p < .0001$, $\eta_p^2 = .47$; see Figure 2.3A). However, planned *t*-tests failed to find any significant differences between gaze conditions.

Error rates increased with eccentricity (main effect of eccentricity for both AG ($F(8, 160) = 27.17$, $MSE = 219.20$, $p < .0001$, $\eta_p^2 = .58$), and DG ($F(8, 160) = 35.19$, $MSE = 177.54$, $p < .0001$, $\eta_p^2 = .64$; see Figure 2.3B). Planned *t*-tests failed to find any significant differences between gaze conditions. Participants also performed above chance at all eccentricities for AG, and from –3° to +6° for DG condition (below 50% using a one-sample *t*-test, $p \leq .002$).

For percent response rates, no main effect of eccentricity was found for either gaze condition (all $p > .3$; see Figure 2.3C). Planned *t*-tests revealed no significant differences between gaze conditions.

Inverted Faces

For RTs, a main effect of eccentricity was found for DG ($F(8, 160) = 4.95$, $MSE = 5097.13$, $p < .005$, $\eta_p^2 = .20$), but not for AG ($p > .3$); see Figure 2.3D). Planned *t*-tests failed to find any significant differences between gaze conditions.

Error rates increased with eccentricity (main effect of eccentricity for both AG ($F(8, 160) = 13.81$, $MSE = 284.48$, $p < .0001$, $\eta_p^2 = .41$), and DG ($F(8, 160) = 28.09$, $MSE = 204.09$, $p < .0001$, $\eta_p^2 = .58$,; see Figure 2.3E). Planned *t*-tests indicated lower error rates for AG than DG faces at –1.5°, from +1.5° to +3°, and at +6° (all $p < .005$). Participants performed at chance level in the DG condition from –6° to –3°, and from +3° to +6° (one-sample *t*-test, $p > .1$), while performances in the AG condition were above chance across all eccentricities, except at –6°.

For response rates, no effect of eccentricity was found for either gaze condition (all $p > .1$; see Figure 2.3F). However, planned *t*-tests revealed larger response rates for AG than DG faces at –1.5°, from +1.5° to +3°, and at +6° (all $p < .005$).

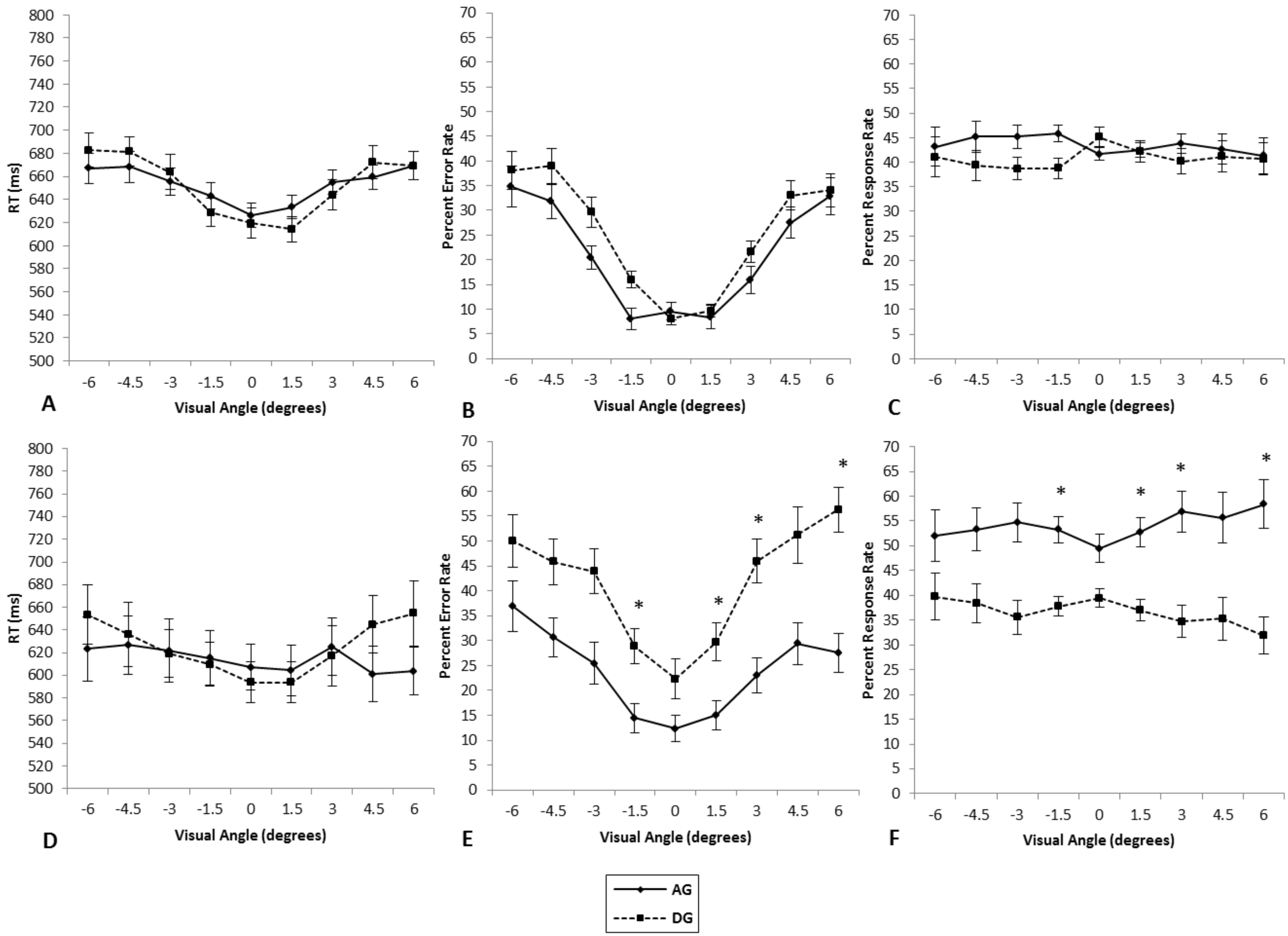

Figure 2.3. Results for Experiment 2b, as a function of gaze direction and eccentricity, for (A) RT responses in the Upright Face condition, (B) Error rates in the Upright Face condition, (C) Response presses in the Upright Face condition, (D) RT responses in the Inverted Face condition, (E) Error rates in the Inverted Face condition, and (F) Response presses in the Inverted Face condition (all shown with standard error bars). DG vs. AG paired comparisons: *$p < .006$.

3.2.3 Experiment 2b Discussion

Similar to Experiment 1c with horizontal eccentricity and deviated heads, RTs and error rates increased with vertical eccentricity. However, unlike Experiment 1c, there were no gaze discrimination differences in favour of detecting AG faces, at least for upright faces. This was likely due to the lack of any significant gaze differences in response rates across eccentricities. Since Experiment 2b used a narrower range of eccentricities than Experiment 1c, there is no way of knowing how far into the vertical periphery participants could accurately detect gaze direction, also because error rates seemed to level off by ±4.5° (although it is entirely possible that error rates for the next eccentricity would have reached chance level). With inverted faces, participants reached chance level quickly, by ±3° in the DG condition, but the limit of vertical gaze detection for deviated heads seemed to extend beyond central vision with upright faces (at least for the right visual field).

Unlike Experiment 1c, gaze differences between AG and DG were not found for RTs. It was predicted that AG would be detected faster than DG beyond foveal vision using deviated heads, and this was not found. However, Experiment 2b used a narrower range of eccentricities than Experiment 1c, and from Figure 2.3A, if the data were extrapolated farther into the periphery, it appears that there might be a general trend for detecting AG faster than DG, although this is simply speculation. Thus, it is possible that faster discrimination for AG deviated heads would be more apparent in the far periphery, as also seen in Experiment 1c.

For upright faces, there was virtually no congruency effect between gaze direction and head orientation, unlike in Experiment 1c. By contrast, for inverted faces, there was a clear response bias for AG over DG for a few eccentricities, leading to larger error rates for DG across these eccentricities. These results suggest that inversion impacted gaze perception by making the gaze signals less visible to discriminate, thus leading to a stronger default response bias than for upright faces, this time for "averted gaze," congruent with the deviated head orientation. This finding is similar to the trend in Experiment 1a, in which inversion exacerbated the gaze difference, but in favour of responding to DG over AG with frontal heads.

In sum, the pattern of results for Experiment 2b was not very similar to Experiment 1c when presenting faces in vertical eccentricities. Gaze discrimination was not mainly driven by head orientation, at least for upright faces. The results of Experiments 1b and 2a suggested that gaze processing was similar for vertical and horizontal eccentricities when using frontal heads. However, when using deviated heads, the differences of Experiments 1c and 2b suggest that gaze processing may be influenced by the design effects of presenting stimuli in different visual fields. However, it is also important to note that the narrower range of eccentricities used in Experiment 2b compared to Experiment 1c could have concealed any potential gaze-head congruency effects which may have emerged in the farther vertical periphery. In Experiments 2a and 2b, only one type of head orientation was used, and it is possible that using both frontal and deviated head views in the same paradigm would increase the gaze-head congruency effects, and thus influence participants to rely more on head orientation when making gaze judgments, just like in Experiment 1d. This possibility was examined in Experiment 2c.

3.3 Experiment 2c: Frontal and Deviated Heads Together

3.3.1 Experiment 2c Methods

Participants. Twenty one participants completed Experiment 2c (13 female, 8 male; 19 right-handed; age range 18-25 years, M = 20.6). No participants were rejected.

Stimuli and Procedure. Stimuli consisted of the same photographs from Experiment 1d (i.e., only upright faces, in both frontal and deviated head views). Each eccentricity consisted of 32 frontal DG trials, 32 frontal AG trials, 32 deviated DG trials, and 32 deviated AG trials, totalling 1152 trials, which were divided into 8 blocks of 144 trials each. All other aspects of the design were identical to Experiments 2a and 2b.

As in Experiment 1d, this experiment investigated possible interactions between gaze and head orientation within participants. RTs, percent error rates, and percent response rates were analyzed using a 2 (head orientations) by 2 (gaze directions) by 9 (eccentricities) repeated measures ANOVA. The Greenhouse-Geisser degrees of freedom correction was used when the sphericity assumption was violated. The Bonferroni correction was used for planned comparison *t*-tests (two-tailed) contrasting the two gaze conditions across the 9 eccentricities and 2 head orientations (significant *p* value threshold = 0.05/36 comparisons = .001). The same significance threshold was also used for planned one-sample *t*-tests (two-tailed, test value = 50) contrasting error rates for each condition at each eccentricity against chance level.

3.3.2 Experiment 2c Results

For RTs (Figure 2.4A), the main effects of eccentricity ($F(8, 160) = 32.37$, $MSE = 4782.45$, $p < .001$, $\eta_p^2 = .62$), gaze direction ($F(1, 20) = 8.75$, $MSE = 8227.99$, $p < .01$, $\eta_p^2 = .30$), and head orientation ($F(1, 20) = 67.06$, $MSE = 3350.62$, $p < .001$, $\eta_p^2 = .77$) were strongly modulated by interactions between eccentricity and gaze direction ($F(8, 160) = 6.17$, $MSE = 1609.39$, $p < .001$, $\eta_p^2 = .24$), eccentricity and head orientation ($F(8, 160) = 3.21$, $MSE = 927.47$, $p < .01$, $\eta_p^2 = .14$), gaze direction by head orientation ($F(1, 20) = 54.35$, $MSE = 5023.39$, $p < .001$, $\eta_p^2 = .73$), and eccentricity by gaze direction by head orientation ($F(8, 160) = 3.03$, $MSE =$

1419.26, $p < .05$, $\eta_p^2 = .13$). All RTs increased steadily with eccentricity, except for the AG deviated head condition, which remained at a constant level for positive eccentricities (i.e., in the upper visual field). RTs were faster for DG than AG for frontal heads from –6° to +3° (planned *t*-tests, all $p < .001$), while no gaze differences were found for deviated heads. RTs were also faster for DG frontal than DG deviated heads across all eccentricities (all $p < .001$), while no differences were found between AG frontal and AG deviated heads.

For error rates (Figure 2.4B), main effects of eccentricity ($F(8, 160) = 97.63$, $MSE = 242.91$, $p < .001$, $\eta_p^2 = .83$) and head orientation ($F(1, 20) = 46.69$, $MSE = 160.21$, $p < .001$, $\eta_p^2 = .70$) were modulated by interactions between eccentricity and head orientation ($F(8, 160) = 2.43$, $MSE = 75.42$, $p < .05$, $\eta_p^2 = .11$), eccentricity by gaze direction ($F(8, 160) = 3.61$, $MSE = 313.22$, $p < .05$, $\eta_p^2 = .15$), head orientation by gaze direction ($F(1, 20) = 49.93$, $MSE = 882.61$, $p < .001$, $\eta_p^2 = .71$), and eccentricity by head orientation by gaze direction ($F(8, 160) = 16.74$, $MSE = 219.13$, $p < .001$, $\eta_p^2 = .46$). In general, lower error rates were found for DG frontal heads followed by AG deviated heads (the two congruent conditions), and then by AG frontal heads followed by DG deviated heads (the two incongruent conditions). All error rates increased steadily with eccentricity, but there was a sharper increase for the incongruent than congruent conditions. Performances were above chance level at every eccentricity for both congruent conditions ($p < .001$). In contrast, chance level was reached from –6° to –4.5° and at +6° for AG frontal heads, and from –6° to –3° and at +6° for DG deviated heads (one-sample *t*-test, all $p > .001$). For frontal heads, lower error rates were found for DG than AG faces from –6° to –3°, and from +3° to +4.5° (planned *t*-tests, all $p < .001$). For deviated heads, lower error rates were found for AG than DG faces at –6° and at –3° (all $p < .001$). Additionally, lower error rates were found for DG frontal than DG deviated heads at all eccentricities (all $p < .001$), while lower error rates were found for AG deviated than AG frontal heads from –6° to –3° (all $p < .001$).

For response rates (Figure 2.4C), a main effect of head orientation ($F(1, 20) = 10.72$, $MSE = 46.27$, $p < .005$, $\eta_p^2 = .35$) was found, which was modulated by interactions between head orientation and gaze direction ($F(1, 20) = 38.89$, $MSE = 1111.08$, $p < .001$, $\eta_p^2 = .66$), eccentricity by gaze direction ($F(8, 160) = 3.77$, $MSE = 332.30$, $p < .05$, $\eta_p^2 = .16$), and eccentricity by head orientation by gaze direction ($F(8, 160) = 15.41$, $MSE = 201.49$, $p < .001$, $\eta_p^2 = .44$). Overall, there was a stronger response bias for the congruent than incongruent conditions. More DG than AG responses were made for frontal heads from –6° to –3°, and from +4.5° to +6° (all $p < .001$), while more AG than DG responses were made for deviated heads from –6° to –3° (all $p < .001$). Additionally, more DG responses were made for frontal heads than for deviated heads at all eccentricities (all $p < .001$), except trending at –1.5°, while more AG responses were made for deviated than for frontal heads from –6° to –3°, and at +4.5° (all $p < .001$).

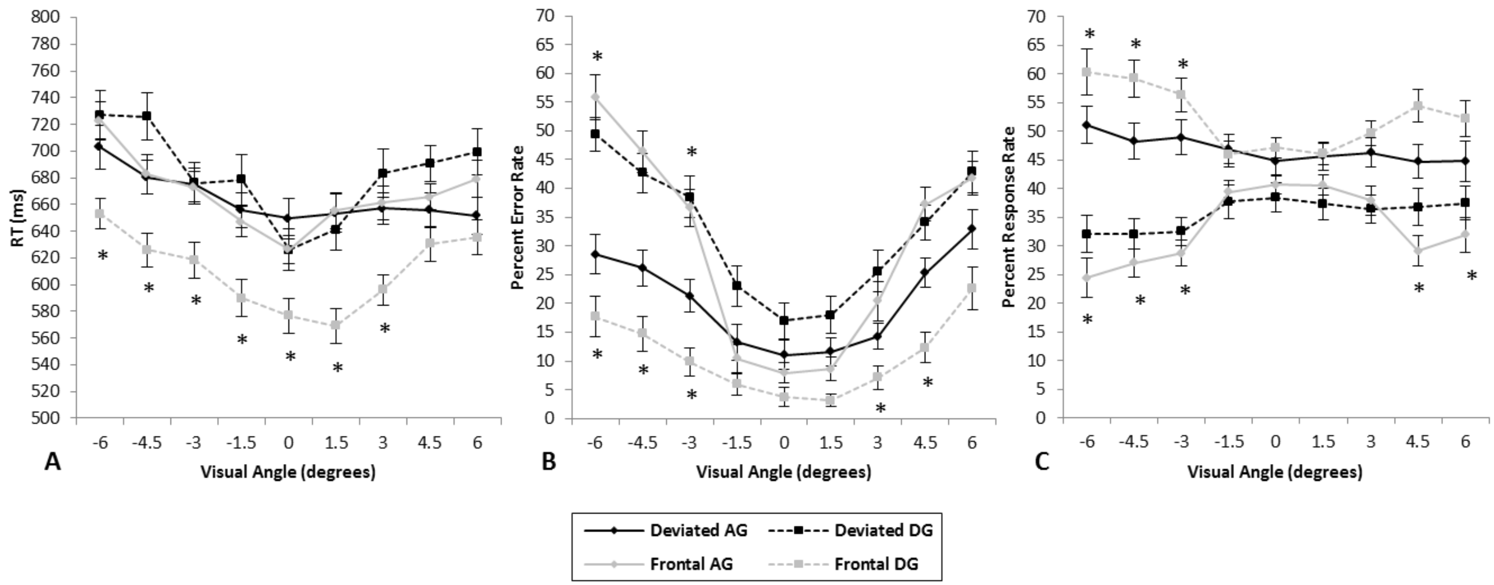

Figure 2.4. Results for Experiment 2c (upright faces only), as a function of gaze direction and eccentricity, for (A) RT responses, (B) Error rates, and (C) Response presses (all shown with standard error bars). Please note for (B) and (C), gaze direction data were computed within each head orientation (i.e., DG vs. AG for frontal heads, and DG vs. AG for deviated heads), so the scale of the graphs remain consistent with Experiments 2a-2b. DG vs. AG paired comparisons: stars above lines represent deviated heads DG vs. AG comparison; stars below lines represent frontal heads DG vs. AG comparison; *$p < .001$.

3.3.3 Experiment 2c Discussion

In Experiment 2c, error rates increased with eccentricity, with a steeper increase for the incongruent gaze-head conditions (i.e., AG frontal and DG deviated faces) than for the congruent conditions (i.e., DG frontal and AG deviated faces), due to the stronger response bias for the congruent than incongruent conditions. For both head orientations, the response bias occurred mainly in the lower visual field, outside of foveal vision. Similar to Experiment 1d, there was a clear trend for DG frontal faces to elicit lower error rates compared to the other three conditions, suggesting a special role played by DG frontal heads in gaze processing. In parafoveal vision, the differences between the congruent and incongruent conditions were more apparent, and head orientation drove gaze judgments. In this experiment, deviated heads yielded chance level accuracy for the DG condition at +6° in the upper visual field and from –6° to –3° in the lower visual field, unlike in Experiment 2b (upright faces) which yielded above chance level performance across all eccentricities. It seems that using both head orientations in the same design increased the gaze-head congruency effects, leading to a stronger response bias for AG, and thus larger error rates for DG with deviated heads in the lower visual field. For frontal heads, performances were at chance level at –6° and –4.5° in the lower visual field and at +6° in the upper visual field for AG. Thus, the data suggest that gaze judgments are predominantly biased toward head orientation in the lower visual field periphery.

The pattern of RTs was a little different from Experiment 2a for frontal heads; RTs were faster for DG than AG faces across nearly all eccentricities, including the foveal position (0°), unlike in Experiment 2a (upright faces) where no gaze difference was seen. In fact, the combination of a frontal head with direct gaze elicited the fastest RTs compared to the other three conditions, similar to the pattern seen in Experiment 1d, and thus supporting a special status for this particular stimulus in summoning attention (Shirama, 2012). Similar to Experiment 2b, for deviated heads, there was no congruency effect in favour of AG for RTs. It seems that using both head orientations in the same design increased congruency effects for frontal heads and influenced performances of gaze judgments. Unlike in Experiment 1d using horizontal eccentricities, RTs were not significantly faster for DG than AG faces in the foveal position for deviated heads. This is perhaps a reflection of the differences in design of presenting stimuli in different visual fields, which could have influenced gaze processing. However, this effect is puzzling considering that foveal presentation (i.e., 0°) was the exact same in both vertical and horizontal eccentricity designs.

3.4 General Discussion and Conclusions

These three experiments replicated and extended the latter three experiments of Chapter 2 by investigating whether and to what extent gaze direction could be accurately detected along vertical eccentricities in the visual field, whether direct gaze was discriminated better than averted gaze, and also to what extent head orientation affected this gaze discrimination. The design was identical to that used in Chapter 2, except that faces were presented across nine vertical eccentricities extending just beyond parafoveal vision in the upper and lower visual fields.

Since only natural faces were used, it was expected that gaze detection would not extend beyond central vision, following the findings from Chapter 2. Experiment 2a (using frontal heads) and Experiment 2c revealed that accurate gaze detection was achieved only to about ±3° of vertical eccentricity, which was similar, but slightly less than the limit of horizontal eccentricity found in Chapter 2 using natural faces. This also supports other research implying that gaze direction can only be discriminated within central vision (Burton et al., 2009; Loomis et al., 2008). Interestingly, Experiment 2b (using deviated heads) revealed that gaze detection was above chance beyond central vision, and the narrow range of eccentricities prevented any conclusions to be made regarding the eccentricity limits with these particular stimuli (although gaze detection was only accurate to ±1.5° with inverted faces). Experiment 2c revealed an asymmetry in chance level gaze detection between the upper and lower visual fields. Accurate gaze detection for frontal heads was achieved to 3° eccentricity in the lower visual field, but 4.5° in the upper visual field, and for deviated heads, accurate detection was achieved to 1.5° in the lower visual field, but 4.5° in the upper visual field. This asymmetry could not have been due to any initial fixation bias since participants had to focus on a centred fixation to trigger each trial, and all trials where more than one fixation was made were eliminated. Additionally, the eye region of the face stimuli was in the centre of the photographs, so each gaze judgment would have been made with equal visual angle increments in the upper and lower visual fields. Thus, the reasons for this discrepancy are unknown since there is little research examining gaze detection in the vertical periphery. However, one theory explains that the visual field may be divided into peripersonal (close to the body) and extrapersonal (beyond reaching distance) space (Previc, 1990, 1998). For this reason, processes such as visual search or scene perception are generally carried out in extrapersonal space and may be more efficient in the upper visual field. We may be more inclined to rapidly shift attention to stimuli in the upper rather than the lower visual field to remain vigilant to salient stimuli in extrapersonal space, which is largely represented in the upper visual field (reviewed in Danckert & Goodale, 2003). Additionally, clinical populations may also lend an explanation for the current findings. For example, in neglect patients, a vertical bias has also been described in addition to the typical horizontal bias in favour of the ipsilesional side of space. Patients with bilateral cortical lesions have shown neglect to stimuli in the lower visual field (peripersonal space; Butter et al., 1989; Mennemeier et al., 1992; Pitzalis et al., 2001; Rapcsak et al., 1988). Furthermore, patients with typical left-sided spatial neglect (damage to right hemisphere) have also been shown to have a vertical bias in various visual attention tasks: behavioural performance is least accurate when targets are located in the lower left visual quadrant compared to the upper quadrants (Cappelletti et al., 2007; Cazzoli et al., 2011; Halligan & Marshall, 1989; Làdavas et al., 1994; Müri et al., 2009; Pitzalis et al., 1997). Although the current study tested a sample of healthy normal participants, perhaps there are specific cognitive mechanisms intertwined to the performance of upper and lower peripheral gaze detection. It is also possible that, since faces are inherently located in the upper visual field of someone's entire body, humans might have a learned preference to be vigilant toward the upper visual field when dealing with faces in order to react to the social cue information given from the face (i.e., such as gaze direction). Nevertheless, the data from Chapter 3 suggest that gaze judgments are not very accurate in the vertical periphery, similar to the horizontal periphery.

As in Chapter 2, head orientation influenced gaze judgments, especially beyond foveal vision. Experiment 2a showed better detection of DG than AG when using frontal heads while Experiment 2b did not show any gaze discrimination differences between AG and DG when using deviated heads (for upright faces). Experiment 2c confirmed gaze-head congruency effects mainly for frontal faces, with gaze differences seen for deviated heads at only two lower visual field eccentricities. These results suggest an asymmetry in AG-DG gaze discrimination between frontal and deviated heads when faces are presented in the vertical visual field. In contrast to Chapter 2 (horizontal eccentricities), gaze discrimination did not seem to be as affected by deviated heads in the vertical periphery. It is possible that the deviated head orientation was more influential during gaze judgments in the horizontal periphery since the head was also oriented side-to-side, in parallel with the horizontal eccentricity. Perhaps if the heads were deviated up-and-down with vertical eccentricities, then they would be more likely to affect gaze judgments, but future studies would have to examine this possibility. Unfortunately, we could not investigate this question since the facial stimulus set used in this thesis only contained faces that were deviated side-to-side, not up-and-down. Overall, the speed, accuracy, and response rates of gaze judgments were biased toward head orientation rather than eye gaze direction beyond foveal vision, but mainly in the lower visual field. For the most part, these findings support the results found in Chapter 2, but with vertical eccentricities, suggesting a Direction of Attention Detector (DAD) mechanism (Perrett & Emery, 1994) that functions in all visual fields to detect social signals in the environment.

Similar results were found for upright and inverted faces in Experiment 2a, but Experiment 2b (using deviated heads) showed that inversion disrupted accurate gaze processing, thus exacerbating the gaze-head congruency difference, and leading to a strong bias toward AG responses. Since inversion decreased the visibility of eye gaze signals (supporting Jenkins & Langton, 2003; Schwaninger et al., 2005; see also Senju et al., 2005; Senju & Hasegawa, 2006), gaze judgments were predominantly made on the basis of head orientation, which is still clearly visible when the face is inverted.

Similar to Chapter 2, gaze discrimination speed was not strongly affected by deviated head orientation when the face was focused overtly (0°), contrary to previous research (Itier et al., 2007a, 2007b; Langton, 2000; Pageler et al., 2003; Ricciardelli & Driver, 2008; Shirama, 2012). Experiments 2b and 2c showed no differences in gaze discrimination between

AG and DG when focused attention was applied, similar the results seen in Experiment 1c (using deviated heads). In conclusion, Chapter 3 replicated and extended most of the findings from Chapter 2 by showing that it is possible to process gaze direction in the upper and lower visual fields, albeit within the general limits of central vision, and with a larger eccentricity in the upper than lower visual field. Eye cues played an important role within foveal vision, but head orientation subsequently drove gaze judgments in the parafovea and periphery, supporting a DAD mechanism that would integrate information from the eyes, head, and body position (Perrett & Emery, 1994). Since these social cues play a fundamental role in nonverbal communication, it makes sense that we can perceive them quickly and accurately along vertical eccentricities, in addition to horizontal eccentricities.

Chapter 4: Inhibition of Return to Eye Gaze and Head Orientation

Thus far, Chapters 2 and 3 predominantly examined top-down processing of gaze detection, in which participants had *a priori* knowledge of the task (i.e., to explicitly discriminate gaze direction). With this information, gaze could accurately be processed within central vision (~4.5° eccentricity around the visual field), and head orientation began influencing gaze judgments by this eccentricity. Chapter 4 primarily examines bottom-up processing of gaze detection, and whether gaze direction and head orientation processing occurs implicitly within these central vision limits. Previous research has shown that, when focused overtly, direct gaze can be processed unconsciously when faces are presented subliminally below visual awareness (Chen & Yeh, 2012; Stein et al., 2011; see also Burra et al., 2013), and can facilitate the detection of a target face in a visual scene even when gaze discrimination is not the primary task at hand (Doi & Shinohara, 2013). This suggests that gaze signals may be processed in a rapid and mandatory fashion. However, it is unknown whether gaze direction is processed implicitly and automatically outside of foveal vision, using covert attention.

One way to study how attention is captured implicitly and involuntarily is by using an inhibition of return (IOR; Posner & Cohen, 1984) cueing paradigm. Chapter 4 investigated how gaze direction and head orientation captured visuospatial attention using this type of paradigm. IOR refers to the relative suppression of detecting stimuli that have recently been the focus of attention. By suppressing orienting toward previously inspected locations and objects, IOR encourages orienting toward novelty (Posner & Cohen, 1984), and consequently can serve as a search or foraging facilitator (Klein, 1988; Klein & MacInnes, 1999). IOR is usually measured with an exogenous cue-response paradigm, in which a peripheral stimulus (i.e., the cue) precedes the presentation of a target stimulus that requires detection. IOR was first described in detail by

Posner and Cohen (1984), who discovered that, contrary to their expectations, RTs to detect objects appearing in previously cued locations (i.e., cued targets; those targets occupying space previously occupied by the cue) could sometimes be longer when compared to locations not previously cued (i.e., uncued targets; targets appearing at a new location). In that experiment, participants were instructed to fixate on a center box that was flanked with a box on its right and left sides. Each trial began with the brightening of the outline of one of the peripheral boxes that was randomly selected for 150 ms. During the trial, a target (a bright filled square) occurred in one of the peripheral boxes at either 0, 50, 100, 200, 300, or 500 ms after the initial brightening (stimulus onset asynchrony—SOA; i.e., the time interval between the onset of the stimulus cue and the target). Participants had to respond to the target as quickly as possible by pressing a specified key. The results showed that RTs were initially faster to cued targets than to uncued targets when the SOA was less than ~200ms, when attention still resided at the cued location. However, after the subsequent withdrawal of attention from the cued location (after ~300 ms), RTs were slower to cued targets compared to uncued targets, showing an inhibition of target detection (IOR). It has also been shown that IOR can continue for SOAs of 3000 ms or more (reviewed in Samuel & Kat, 2003), and can occur with both behavioural responses in cue-response paradigms (as described above) or with eye movements during visual search paradigms (Klein, 2000). Ultimately, the initial response to a peripheral visual event is facilitation of the processing of nearby stimuli, presumably due to a reflexive shift of attention towards the source of stimulation. However, when the event is not task-relevant and attention has had time to disengage from it, IOR occurs, resulting in a delayed response to the cued stimulus, and it seems that the function of IOR is to encourage orienting to novel objects and events.

Although the majority of researchers have observed that IOR at long SOAs always follows facilitation at short SOAs (Lambert & Hockey, 1991; Posner et al., 1985; Posner et al., 1987; Rafal et al., 1989; Rafal & Henik, 1994), others have found that RTs to cued targets are slower than RTs to uncued targets at both short and long SOAs, with IOR being found for SOAs ranging from 0 to 4000 ms (Berlucchi et al., 1989; Tassinari et al., 1994; Tassinari & Berlucchi, 1995; Tassinari et al., 1989). This is interesting considering that these studies all used the same type of cue-response paradigm with low-level peripheral stimuli (e.g., brightened boxes) as described above. These findings suggest that IOR does not have to follow facilitation, and these two processes may be independent (Collie et al., 2001). It has been inferred that this inhibition occurs as a result of maintaining fixation at a central location while *covertly* orienting visual attention to a peripheral cue. Although the peripheral cue initiates the preparation of a saccade toward the cued location, a covertly orienting task requires that this saccade be inhibited. Consequently, there is a motor inhibition that prevents the response to targets appearing at previously cued locations (Klein & Taylor, 1994; Rafal & Henik, 1994). The magnitude of IOR is assumed to be constant across the entire cued visual field, and this theory of motor inhibition proposes that facilitation observed at short SOAs only arises because there is a temporal overlap between the cue and target (Tassinari et al., 1994; Tassinari & Berlucchi, 1995; Tassinari et al., 1989). In other words, if the stimulus cue is still presented when the target appears (as also shown by the early SOAs of Posner & Cohen, 1984), then attention would not have disengaged from the cued location by the time the target is to be detected; however, if there is no temporal overlap between the cue and the target, then inhibition should occur (Collie et al., 2001). This theory of motor inhibition is also supported by evidence from attentional paradigms that require overt saccadic responses to previously cued locations (Klein & Taylor, 1994; Taylor & Klein, 1998). Furthermore, this previous research only used low level visual stimuli (e.g., a brightened square in the periphery), and it is possible that the processing of more meaningful stimuli, such as faces, would require more cognitive resources and thus elicit different IOR response patterns than the traditional facilitation-IOR curve.

The few studies that have examined IOR with faces usually involve the same type of exogenous cue-response paradigm as described above, but with faces instead of squares. In these cases, after a face cue is presented to the left or to the right of a central fixation, a target (e.g., an asterisk) is presented at the cued location (where the face was previously) or the uncued location. Participants then either detect the target via button press or make a speeded saccade to the target location. Sometimes, these studies use other control stimulus cues (e.g., household objects or scrambled faces) to compare the IOR response to faces (e.g., Taylor & Therrien, 2005; Taylor & Therrien, 2008; Theeuwes & Van der Stigchel, 2006; Weaver et al., 2012). In these paradigms, both types of stimuli should capture attention and lead to an IOR response. However, faces should initially capture more reflexive attention compared to other stimuli (Bindemann et al., 2005; Langton et al., 2008; Palermo & Rhodes, 2007; Ro et al., 2001) since faces are processed faster and more in depth than other stimuli. This means that after attention is disengaged from the stimulus cue (and brought back to fixation), there should be a stronger inhibition to return to that previously attended area where the face was, compared to if another stimulus was there, since the faces were more thoroughly attended to, and there should be a stronger bias to search for novel locations (perhaps for new faces). This would lead to a greater IOR response elicited by faces compared to other stimuli. Some of these studies have found an IOR effect for faces compared to other stimuli (Taylor & Therrien, 2008; Theeuwes & Van der Stigchel, 2006), while others have found no difference in IOR magnitude (Taylor & Therrien, 2005). However, it should be noted that these studies used a relatively narrow range of SOAs (e.g., 800-1000 ms), so it is unknown what time course IOR may follow for face stimuli. Weaver et al. (2012) used two SOAs (200 ms and 700 ms) and found that both faces and household objects induced an IOR response for both short (200 ms) and long (700 ms) SOAs; however, faces reduced saccade latencies toward subsequently presented targets (in both cued and uncued locations), independent of an IOR, only at the short SOA (Weaver et al., 2012). That is, saccade latencies to targets for face trials were faster overall compared to saccade latencies to targets for household object trials, but only at the 200 ms SOA. These authors suggested that this reflected a short-lived priming effect or social facilitation effect from the mere presence of a face, due to the higher level of vigilance to respond to social stimuli. This effect was also only found when single cue stimuli were used (i.e., either the individual presentation of a face or an object in the left or right visual field) rather than double cue stimuli (i.e., the simultaneous presentation of both a face and an object in the left and right visual fields).

Since there are so few studies examining IOR in the context of faces, it is unclear how and when faces actually capture attention via an IOR cueing paradigm. Furthermore, previous research has failed to investigate the development of IOR for faces over multiple SOAs, and whether gaze direction or head orientation influence the IOR response for faces, since these previous studies have only used front-view faces with straight gaze as facial stimuli. The purpose of Chapter 4 was to examine these issues. In two experiments, faces with frontal heads (Experiment 3a) and deviated heads (Experiment 3b) were used, with house stimuli used as a control in both experiments. Stimuli were presented at ±4.5° horizontal eccentricity while participants focused on a central fixation throughout all trials, thereby using only covert attention; from Chapter 2, it was shown that gaze could be accurately discriminated at this eccentricity. The stimulus cue (either a house, direct gaze face, or averted gaze face) was presented to the left or to the right of fixation for 150 ms, and after a variable SOA (150 ms, 300 ms, 800 ms, 1200 ms, 2400 ms), participants responded to a peripheral target (an asterisk) via button press. Importantly, there was no temporal overlap between stimulus cue and target. Thus, based on previous IOR research using covert attention, all SOAs were expected to produce IOR effects, regardless of stimuli, as reflected by longer RTs in cued versus uncued trials (Berlucchi et al., 1989; Tassinari et al., 1994; Tassinari & Berlucchi, 1995; Tassinari et al., 1989). However, multiple SOAs were used (both short and long) in order to investigate whether any possible facilitation effects would be seen at the short SOAs (e.g., 150 ms), and also to examine the time course of IOR development for face stimuli. Based on Weaver et al. (2012), it was predicted that a priming effect[7] would occur for faces compared to houses at the early SOA (150 ms in the current study), independent of an IOR response. That is, an IOR response (longer RTs to cued than uncued targets) is still expected to occur at the 150 ms SOA, but overall RTs should be faster for face trials compared to house trials, regardless of cued or uncued positions. Since faces should initially capture a faster shift of attention compared to houses (Bindemann et al., 2005; Langton et al., 2008; Palermo & Rhodes, 2007; Ro et al., 2001), it is then predicted that at the later SOAs, a greater IOR response should be seen for faces in general compared to houses.

In addition to the face-object difference, these experiments investigated how gaze direction and head orientation would modulate these effects. Chapters 2 and 3 revealed that head orientation strongly influenced gaze detection beyond foveal vision. Thus, congruent stimuli (i.e., frontal heads with direct gaze and deviated heads with averted gaze) should capture more

[7] Weaver et al. (2012) used the terms "priming effect" and "social facilitation effect" synonymously to describe their finding of faces eliciting shorter responses than objects toward subsequently presented targets, independent of an IOR response, at the short (200 ms) SOA. However, to avoid confusion with the facilitation effects that have occurred in traditional IOR paradigms (e.g., Posner & Cohen, 1984), only the term "priming effect" will be used to describe this finding throughout the remainder of the thesis.

reflexive attention than incongruent stimuli (i.e., frontal heads with averted gaze and deviated heads with direct gaze). At the short SOA, the priming effect should be more enhanced (i.e., faster RTs) for congruent than incongruent face stimuli. At the longer SOAs, the IOR response should be larger for congruent stimuli than incongruent stimuli. The SOA at which this gaze-head congruency difference would occur was however unknown. One possibility is that this congruency difference would only arise at the longest SOA (2400 ms) based on results from gaze-cueing paradigms. In these paradigms, a face cue is centrally presented prior to averting its eyes to a lateral target, and target detection is faster for cued targets (i.e., where the face looks) than uncued targets at short SOAs (~200 ms), but actually slower for cued targets at longer SOAs (~2400 ms; Frischen et al., 2007b; Frischen & Tipper, 2004; Marotta et al., 2013). This suggests that gaze cues may only interact with IOR at very long SOAs. Lastly, it should be noted that both congruent and incongruent face stimuli should capture more attention than houses, since faces in general should be more attention-grabbing than other stimuli. Thus, the order of IOR magnitudes should be largest for congruent face stimuli, followed by incongruent face stimuli, and then followed by house stimuli.

An important feature about the current study was that no information was given to participants about the meaning of the stimuli or the purpose of the study, and the stimuli were always presented outside of foveal vision. In Chapters 2 and 3, participants knew the purpose of the study and were explicitly asked to discriminate gaze, whereas in Chapter 4, the gaze direction of the faces was not relevant for the task, which was to detect a peripheral asterisk after stimulus presentation. Therefore, if any of these predicted effects occurred, it would have indicated that gaze direction and head orientation implicitly influenced attention capture.

4.1 Experiment 3a: Frontal Head Orientation

4.1.1 Experiment 3a Methods

Participants. A total of 27 participants completed Experiment 3a. Three participants were rejected due to tiredness/fatigue, which left 24 participants in the final analyses (12 female, 12 male; 22 right-handed; age range 18-23 years, M = 19.8).

Stimuli and Procedure. House stimuli included greyscale photographs of 8 different houses. Face stimuli included the same photographs from Experiment 1b presented upright (i.e., frontal views of naturally-looking faces with a straight or averted gaze). With the use of an eye-tracker, participants initiated trials by fixating a central black fixation cross (1° x 1°) on a white background; the fixation cross was presented for 1200 ms, which then became a fixation trigger for 300 ms to activate the next trial (see Figure 3.1). A stimulus cue was then presented for 150 ms, the center of which was situated 4.5° to the left or to the right of fixation. Following a variable cue–target SOA of 150 ms[8], 300 ms, 800 ms, 1200 ms, or 2400 ms, a response target (a black asterisk (*) symbol, 0.8° x 0.8° of visual angle) appeared to the left or to the right at the same eccentricity as the center of the stimulus cue for 1000 ms regardless of whether a response was made or not. The central fixation cross remained visible throughout the trial. Participants were instructed to focus on the central fixation at all times and respond to the target as quickly as possible. Responses were made on a standard keyboard layout, using the keys *z* (for left position targets), and *m* (for right position targets), with the index fingers of both hands. After 12 practice trials, 8 experimental blocks of 120 trials were completed, totaling 960 trials. A rest was given between blocks. One third of the stimulus trials consisted of DG faces; one third of the trials consisted of AG faces (left-averted and right-averted gaze were counterbalanced); and, one third

[8] A cue–target SOA of 150 ms indicates that the target appeared immediately (i.e., with 0 ms delay) after the 150 ms stimulus cue presentation. A total cue–target SOA of 300 ms indicates that there was a 150 ms delay after the 150 ms stimulus cue presentation before the target appeared.

of the trials consisted of houses. All stimuli were presented randomly and were counterbalanced across all SOAs and cued/uncued positions (i.e., each block had the same number of stimuli, SOAs, and cueing positions). Targets appeared in cued and uncued locations with equal probability. Participants were given no information about the stimuli, and all were told that the purpose of the study was to examine visual perception. The entire experiment lasted approximately 75 minutes.

Apparatus. This was identical to all other experiments in this thesis; the same 19 inch monitor and eye-tracker were used with the participants' viewing position maintained by chin and forehead rests (viewing distance of 70 cm; the monitor subtended a visual angle of 29.2° x 22.2°).

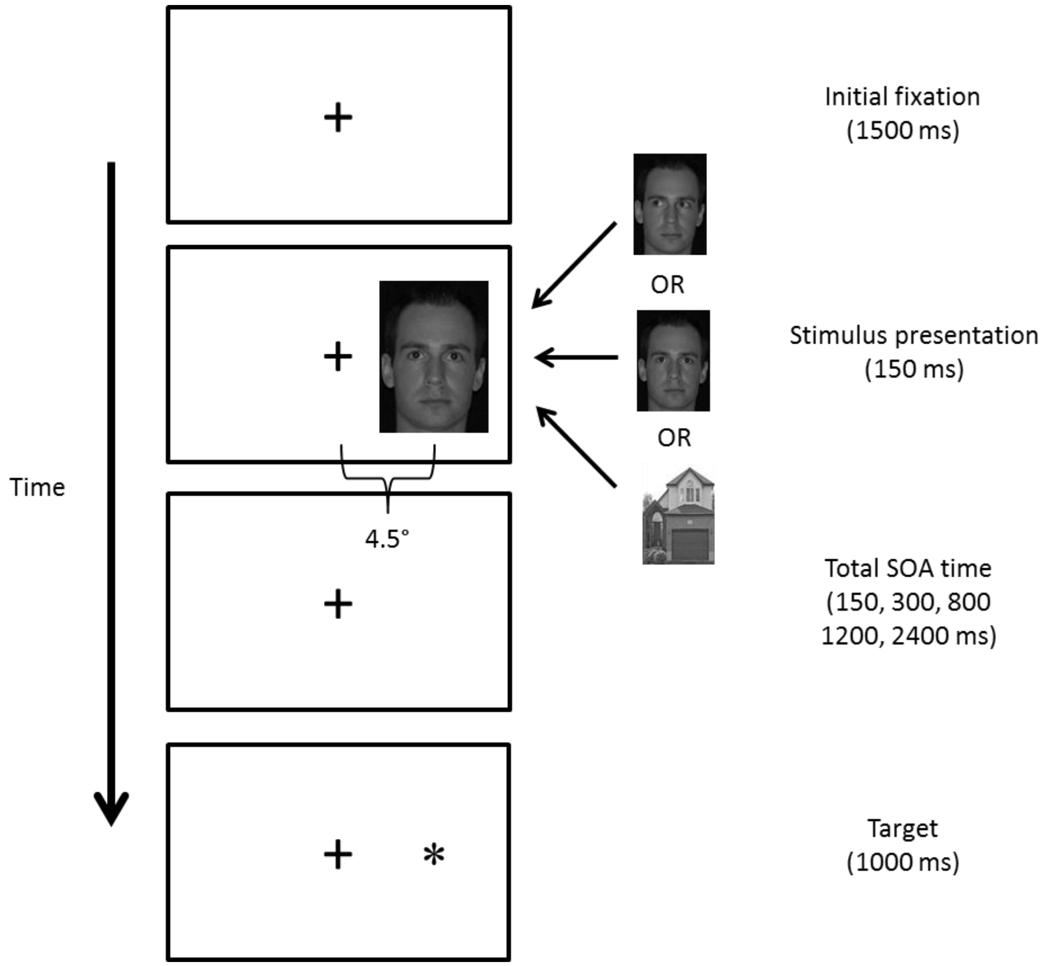

Figure 3.1. Stimulus presentation, with reproductions (i.e., not the actual photos) of the George et al. (2001) faces used in the experiments (an example of an actual house stimulus used in the experiments is shown). Please note that stimulus cues and/or targets could have appeared on either the left- or right side of fixation. The fixation cross was shown during the entire duration of each trial to keep participants' fixation focused. Please also note that for averted gaze faces, both left- and right-looking faces were used (in equal proportions).

4.1.2 Experiment 3a Data Analysis

Left- and right-averted gaze directions were combined and averaged for each target position. Preliminary analyses revealed no effect of gaze direction on cued or uncued targets (i.e., no gaze orienting effect was found). That is, the averted gaze faces did not increase or decrease the RTs to subsequently presented targets in either the "looked-at" or "not looked-at" locations[9]. The dependent variable was the response time (RT) which followed target presentation. For each subject, RTs that were below 100 ms or exceeded 2.5 standard deviations from the mean of each stimulus condition were discarded, removing any anticipatory responses or outliers from the data (Van Selst & Jolicoeur, 1994), which eliminated 10.2% in Experiment 3a, and 7.8% in Experiment 3b. All trials where more than one fixation was made were eliminated (3.7% in Experiment 3a; 3.4% in Experiment 3b). Target accuracy was 99.2%. Preliminary analyses also revealed no significant effects of participant gender, stimulus gender, or stimulus location (left- or right side of fixation) for either experiment.

A repeated measures ANOVA was run with the following within-subject factor design: 5 SOAs (150, 300, 800, 1200, and 2400 ms) x 2 cuing conditions (cued and uncued) x 3 stimulus cues (DG, AG, and House). For all ANOVAs, the Greenhouse-Geisser degrees of freedom correction was used when the sphericity assumption was violated. As the omnibus ANOVA revealed a three-way interaction (see results below), 2 (cueing condition) by 3 (stimulus cue) repeated measures follow-up ANOVAs were conducted at each SOA. As the main question pertained to the IOR effect and how it varied as a function of stimulus cue, when a cueing by stimulus cue interaction was found for a given SOA, a separate ANOVA using the factor cue type was run on the IOR effect directly (i.e., on the difference between the cued and uncued conditions), and IOR was compared between the three stimulus cues using post-hoc paired comparisons. For all post-hoc tests, the Bonferroni correction was used to control for multiple comparisons.

[9] Although the gaze orienting effect has been well established (Driver et al. 1999; Friesen & Kingstone 1998; Frischen et al. 2007a; Langton & Bruce 1999; Ricciardelli et al. 2009), it is unknown whether gaze orients attention *from* the periphery using covert attention. Thus, no comment could be made on this finding.

4.1.3 Experiment 3a Results

The omnibus ANOVA revealed main effects of SOA ($F(4, 92) = 70.65$, $MSE = 661.75$, $p < .0001$, $\eta_p^2 = .75$), cueing condition ($F(1, 23) = 39.60$, $MSE = 410.37$, $p < .0001$, $\eta_p^2 = .63$), and interactions between SOA and cueing condition ($F(4, 92) = 23.80$, $MSE = 199.97$, $p < .0001$, $\eta_p^2 = .51$), and between SOA and stimulus cue ($F(8, 84) = 6.47$, $MSE = 143.70$, $p < .0001$, $\eta_p^2 = .22$). There was also a significant three-way interaction between SOA, cueing condition, and stimulus cue ($F(8, 184) = 2.44$, $MSE = 111.98$, $p < .05$, $\eta_p^2 = .10$). Accordingly, 2 (cueing condition) by 3 (stimulus cue) repeated measures ANOVAs were conducted at each SOA.

For the 150 ms SOA (Figure 3.2A), a main effect of cueing condition ($F(1, 23) = 74.61$, $MSE = 307.30$, $p < .0001$, $\eta_p^2 = .76$) revealed slower RTs for cued versus uncued targets, indicating an overall IOR effect. A significant main effect of stimulus cue was found ($F(2, 46) = 13.91$, $MSE = 117.97$, $p < .0001$, $\eta_p^2 = .38$) and post-hoc comparisons revealed slower RTs for Houses than both DG and AG faces (all $p < .001$), indicating a priming effect for faces. Lastly, there was a cueing condition by stimulus cue interaction ($F(2, 46) = 4.19$, $MSE = 101.27$, $p < .05$, $\eta_p^2 = .15$). The ANOVA on the IOR effect confirmed an effect of cue type ($F(2, 46) = 4.19$, $MSE = 202.54$, $p < .05$, $\eta_p^2 = .15$). Post-hoc paired comparisons revealed that the IOR effect (i.e., RT between cued stimulus and uncued stimulus) was significantly larger for Houses ($M = 32$ ms) than for AG faces ($M = 22$ ms; $p < .05$; Figure 3.3A); the IOR magnitude for DG faces ($M = 22$ ms) was not different from either Houses or AG faces.

For the 300 ms SOA (Figure 3.2B), there were no main effects of cueing condition or stimulus cue, and no interaction between the two variables (all $p > .1$). That is, there was no IOR effect for any stimulus cue (Figure 3.3B).

For the 800 ms SOA (Figure 3.2C), there was a main effect of cueing condition ($F(1, 23) = 25.83$, $MSE = 187.29$, $p < .0001$, $\eta_p^2 = .53$), indicating slower RTs for cued versus uncued targets (IOR effect). A main effect of stimulus cue ($F(2, 46) = 4.44$, $MSE = 126.09$, $p < .05$, $\eta_p^2 = .16$) was found, and post-hoc tests revealed slower RTs for AG faces than Houses ($p < .05$). The other paired comparisons were not significant ($p > .1$). No interaction was found between cueing condition and stimulus cue ($p > .7$; Figure 3.3C).

For the 1200 ms SOA (Figure 3.2D), a main effect of cueing condition was found ($F(1, 23) = 6.06$, $MSE = 212.69$, $p < .05$, $\eta_p^2 = .21$), indicating slower RTs for cued versus uncued targets (IOR effect). No main effect of stimulus cue, and no interaction between cueing condition and stimulus cue was found (all $p > .6$; Figure 3.3D).

For the 2400 ms SOA (Figure 3.2E), a main effect of cueing condition ($F(1, 23) = 9.26$, $MSE = 72.43$, $p < .01$, $\eta_p^2 = .29$) revealed slower RTs for cued versus uncued targets (IOR effect). No effect of stimulus cue was found ($p > .3$), but there was a significant cueing condition by stimulus cue interaction ($F(2, 46) = 3.56$, $MSE = 77.48$, $p < .05$, $\eta_p^2 = .13$). The separate IOR analysis confirmed a main effect of stimulus cue ($F(2, 46) = 3.56$, $MSE = 154.95$, $p < .05$, $\eta_p^2 = .13$), and post-hoc comparisons revealed a trend for the IOR for DG faces ($M = 8$ ms) to be larger than for Houses ($M = –1$ ms; $p = .055$; Figure 3.3E); the IOR magnitude for AG faces ($M = 6$ ms) was not different from DG faces or Houses ($p > .1$).

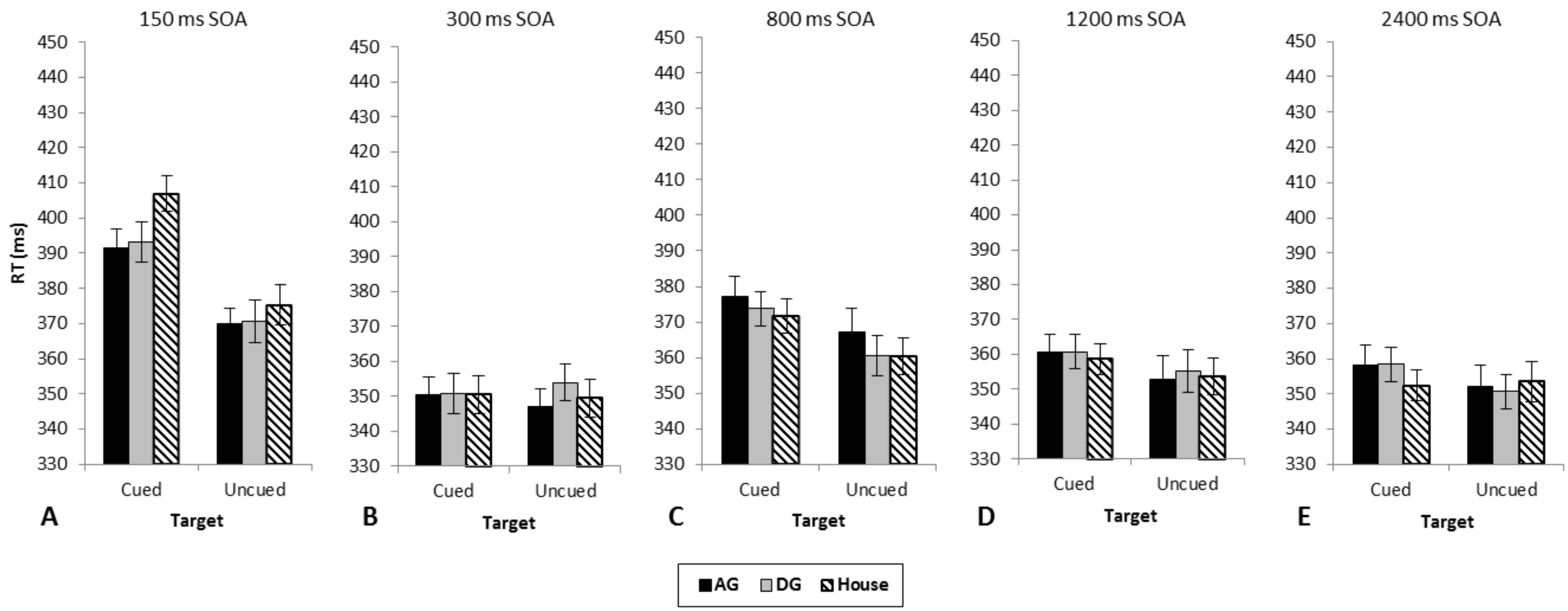

Figure 3.2. Target response RTs for Experiment 3a, as a function of cueing condition, stimulus cue, and SOA. Results for (A) 150 ms SOA, (B) 300 ms SOA, (C) 800 ms SOA, (D) 1200 ms SOA, and (E) 2400 ms SOA (all shown with standard error bars). See text for details.

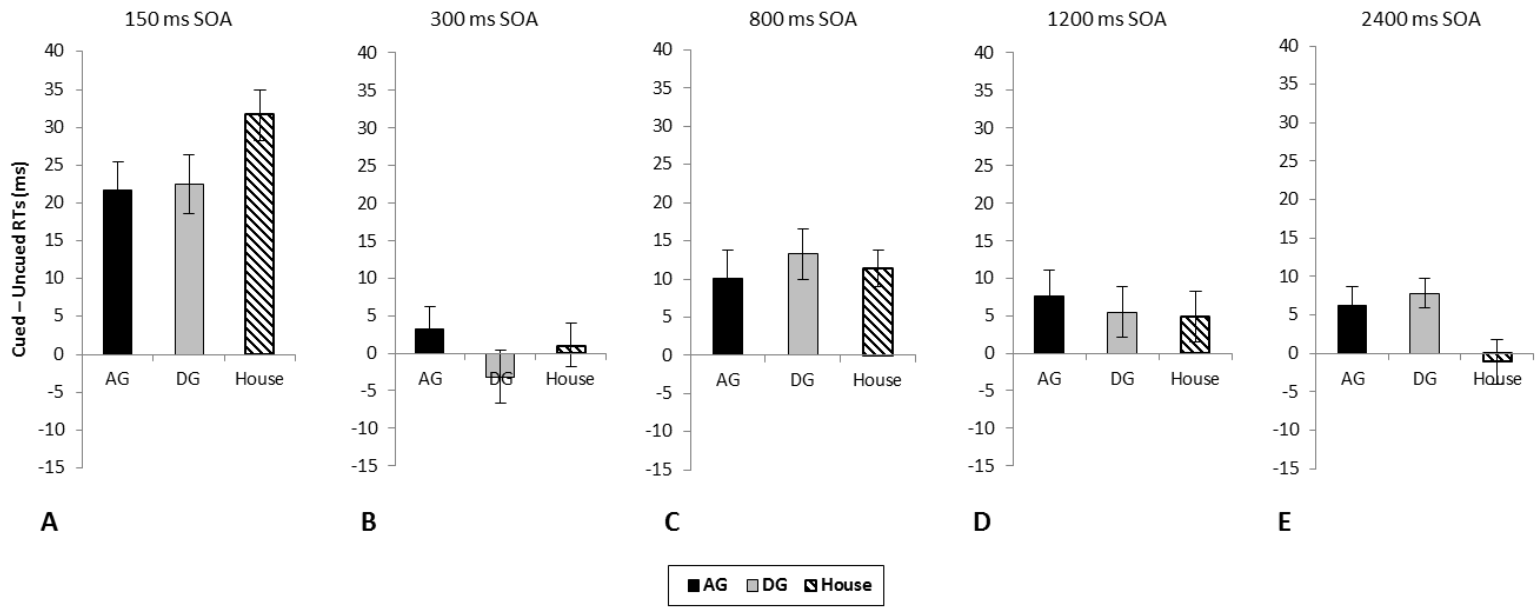

Figure 3.3. IOR magnitudes (i.e., difference scores between cued stimulus RTs and uncued stimulus RTs) for Experiment 3a, as a function of stimulus cue and SOA. Results for (A) 150 ms SOA, (B) 300 ms SOA, (C) 800 ms SOA, (D) 1200 ms SOA, and (E) 2400 ms SOA (all shown with standard error bars). See text for details.

4.1.4 Experiment 3a Discussion

This experiment used frontal heads to examine how gaze direction captured covert attention in an IOR paradigm over a variety of SOAs. A general IOR effect was found at almost every SOA (except for 300 ms), even at the shortest SOA (150 ms), in line with other research showing a lack of facilitation (i.e., no faster responses to cued versus uncued targets) at short SOAs (Berlucchi et al., 1989; Tassinari et al., 1994; Tassinari & Berlucchi, 1995; Tassinari et al., 1989). This finding is in line with the notion that covertly orienting towards a peripheral cue inhibits eye movements, thus causing a motor bias against responding to cued targets (Klein & Taylor, 1994; Rafal & Henik, 1994). Additionally, there was no temporal overlap between stimulus cue and target presentation in the current study. Even at the shortest SOA (150 ms), targets were presented *after* the stimulus cues vanished (albeit immediately after, without any delay). This also helps explain the IOR effects across the majority of SOAs, without any facilitation preceding inhibition (Collie et al., 2001).

A priming effect was also found for faces compared to houses at the short SOA (150 ms), similar to the one found in Weaver et al. (2012) at the 200 ms SOA. That is, even though an IOR was found for both faces and houses, RTs were faster overall for face trials compared to house trials, indicating that the mere presence of faces elicited faster responses, possibly due to the biological and social significance of faces (Palermo & Rhodes, 2007) for which responses require a high level of vigilance. Since frontal heads with direct gaze (i.e., congruent face stimuli) should capture more reflexive attention than frontal heads with averted gaze (i.e., incongruent stimuli), it was expected that a larger priming effect would occur for DG faces compared to either AG faces or Houses. Instead, both DG and AG faces produced a similar priming effect at 150 ms compared to Houses, perhaps reflecting how faces in general (regardless of gaze direction) are capable of eliciting a quick capture of attention compared to other stimuli (e.g., Bindemann et al., 2005; Langton et al., 2008; Palermo & Rhodes, 2007; Ro et al., 2001).

A trend toward a larger IOR magnitude was found at 2400 ms for DG faces (but not AG faces) compared to Houses. Thus, it seems that the congruency of frontal heads with direct gaze captured slightly more attention than houses, leading to the largest IOR response for these stimuli.

Experiment 3a used faces with a frontal head orientation, and although there was a trend toward a larger IOR magnitude for direct gaze faces compared to houses, there was no effect of gaze direction on the priming effect at the short SOA. Thus, gaze direction influenced attention capture only very weakly using this type of IOR cueing paradigm. If faces attract attention regardless of gaze direction, then Experiment 3b using deviated heads should find similar results, in that both DG and AG faces will elicit a priming effect and subsequently larger IOR compared to houses. However, if head orientation interacts with gaze direction and influences how attention is captured using this type of paradigm, then it is possible that gaze-head congruency effects would occur, similar to those seen in Chapters 2 and 3. This would mean that with deviated heads, AG faces should capture more attention than DG faces, and lead to a larger priming effect when compared to houses. At longer SOAs, AG faces should also have the largest IOR magnitude, followed by DG faces, and then houses. The purpose of Experiment 3b was to examine this issue by using deviated heads.

4.2 Experiment 3b: Deviated Head Orientation

4.2.1 Experiment 3b Methods

Participants. A total of 26 participants completed Experiment 3b. Three participants were rejected due to tiredness/fatigue, which left 23 participants (10 female, 13 male; 22 right-handed; age range 18-22 years, $M = 19.7$).

Stimuli and Procedure. Face stimuli included the same deviated head photographs from Experiment 1c (using upright faces only). All other aspects of the design were identical to Experiment 3a.

4.2.2 Experiment 3b Results

A mixed omnibus ANOVA analyzing both Experiments 3a and 3b together revealed a significant four-way SOA (within) by cueing condition (within) by stimulus cue (within) by head orientation (between) interaction ($F(8, 360) = 2.43$, $MSE = 138.41$, $p < .05$). This indicates that both experiments were indeed different from one another, and that head orientation affected the performances.

For Experiment 3b, the 5 (SOA) x 2 (cueing condition) x 3 (stimulus cue) omnibus ANOVA revealed main effects of SOA ($F(4, 88) = 40.92$, $MSE = 1927.86$, $p < .0001$, $\eta_p^2 = .65$), cueing condition ($F(1, 22) = 18.75$, $MSE = 764.46$, $p < .0001$, $\eta_p^2 = .46$), and stimulus cue ($F(2, 44) = 4.33$, $MSE = 174.22$, $p < .05$, $\eta_p^2 = .16$), and interactions between SOA and cueing condition ($F(4, 88) = 23.99$, $MSE = 317.08$, $p < .0001$, $\eta_p^2 = .52$), and between SOA and stimulus cue ($F(8, 176) = 3.58$, $MSE = 192.69$, $p < .005$, $\eta_p^2 = .14$). There was also a significant three-way interaction between SOA, cueing condition, and stimulus cue ($F(8, 176) = 3.66$, $MSE = 213.89$, $p < .005$, $\eta_p^2 = .14$). Thus, 2 (cueing condition) by 3 (stimulus cue) repeated measures ANOVAs were conducted for each SOA, and separate ANOVAs were conducted for an IOR effect if there was a cueing by stimulus cue interaction. For all post-hoc tests, the Bonferroni correction was used to control for multiple comparisons.

For the 150 ms SOA (Figure 3.4A), slower RTs were found for cued than uncued targets (IOR effect), as revealed by a main effect of cueing condition ($F(1, 22) = 38.14$, $MSE = 755.88$, $p < .0001$, $\eta_p^2 = .63$). There was also a main effect of stimulus cue ($F(2, 44) = 6.58$, $MSE = 139.12$, $p < .005$, $\eta_p^2 = .23$). Post-hoc comparisons revealed slower RTs for DG faces and Houses compared to AG faces (all $p < .05$), indicating a priming effect for AG faces. No interaction was found between cueing condition and stimulus cue ($p > .2$; Figure 3.5A).

For the 300 ms SOA (Figure 3.4B), there were no main effects of cueing condition or stimulus cue, and no interaction between the two variables (all $p > .1$). Thus, there was no IOR effect for any stimulus cue (Figure 3.5B).

For the 800 ms SOA (Figure 3.4C), slower RTs were found for cued than uncued targets (IOR effect), as revealed by a main effect of cueing condition ($F(1, 22) = 10.99$, $MSE = 290.23$, $p < .005$, $\eta_p^2 = .33$). Additionally, a main effect of stimulus cue ($F(2, 44) = 4.78$, $MSE = 178.23$, $p < .05$, $\eta_p^2 = .18$) was found, and post-hoc comparisons revealed slower RTs for AG faces and Houses compared to DG faces (only the DG-House comparison was significant, $p < .05$). No interaction was found between cueing condition and stimulus cue ($p > .1$; Figure 3.5C).

For the 1200 ms SOA (Figure 3.4D), slower RTs were found for cued versus uncued targets (IOR effect), as revealed by a main effect of cueing condition ($F(1, 22) = 6.93$, $MSE = 143.69$, $p < .05$, $\eta_p^2 = .24$). No main effect of stimulus cue, and no interaction between cueing condition and stimulus cue was found (all $p > .2$; Figure 3.5D).

For the 2400 ms SOA (Figure 3.4E), there was no main effect of cueing condition ($p >$ .6) or stimulus cue ($F(2, 44) = 3.17$, $MSE = 88.81$, $p = .059$, $\eta_p^2 = .13$), but there was a cueing condition by stimulus cue interaction ($F(2, 44) = 8.38$, $MSE = 139.38$, $p < .005$, $\eta_p^2 = .28$). The separate IOR analysis confirmed a main effect of stimulus cue ($F(2, 44) = 8.38$, $MSE = 278.75$, $p < .001$, $\eta_p^2 = .28$), and post-hoc comparisons revealed that the IOR effect for AG faces ($M = 12$ ms) was significantly larger than for both DG faces ($M = –2$ ms) and Houses ($M = –7$ ms; all $p < .05$; Figure 3.5E), which were not different from one another.

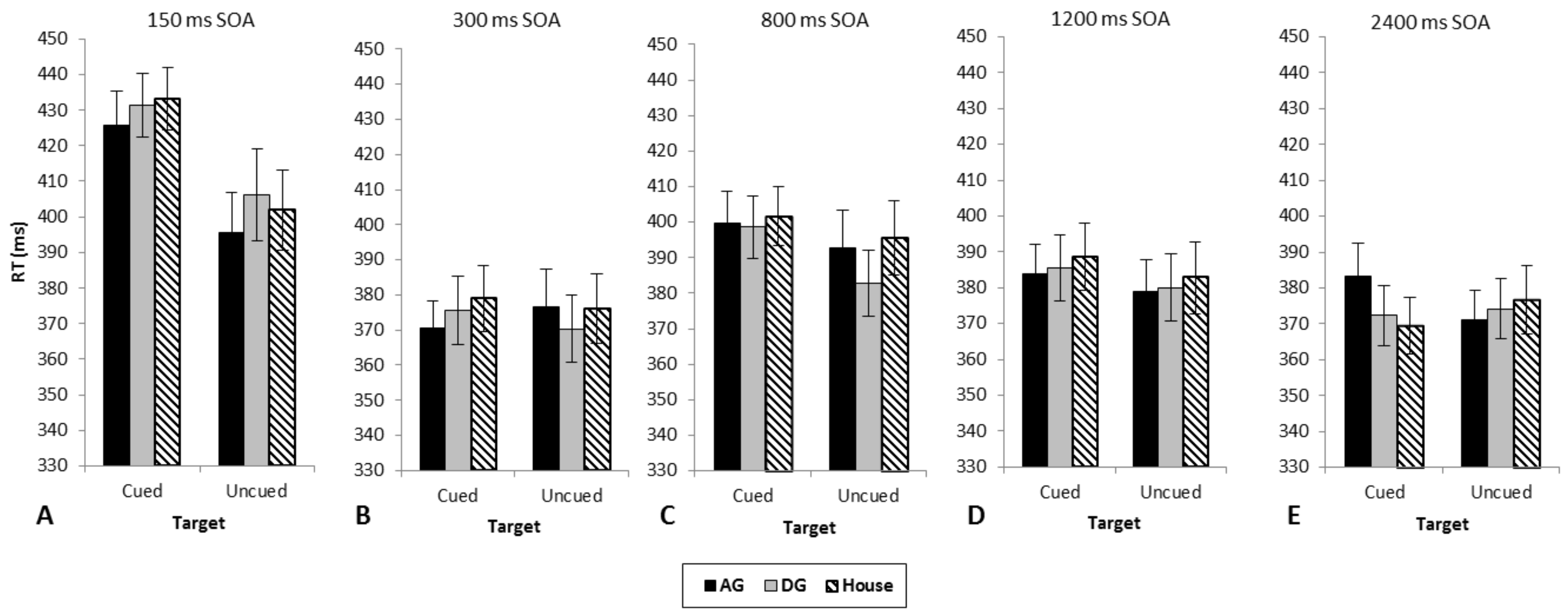

Figure 3.4. Target response RTs for Experiment 3b, as a function of cueing condition, stimulus cue, and SOA. Results for (A) 150 ms SOA, (B) 300 ms SOA, (C) 800 ms SOA, (D) 1200 ms SOA, and (E) 2400 ms SOA (all shown with standard error bars). See text for details.

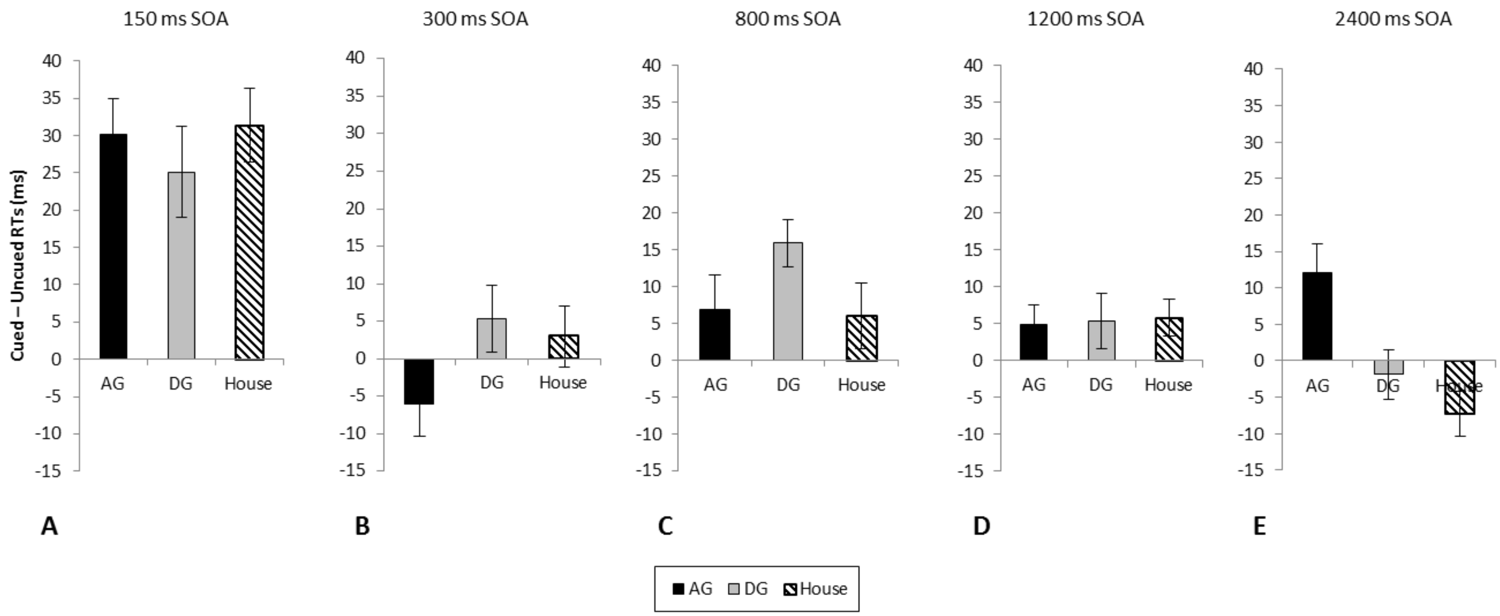

Figure 3.5. IOR magnitudes (i.e., difference scores between cued stimulus RTs and uncued stimulus RTs) for Experiment 3b, as a function of stimulus cue and SOA. Results for (A) 150 ms SOA, (B) 300 ms SOA, (C) 800 ms SOA, (D) 1200 ms SOA, and (E) 2400 ms SOA (all shown with standard error bars). See text for details.

4.2.3 Experiment 3b Discussion

Similar to Experiment 3a, a general IOR effect was found at every SOA except at the 300 ms SOA. Additionally, a priming effect occurred at 150 ms only for AG faces (but not DG faces) compared to houses, independent of the similar IOR effect found for all stimuli. Subsequently, at 2400 ms, a larger IOR response occurred for AG faces compared to the other stimuli. Thus, gaze direction influenced how attention was captured compared to other stimuli (i.e., houses) at 2400 ms, and this was congruent with the head orientation of the face stimuli. Overall, deviated heads with averted gaze seemed to capture more reflexive attention compared to deviated heads with direct gaze in this IOR paradigm, thus leading to an enhanced priming effect and subsequently larger IOR response compared to houses. Although these effects were relatively small in magnitude, they indicate a significantly robust effect for congruent gaze-head stimuli in capturing attention compared to the other competing stimuli.

4.3 General Discussion and Conclusions

The current study used an IOR paradigm to examine how gaze direction and the influence of head orientation captured covert attention over a variety of SOAs. The main results showed that all SOAs, with the exception of the 300 ms SOA, produced an IOR, regardless of stimulus type. Additionally, a priming effect occurred for faces compared to houses at the short SOA (150 ms), independent of a general IOR response for all stimuli, and this was modulated by gaze direction for deviated heads. Lastly, at the longest SOA (2400 ms), a larger IOR magnitude was found for the faces whose gaze was congruent with head orientation compared to houses. These findings are discussed in more detail below.

Across both experiments, an IOR response was found even at the shortest SOA (150 ms), in line with other research showing a lack of facilitation at short SOAs (Berlucchi et al., 1989; Tassinari et al., 1994; Tassinari & Berlucchi, 1995; Tassinari et al., 1989). In fact, the shortest SOA in the current study actually produced the largest IOR magnitude (across head orientations), which is similar to these previously mentioned studies (Berlucchi et al., 1989; Tassinari et al., 1994; Tassinari & Berlucchi, 1995; Tassinari et al., 1989) that also showed the largest IOR effects at the shortest SOAs (~200 ms). This finding is also similar to the larger IOR magnitude at the 200 ms SOA than the 700 ms SOA found in Weaver et al. (2012). It is possible that the active suppression of overt orienting, which is normally linked with the shift of attention (Tassinari et al., 1987), causes a momentary interference with the motor predisposition to react to stimuli from the same direction, and also entails a temporary benefit for motor reactions to stimuli which come from the opposite direction (Tassinari et al., 1994; Tassinari & Berlucchi, 1995; Tassinari et al., 1989), perhaps reflecting an efficient foraging strategy (Klein, 1988; Klein & MacInnes, 1999) to search for novel targets, such as new faces. Due to the stimulus cue presentation time of 150 ms, this was the shortest possible SOA that could be tested in this study. Additionally, since the target appeared immediately after the stimulus cue vanished (in the same location), there was no temporal overlap between stimulus cue and target. Thus, no facilitation (i.e., faster RTs to cued trials than uncued trials) was expected to occur. However, facilitation may have occurred if the target was placed just outside the location of the stimulus cue, and the stimulus cue was still being presented during target detection. This design would also allow the possibility to test even shorter SOA times than 150 ms, which may have shown a possible facilitation as well (similar to the short SOAs demonstrated by Posner & Cohen, 1984). Thus, future research may investigate this issue. It should also be noted that the current study used faces, rather than flickering squares (as in Posner & Cohen, 1984), as stimulus cues, which may have facilitated different IOR response patterns than previous studies using low-level stimuli.

Interestingly, all SOAs produced an IOR response (across stimulus types and face orientations) except for the 300 ms SOA. Since the shorter, 150 ms, SOA, and longer SOAs produced an IOR response, the lack of any effect (facilitation or IOR) at 300 ms was unlikely due to the "crossover" between facilitation and IOR curves, as found historically (Posner & Cohen, 1984). All SOAs were tested within subjects, rather than between subjects or between blocks of trials, which may have produced different response strategies. Intermixing SOAs within blocks makes the timing of the target presentation uncertain. Under such conditions, the 150 ms SOA would be immediately apparent (since the target directly succeeded stimulus cue presentation), and the longer SOAs (800 ms and greater) would give participants more time to process the type and location of the visual stimulus; the intermediate SOA of 300 ms may involve a temporary interference or lapse of processing the stimulus information. It is also possible that two different cognitive processing mechanisms were simultaneously at play during this IOR paradigm: one that inhibited target responses at very short SOAs, and one at very long SOAs, thus leaving intermediate SOAs with neither a facilitation nor inhibitory target response. Future research could test different SOAs between subjects or between blocks of trials to examine whether these task effects influence the processing of these stimuli or strategy for detecting targets.

A priming effect was found for faces at the shortest SOA, independent of an IOR response (i.e., faster RTs for face trials than house trials, regardless of cueing condition). This effect was found at 150 ms, very close to the priming effect found at 200 ms SOA by Weaver and colleagues (2012), and this finding in the current study was influenced by gaze-head interactions. With frontal heads, both direct- and averted gaze faces elicited faster responses than houses, perhaps supporting the notion that faces, in general, are a special type of stimulus for attracting attention (Bindemann et al., 2005; Langton et al., 2008; Palermo & Rhodes, 2007; Ro et al., 2001). Weaver and colleagues (who also used frontal heads) suggested this effect to be an efficient strategy of visual attention to favour the priming of meaningful stimuli (i.e., faces) that may require immediate action from the observer. That is, it may be necessary to react to the unpredictability produced by social contexts, thereby eliciting a higher level of vigilance to faces, similar to a "threat detector" mechanism for processing threatening faces (Morris et al., 2001; Öhman, 2002). Although the current study only used faces with neutral expression, these findings highlight the fact that faces in general are capable of rapidly capturing attention compared to other stimuli. The fact that Weaver et al. (2012) found this priming effect with overt eye saccades, while this study found it with covert attention (button press) suggests that a higher level cognitive processing mechanism is at play for facial stimuli, and also supports the evidence that IOR processes can occur with either eye movements or behavioural responses (Klein, 2000). With deviated heads, this priming effect only occurred for averted gaze faces, which suggests that there was a gaze-head congruency effect, but only for deviated heads. If there was a general gaze-head congruency effect, then it would also be expected that this priming effect be replicated only for frontal heads with direct gaze. Based on Chapters 2 and 3, this was one of the main predictions. Instead, both direct- and averted gaze faces with frontal heads elicited this response. This may have occurred because a frontal head corresponds to the innate face template that human infants show a preference for (Johnson et al., 1991; Morton & Johnson, 1991), rather than a deviated head. Thus, a frontal oriented face may inherently capture attention, regardless of gaze direction, and lead to faster priming of target responses (which is also in line with the idea that frontal faces guide attention; see Shirama, 2012). It is also important to note that the two head orientations (frontal and deviated) were tested between subjects. This was due to the time constraints of the relatively long experimental design. As seen in Experiments 1d and 2c, combining both head orientations within the same design influenced the response bias for gaze-head congruent targets even more so than using a design with just one head orientation. Of course, this IOR paradigm was different than the previous gaze detection studies as participants were not told any information about the stimuli, and all of the stimuli were always presented outside of foveal vision. Future research could examine whether the effect of head orientation was due to task demands or paradigm design. Lastly, it should be noted that the house pictures were not equated to the face pictures in terms of luminance and contrast (as the stimuli came from different databases), and this could have contributed to the priming effects seen in the current study. Future research would have to investigate whether the difference in brightness and contrast played more of a role in the priming effect than the semantic characteristics of the stimuli (i.e., the meaningfulness or relevance of faces compared to houses).

An unpredicted main effect of stimulus cue occurred at 800 ms, independent of an IOR response, for both experiments. Overall, RTs were faster for DG faces with frontal heads (compared to AG faces) and with deviated heads (compared to both AG faces and houses). This appeared to be a priming effect for direct gaze faces across head orientations at the 800 ms SOA. Since there were no facilitation (or IOR) effects at the 300 ms SOA, this result was unlikely due to carryover effects from the 150 ms SOA. This finding could have genuinely reflected a faster processing of direct gaze stimuli due to its attention-grabbing capability, but it is unclear why this effect would occur at 800 ms, since it did not happen immediately before or after this SOA.

As no interactions were found between cueing condition and stimulus cue at this SOA, these findings did not reflect any specific IOR effects.

Finally, a larger IOR effect occurred for faces compared to houses at the longest SOA (2400 ms), and this was modulated by gaze direction and head orientation. With frontal heads, a trend toward a larger IOR for direct gaze faces compared to houses was seen; with deviated heads, a larger IOR was elicited by averted gaze faces compared to the other stimuli. This indicates that the congruent face stimuli (i.e., frontal heads with direct gaze and deviated heads with averted gaze) may have captured more initial attention than the incongruent stimuli, when compared to houses, thus leading to a larger inhibition of target responses when subsequent targets were placed in those previous locations that contained the congruent facial stimuli. This effect is in line with the other gaze-head congruency effects found in the other chapters of this thesis. It is also interesting that there were no specific IOR effects for faces (or houses) at the other, intermediate SOAs. This contrasts with other research showing a stronger IOR effect for faces compared to other stimuli at around 800-1000 ms (e.g., Theeuwes & Van der Stigchel, 2006). This could be due to task effects of the multiple different SOAs tested within each participant, but future research would have to examine this issue. These findings may also reflect the influence of gaze direction that moderated the IOR effects, and it is possible that gaze cues only interact with IOR at very long SOAs. It has been shown, for example, that in gaze-cueing paradigms, where a face cue is centrally presented prior to the onset of a lateral target, target detection is faster when the face is looking toward the same side where the target later appears versus the opposite side, but only at short SOAs (~200 ms); at longer SOAs (~2400 ms), target detection is actually slower for these same-side targets, suggesting a delayed onset of inhibition of return process for gaze cues (Frischen et al., 2007b; Frischen & Tipper, 2004; Marotta et al., 2013). Although gaze-cueing paradigms are different in design than the current IOR paradigm, these findings may suggest that gaze cues only interact with inhibitory processes at long SOAs.

An important feature of Chapter 4, compared with Chapters 2 and 3, was that participants were not given any specific information regarding the stimuli, nor were they told the true purpose of the study. Furthermore, participants did not fixate on the stimuli during trials. Thus, these results indicate that the congruent combination of head and gaze direction may influence the exogenous attention capture of faces in a bottom-up fashion, such that congruent facial stimuli were able to capture more reflexive attention than incongruent stimuli, even when viewed covertly, outside of foveal vision, implying that it is possible to perceive these social cues implicitly.

Chapter 5: General Discussion

5.1 Summary of Findings

The experiments of Chapter 2 revealed that the speed and accuracy of gaze detection in the horizontal periphery was dependent on eccentricity, type of face stimuli, and head orientation. For Photoshopped faces (only front-view), gaze was detected above chance level up to 10.5° eccentricity. For natural faces with frontal and deviated heads, gaze was accurately detected to about 4.5° eccentricity. There was also a general response bias with better discrimination for gaze-head congruent than incongruent targets beyond central vision. Nevertheless, direct gaze was generally detected faster than averted gaze in foveal vision, regardless of head orientation.

The experiments of Chapter 3 revealed similar results of gaze detection along vertical eccentricities, with gaze being accurately detected within central vision limits (~3°-4.5°). Again, there was a congruency effect between gaze direction and head orientation beyond foveal vision, although this congruency effect was stronger for frontal than deviated heads. The congruency effect for deviated heads was stronger when both head orientations were tested in the same design.

The experiments of Chapter 4 revealed that face stimuli affected IOR responses, and gaze direction modulated these effects. At the shortest SOA (150 ms), faster RTs were found for faces compared to houses, independent of an IOR response, suggesting a priming effect elicited by faces. This effect was seen regardless of gaze direction for frontal heads, but for deviated heads, it was seen only for averted gaze. At the longest SOA (2400 ms), a larger IOR magnitude was found for faces compared to houses. For frontal heads, this effect was trending for direct gaze, and for deviated heads, this effect was significant for averted gaze.

All of these studies used the same set of naturally-looking facial stimuli (with the exception of Experiment 1a in which Photoshopped faces were used), and the same stimulus presentation time of 150 ms to maintain consistency. Thus, any minor differences between studies could not have been due to these factors. Eye-tracking was also used to control participants' eye movements and to truly ensure the use of covert, rather than overt, attention. Lastly, these studies measured both top-down processing (Chapters 2 and 3) and bottom-up processing (Chapter 4), suggesting that gaze direction and head orientation influenced both explicit and implicit gaze processing.

5.2 Sensitivity to Eye Gaze Detection

The present research demonstrated that the type of face stimuli affected how far in the periphery observers could process gaze direction. When naturalistic faces were used, gaze could only be discriminated within central vision. However, when the faces were controlled for contrast and luminance, and gaze was manually manipulated, gaze direction could be discriminated well beyond parafoveal vision. It seems that these manipulations of the face, without natural contrasts or shadows and greater luminance, created a "superstimulus" that allowed easy gaze detection, even at peripheral eccentricities. The large ratio of exposed sclera to iris in human eyes already makes gaze easy to discriminate (Kobayashi & Kohshima, 1997), and any modification to the eye region to reduce shadows or obscurity would enhance the gaze signals even more than usual. Since human eyes evolved for complex social interactions (Emery, 2000), this is perhaps the point of an easily detectable eye region. Larger eyes (especially in women) are also rated to be more attractive than smaller ones (Geldart et al., 1999; Rhodes, 2006), and many women use cosmetics (e.g., eyeliner, eye shadow, and mascara) to increase the visual salience of the eye region, creating the illusion of larger eyes, thus enhancing physical attractiveness (Mulhern et al., 2003) and the perception of gaze direction (Ueda & Koyama, 2011). In sum, humans have evolved with large, easy-to-see eyes, and the more salient they are, the easier it is to discriminate their gaze direction, even in the visual periphery.

When viewing natural faces, the present research indicated that gaze can be accurately discriminated to about 4.5° eccentricity around the fixation point (although slightly less in the lower visual field). Head orientation then strongly biases gaze judgments past this eccentricity. This means that humans have a “gaze sensitive” field of view that roughly measures a total of 9° horizontally by 8-9° vertically. This may seem like a relatively small window, but considering that the fovea only comprises the central 2° of vision, this gaze sensitive field of view extends well beyond foveal vision. This gaze sensitive window may also help with the processing of social information, for example, like walking down a hallway and noticing a fellow colleague glancing at you for a friendly greeting (even if they are much shorter or taller than you are). It should also be noted that the present research demonstrated that gaze direction influenced both explicit (Chapters 2 and 3) and implicit (Chapter 4) gaze processing. Thus, even when you are unaware of any potential gaze signals in your environment (e.g., like walking down a hallway and noticing an unexpected fellow colleague glancing at you), you are able to respond to that signal quickly and effectively. Chapter 4 also indicated that gaze direction may influence attention to subsequent targets so that when a gaze signal has already been attended to, it promotes a bias to attend to novel areas, perhaps to search for new faces that are socially relevant to the observer. A limitation of the current research is that these studies only measured gaze detection using horizontal or vertical eccentricities, but not other locations in visual space, such as if targets were positioned diagonally from the centred fixation, which future research could examine. However, it is likely that this gaze sensitive field of view would allow observers to accurately detect and discriminate gaze from all angles and locations within this visuospatial window since a specialized mechanism dedicated to perceiving social signals should function in all directions of an environment.

One may also wonder how generalizable these gaze sensitivities may be? It should be noted that the present research only used faces of neutral emotional expression, and of equal size (roughly 3° by 4.5°). It is possible that the gaze of faces with different emotional expression, such as those with a fearful or surprising expression, would actually be able to be discriminated at a farther eccentricity in the visual field because there is more visible white sclera shown in these faces compared to faces of neutral expression (Whalen et al., 2004), which may contribute to an easier discrimination of eye gaze. Additionally, other research proposes that gaze and expression are processed in an integrated manner, such that direct gaze facilitates the processing of approach-oriented emotions (joy and anger), whereas averted gaze facilitates avoidance-related emotion processing (sadness and fear; Adams & Franklin, 2009; Adams & Kleck, 2003, 2005). According to the appraisal theory of emotion, for example, angry faces are evaluated as being angrier when showing direct gaze, as eye contact implies an imminent potential threat from the sender, whereas fearful faces are perceived as more fearful when showing averted gaze, as this might indicate a potential threat in the environment (for a review, see Graham & Labar, 2012). In line with this assumption, direct gaze may be discriminated faster when paired with happy and angry faces, whereas averted gaze may be discriminated faster when paired with sad and fearful faces. The present research only used neutral expressing faces to control for the amount of visible sclera and iris, and any potential approach-avoidant signals. Thus, any claims on the sensitivity of covert gaze detection may only be limited to faces of neutral expression.

However, future research may examine how different facial emotions contribute to covert gaze detection.

Faces of different sizes may also influence covert gaze detection as larger faces have larger eye regions, and thus, an easier potential to discriminate gaze. For example, if the faces in the present research were doubled in size (to about 6° by 9°), then a face that was positioned 4.5° horizontally from centre would be overlapping an area between 1.5° and 7.5° horizontal eccentricity. Consequently, the eye region would be wide enough such that gaze may only need to be detected from one eye of the stimulus face (the one closer to the centre at 0°). Furthermore, the iris diameter of these larger faces would be about 40 minutes of arc (0.67° of visual angle), which would essentially be 40 times the resolution threshold at the fovea. As a result, the gaze of this face could probably be discriminated from a farther eccentricity from centre than the smaller faces used in the present research. The eye region of the facial stimuli used in the present thesis measured about 2.5° horizontally by 0.5° vertically, and the eccentricity at which faces were positioned was measured from the centre of the face (and also eye region); this was to keep the exact eccentricities consistent across both horizontal and vertical visual fields in all directions. Additionally, larger faces may indicate that they are closer to the observer, while smaller faces indicate more distant stimuli. For example, an actual face that measures 3° by 4.5° in real life might be about 8 or 9 feet away from the observer, whereas a face doubled in size may only be about 4 feet from the observer, and observers may react differently to faces seen at different distances. For instance, a face that is 4 feet away is a typical distance of one-on-one social interactions, which may influence your attention differently than a face that is 8 or more feet away, which may be someone in the distance that has not *yet* grabbed your attention; thus, it may be helpful to have a specialized mechanism to detect this person's gaze signals since their subsequent form of communication (e.g., verbal speech) would be to indicate their behavioural intent toward you, and this would be vital for proper social interaction. It is important to note that the faces in the present research were only two dimensional on a computer screen, and there were no immediate social consequences of the stimuli, task-related or otherwise. Thus, the implications of the current research can only make claims on faces of about 3° by 4.5° in size, so future research may investigate how different-sized faces could affect covert gaze detection.

Additionally, participants did not have any explicit social tasks in the current studies, other than to detect a target. Perhaps if participants were given a specific task relevant to the social signals of the face (e.g., which face they find most attractive, who would they befriend, who would they ask for a helping hand), then this would elicit a different frame of mind, which could in turn facilitate different reactions from the faces. That is, the gaze of the faces may emit different social vibes depending on the task, which may lead to better detection of certain gaze signals (e.g., detecting a female face with direct gaze might be easier to do if a male participant were asked who he would want to date). Furthermore, human faces and eyes in real life are normally associated with movement (e.g., when someone shifts their eye gaze toward you from another location), rather than viewed statically. The added movement of the eyes and/or head would presumably increase the saliency of the stimuli and be much easier to detect. Thus, the effects of task social relevance and dynamic versus static facial stimuli could be examined with future research.

5.3 Role of Head Orientation in Gaze Perception

Overall, the data supported the idea of a cognitive mechanism for detecting social attention that integrates both eye gaze and head orientation information (i.e., Direction of

Attention Detector (DAD) mechanism). Gaze detection was generally best for a direct gaze with a frontal head, and averted gaze with a deviated head, compared to the opposite gaze-head combinations. Thus, the congruency between same-gaze and -head oriented stimuli elicited stronger attention and better detection performance than the other competing stimuli. These findings imply that gaze direction and head orientation can be powerful social cues for capturing and engaging attention, and both contribute to gaze detection in the environment. However, it is important to note that the gaze-head congruency effects were more prominent beyond foveal vision, and head orientation did not strongly influence gaze discrimination when focused attention was applied. The current research showed that when participants actually fixated the target (i.e., using overt rather than covert attention), direct gaze was detected faster than averted gaze (Chapter 2). This implies that eye contact has a powerful effect on capturing overt attention that is robust to differing head orientations (at least within the confines of being presented with faces along horizontal eccentricities). This also indicates that the detection asymmetry in favour of direct gaze was due to the gaze signals of the face rather than to the visual symmetry of the eyes. However, beyond foveal vision, head orientation seems to be the primary cue by which observers judge gaze direction.

The main purpose of this research was to examine whether gaze direction captured covert rather than overt attention. The findings of this thesis have clearly demonstrated that head orientation strongly influenced gaze perception when stimuli were viewed covertly, especially with increasing eccentricity. This suggests a hierarchy of social cues used for judging attention direction (Perrett et al., 1992). For example, when the eyes are clearly visible, then local information from the eye region can be used for gaze judgments; when eye gaze cues become less visible in the periphery, then head orientation serves as the main cue for gaze judgments. It has also been shown that with single cell recordings in monkeys, 60% of the cells responsive to the sight of faces in the temporal cortex are also sensitive to the presence of eyes (Perrett et al., 1982, 1985). About 95% of these cells are tuned to head and eye gaze oriented in one particular direction (Perrett et al., 1985); some cells are more responsive when the head and eyes are directed toward the observer, and other cells are more responsive when the head and eyes are turned away from the observer (e.g., 45° to the left or to the right). These cells are sensitive to information derived from both head and gaze direction, with eye gaze direction having priority over head orientation in control of cell responses. Additionally, about 60% of cells responsive to head direction are also sensitive to information derived from the rest of the body (Wachsmuth et al., 1994). These cells also show a preference for the head and body pointing in the same direction. Taken together, these findings support the general DAD mechanism (Perrett & Emery, 1994). This mechanism would account for how an observer would analyze another's attention direction using a priority order of visual cues in which gaze direction is the most important, and body direction is the least important. For example, if the eyes are either occluded or obscured by shadows, then the head could be used to define attention direction. Moreover, if the head is hidden from view, then information from the body could be used. In fact, the cells in the temporal cortex of monkeys exhibit exactly this priority of cue control over responses (Perrett et. al., 1985, 1990). However, these observations in monkeys occur when stimuli are directly fixated. Perhaps, a similar hierarchy of visual cues would occur when viewing stimuli covertly, in the periphery. For example, body direction would be a much larger and easier social cue to perceive in the far distance or periphery, followed by head orientation, and then gaze direction. The present research indeed showed that head orientation had priority over gaze direction when perceiving gaze beyond foveal vision. Future research could similarly test whether body direction has priority over head orientation when processing gaze judgments in the periphery.

From the present research, one may wonder what brain area(s) account for the DAD mechanism. If gaze detection in the periphery operates similar to a "threat detection" mechanism in other mammals then one of two neuronal circuits may be used. In the cortical pathway, visual information travels from the retina to the lateral geniculate, the early visual areas, the STS, and finally toward attention control circuitry including the lateral intraparietal area, frontal eye fields, and superior colliculus (Shepherd, 2010). On the other hand, the subcortical pathway offers a rapid but crude route to processing faces and gaze direction in the periphery, where contrast information between the dark iris and the white sclera of the eyes is sent to the superior colliculus, pulvinar, and amygdala (Johnson, 2005; Senju & Johnson, 2009; Shepherd, 2010). However, it is also possible that both circuits work simultaneously (Shepherd, 2010). For example, Vuilleumier et al. (2003) found that when processing faces with a fearful expression, shorter subcortical pathways provided the amygdala with coarse but rapid sensory information, while longer cortical pathways provided more detailed information over a longer time-scale. This shows that socially relevant visual information can be processed within, as well as across, different neuronal mechanisms in the same individual. Thus, it is possible that the DAD mechanism may initially function through the subcortical route, which then projects to various cortical regions of the "social brain network" (e.g., STS, fusiform gyrus, and medial prefrontal cortex; Senju & Johnson, 2009). The signals from the subcortical route may interact or modulate activation of cortical gaze processing areas based on task demands or social context (George et al., 2001; Kleinhans et al., 2008), but future research is needed to examine these possibilities more carefully.

5.4 Limitations and Future Research

It is important to note some other limitations of this research, and the future directions that one could follow to examine these issues. First, all of the experiments in this thesis employed volunteer undergraduate university students, between the ages of 17-25, as participants. This was to keep all of the research studies consistent with each other, but this sample of participants only covers a relatively small range of adult ages. Perhaps older adults would yield different results during gaze processing, such as age-related declines with assessing differences in eye gaze direction (e.g., Slessor et al., 2008). Nevertheless, young adults in a university setting can be ideal candidates for this type of research as they are surrounded by thousands of their peers every day, and it would be beneficial for them to have an accurate gaze detection mechanism to help spot important individuals (e.g., friends, professors).

Second, all of the experiments kept a relatively equal balance of male and female participants in order to generalize the results across genders. The stimuli were also comprised of male and female faces. None of the experiments showed any significant effects of participant gender or stimulus gender, however it has been shown that participant gender can potentially affect gaze processing (e.g., Goodman et al., 2012; Jun et al., 2013; Porter et al., 2006). For example, one study showed that male participants had better recognition of direct gaze than averted gaze faces, but there were no differences between recognition of direct and averted gaze faces for female participants (Goodman et al., 2012). Another study showed that female observers had significantly larger pupil dilation when viewing direct gaze than averted gaze faces, but male observers did not show any differences of pupil dilation in response to gaze direction (Porter et al., 2006). There are few studies in the literature that examine gender differences in gaze processing, which may be affected by different tasks. Perhaps the particular paradigms used in the current research were impervious to gender differences, or there were not large enough sample sizes to detect any differences. Future research could investigate this issue more carefully. Nevertheless, the equal balance of genders across studies allows more generalizable claims for the current findings.

Third, the gaze directions of the face stimuli used in this thesis were either direct (straight gaze) or averted by 30°. Perhaps different gaze angles would affect gaze perception, and using more subtle visual angle differences between direct and averted gaze would influence the results. For example, it has been shown that gaze discrimination sensitivity drops for gaze deviated by 5° compared to 10° of visual angle (Jenkins et al., 2006), and direct gaze discrimination can be strongly biased by gaze directional adaptation (Calder et al., 2007, 2008; Jenkins et al., 2006; Kloth & Schweinberger, 2008). That is, if a face that is looking 25° to the right is viewed for a prolonged period of time, and followed by another face looking 5° to the right, then that face will be misperceived as looking straight ahead. However, it is unlikely that the current studies in this thesis were influenced by adaptation effects as the stimuli were only presented for 150 ms at a time, and differed clearly by either direct gaze (0°), or averted gaze (30°).

Fourth, the current findings show that head direction strongly influenced gaze perception, but the inverse may also be true—that gaze direction influences head perception. In fact, research has shown that judgments of an agent's head direction are influenced by the perceived gaze direction of the head (Hudson & Jellema, 2011; Hudson et al., 2009). Thus, future research could examine how gaze direction affects head perception in the periphery using the current set of paradigms.

Fifth, these findings strongly support the idea of a general DAD mechanism; however, all of the studies in this thesis involved behavioural paradigms, without any neuroimaging techniques. This was done for a few reasons. It was unknown whether gaze could be accurately discriminated in the periphery, and it was important to examine the limit of eccentricity for gaze processing before any advanced (and expensive) neuroimaging techniques were employed. The use of functional magnetic resonance imaging (fMRI) may have been practical to test for a potential subcortical gaze detection mechanism, so future research could investigate this possibility. Additionally, event related potential (ERP) research may examine the temporal aspects of gaze detection, so future research could also examine the speed of gaze processing outside of foveal vision. Nevertheless, the current research was seminal in examining the visual limits of accurate gaze detection.

In sum, this PhD thesis was the first, to the best of my knowledge, to examine how gaze direction and head orientation affected gaze perception in both the horizontal and vertical periphery. Future research could use these same paradigms and examine a multitude of other factors that have been shown to affect gaze processing, including age (Slessor et al., 2008), gender (Goodman et al., 2012), culture and ethnicity (Akechi et al., 2013; Krämer et al., 2013), introversion/extraversion (Ponari et al., 2013), neuroticism (Helminen et al., 2011), social dominance (Fromme & Beam, 1974), empathy (Deladisma et al., 2007), stress (Rimmele & Lobmaier, 2012), trait anxiety (Wieser et al., 2009), mood state (Wyland & Forgas, 2010), alcohol consumption (Penton-Voak et al., 2011), oxytocin (Domes et al., 2007), female menstrual cycle (Wolohan et al., 2013), hearing one's own name while viewing faces (Stoyanova et al., 2010), attractiveness of facial stimuli (Kampe et al., 2001), familiarity of facial stimuli (Hoehl et al., 2012), emotional expression of facial stimuli (Bindemann et al., 2008), viewing real faces versus pictures of faces (Hietanen et al., 2008), or mental disorders, such as autism (Senju et al., 2005), social anxiety disorder (Schneier et al., 2011), schizophrenia (Tso et al., 2012), social phobia (Gamer et al., 2011), anorexia nervosa (Cipolli et al., 1989), and prosopagnosia (Campbell et al., 1990). Thus, future research could examine gaze perception in many different sample populations, which would give greater insight into how the human brain's cognitive mechanism functions to detect and discriminate eye gaze. The abundance of factors shown to influence gaze processing would allow researchers to explore how powerful this mechanism is, and through what potential brain pathways it operates.

5.5 Conclusions

We are enthralled by the eyes. From the moment of birth, we seem programmed to respond to our parents' eyes. Eye contact is intimate, persuading, intriguing, mesmerizing, and can have a magical effect on some people. Eye contact is fundamental to form and maintain interpersonal relationships, and we have developed an amazing ability to gaze back into the eyes of our beholders to gauge their feelings. These are major reasons why we are so attracted to the signals of eye gaze in our surroundings. Of course, human eyes are rarely seen without the context of a face, and the orientation of the head plays an important role to capture and influence attention, and to enhance the gaze signal. Overall, the data in this thesis support the idea that humans have a cognitive mechanism for detecting social attention cues that integrates both eye gaze and head orientation information, at least when viewed covertly, outside of foveal vision. Eye cues seem to play a more important role under focused attention, while head orientation seems to influence gaze perception beyond foveal view and especially in the periphery. This research is significant to the field of social cognition since eye contact and face processing play a fundamental role in everyday life, as these social cues convey important social information from the perceived individual. Future research could also examine these processes in order to better understand the physiological basis of the human visual system during visual search, or the basis of clinical disorders in which eye contact detection may be especially impaired, such as autism or social anxiety disorder.

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