Attentional Prioritisation of Another’s Direct Gaze:
Stimulus, Template, and Expectation

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This thesis is submitted for the degree of Doctor of Philosophy
To, The world
May we find our light in the darkest of nights
This thesis is the result of my own work and includes nothing which is the outcome of work done in collaboration except as specified in the text. It is not substantially the same as any work that has already been submitted before for any degree or other qualification. It does not exceed the prescribed word limit for the Biology Degree Committee.

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Abstract

Another’s direct gaze, a crucial social cue, is presumed to be attentionally prioritised even in the presence of other gazes. Consistent with this notion is the stare in the crowd effect (SITCE) — the finding that direct gazing eyes are often detected faster and more efficiently from among averted gazing ones than vice versa. An investigation of top-down influences on the SITCE, through pre-cues, revealed two dissociable effects, both in favour of direct gaze — one scaling with set size, unaffected by templates, and likely reflecting noisy parallel processing (Process 1), and the other, independent of set size, selectively applying prior knowledge to speed overall responses (Process 2) — taken as evidence for an obligatory direct gaze prior. Examination of initial saccade patterns to target gaze within this paradigm suggested ‘odd-one-out’ direct gaze does not attract exogenous attention — an averted gaze bias was revealed when task conditions highlighted gaze uniqueness, consistent with Predictive Coding models — rather, task goals may determine how expectation influences perception. Investigation of the mechanism underpinning gaze prioritisation in visual search found evidence for sophisticated socio-cognitive processing rather than simple feature-based templates — search for target eyes gazing at a salient object was more efficient than for eyes gazing away, the effect obscured by a pre-cue to target gaze. Finally, an exploration of whether autistic traits influence SITCE task performance revealed a similar tendency for individuals with higher autistic traits to preferentially select direct gaze targets over averted, both with and without top-down cues guiding attention, suggesting a propensity to apply direct gaze priors at least within the particular context of the SITCE. To conclude, findings from the present thesis reveal that a complex interplay of factors guides attentional prioritisation of direct gaze.
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Chapter 1. Introduction

1.1 Background and Relevance

Another’s eye gaze is a crucial source of social information, signalling where their attention is directed (vis-à-vis the observer) – either toward you (direct gaze) or away from you (averted gaze) – leading to differing consequences for one’s own behaviour in response to such gaze. Models for face processing, which incorporate gaze as an essential component, as well as more specialised conceptualisations of gaze processing, propose a special status accorded to direct gaze by human vision. This has received some support from both neurological and psychophysical evidence, particularly with respect to the crucial role direct gaze plays in both the initiation and maintenance of socio-cognitive interactions. Given that direct gaze signals attention toward the observer, potentially triggering its socio-cognitive appraisal, it is believed to be attentionally prioritised over gaze types in the visual environment — the starting point for this thesis.

Visual search for direct gaze situated among varying numbers of averted gaze eyes is often reported to be faster and more efficient than search for averted gaze eyes from among direct gaze ones. This Stare in the Crowd Effect (SITCE) offered, at first glance, a relatively straightforward task design to investigate the attentional effects of direct gaze, a high priority social stimulus, relative to those of averted gaze, also of social significance but less self-referential in nature. A review of previous literature on the SITCE, although generally revealing faster responses to direct gaze compared to averted, also revealed methodological inconsistencies across previous studies. By identifying and adopting the best of those practices (which appeared to minimise effects of confounding variables), the present studies sought to elucidate the underlying mechanisms that constitute the SITCE. Further aims were driven by findings from this basic optimisation of task parameters — using eye movements to index rapid initial attentional shifts in response to gaze stimuli within the SITCE paradigm, to answer whether direct gaze exogenously attracts attention; whether visual search for direct gaze is driven by a perceptual ‘template’ or whether it recruits more sophisticated socio-cognitive processes, such that a non-direct but contextually-salient target gaze might be preferentially selected from among other gazes; and, finally, whether individual differences in autistic traits could potentially reveal differences in how gaze stimuli are processed by individuals with higher autistic traits.

The next sections review the main themes that provide the theoretical foundations for this thesis and state the research questions formed on the basis of these.
1.2 Models for Face and Gaze Detection: Is there an Innate Bias?

The unique status of faces and eye gaze in human vision is supported by studies finding that, from birth, humans have a greater proclivity to follow faces/face-like stimulus than scrambled faces or inverted/reversed contrast faces (Goren, Sarty, & Wu, 1975; Farroni et al., 2005); although this preferential orienting declines around one month of age (Johnson, Dziurawiec, Ellis, & Morton, 1991), and reappears later in development (Shah, Happé, Sowden, Cook, & Bird, 2015). This visual bias in early infancy is extended to faces with open instead of closed eyes (Batki, Baron-Cohen, Wheelwright, Connellan, & Ahluwalia, 2000) and direct rather than averted gaze (Farroni, Csibra, Simion, & Johnson, 2002). In their influential two-stage model of face detection, Johnson and Morton (1991; Morton & Johnson, 1991; Johnson, Senju & Tomalski, 2015) proposed that this preferential orienting reflects, as a first process (termed ‘conspec’), an innate predisposition, subserved by sub-cortical pathways, to bias visual input in favour of face stimuli to still developing cortical pathways; which is unlikely to be due to alternative accounts such as low spatial frequency visibility of stimuli or the presence of complex face-processing mechanisms at birth. Support for a sub-cortical face-processing route in adults lies in studies which find that adults also preferentially orient to face-like stimuli (Tomalski, Csibra, & Johnson, 2009) and make rapid saccades to target faces (~ 100 ms; Crouzet, Kirchner, & Thorpe, 2010; Visconti & Gobbini, 2015), shorter than would be expected if controlled by cortical pathways (Schmolesky et al., 1998), and more indirectly, that faces are detected faster when presented among an array of other stimuli (such as houses and cars; Hershler & Hochstein, 2005) or in peripheral vision (Hershler, Golan, Bentin, & Hochstein, 2010), and delay detection of a non-face target when presented as distracters in a search array (Langton, Law, Burton, & Schweinberger, 2008). Research on adults finds that this sub-cortical route engages brain areas involved in threat detection (Costafreda, Brammer, David, & Fu, 2008; Luo, Holroyd, Jones, Hendler, & Blair, 2007) potentially suggesting an evolutionary basis for the conspec mechanism (Johnson et al., 2015).

The second process (conlern) is proposed to be driven by a more extensive network of brain regions involved in socio-cognitive functioning (e.g., Carlin & Calder, 2013; Calder et al., 2004; McCrackin & Itier, 2019), often referred to as the ‘social brain’, which accumulates face- and gaze-specific information to eventually develop specialisation for these stimuli. In support of this proposition is the finding that face and gaze biases are only apparent when stimuli have a positive contrast polarity (e.g., for eyes, a darker iris surrounded by lighter sclera; Ricciardelli, Baylis, & Driver, 2000; Tomalski, et al., 2009), suggesting that these
biases reflect a preferential orienting to stimuli of social and communicative salience. A key extension of the two-process theory is the fast-track modulator model, which proposes that eye contact is initially detected by a sub-cortical route which sends a task- and social-context-modulated signal to the social brain, which then influences cognitive and behavioural responses such as determining gaze direction, emotions, and intentionality (Senju & Johnson, 2009b). The watching eyes effects model (Conty, George, & Hietanen, 2016) similarly suggests that direct gaze triggers an important range of self-referential processes such as self-awareness (e.g., Carver & Scheier, 1978; Reddy, 2003), memory for faces (e.g., Mason, Hood, & Macrae, 2004), and pro-social behaviour (e.g., Rigdon, Ishii, Watabe, & Kitayama, 2009). The theory of mind model (ToMM; Baron-Cohen, 1994, 2005) also puts forth a similar proposition, and in some sense anticipates this idea of an innate direct gaze bias — proposing an innate mechanism to detect eyes (Eye Direction Detector, ‘EDD’) hypothesised to be a developmental building block for more complex behaviours such as gaze following and proto-declarative pointing (together called Shared Attention Mechanism, ‘SAM’), understanding of beliefs and intention (together known as Theory of Mind, ‘ToM’), and the detection and response to one’s own and others’ emotional states (i.e., empathising ability, called The Empathising System, ‘TESS’). The ToMM extends the evolutionary perspective to postulate that communication between members of a species, and social cognition in general, has been a central component in human evolution (e.g., Dunbar, 1998).

Given the emphasis placed on direct gaze in all the models discussed, a key question is whether direct gaze, specifically, constitutes an innate bias in human vision. Mareschal, Calder, and Clifford (2013) presented observers with a simulated face with varying degrees of certainty regarding eye direction, and found that in conditions of high uncertainty (noisy eye region), observers more often tended to report gaze as directly looking at them, and that this effect persisted when the head was laterally oriented away from observers. A follow-up study (Mareschal, Otsuka, & Clifford, 2014) found that this direct gaze prior existed regardless of head rotation; a head rotated away from observers representing greater visual uncertainty than a head facing observers. Interestingly, this direct gaze prior has been found to sharpen across development, such that younger children categorise a wider range of gaze uncertainties as direct gaze than older children do (Mareschal, Otsuka, Clifford, & Mareschal, 2016). A Bayesian model has been put forth by these authors to suggest that, in conditions of visual uncertainty, prior expectations bias gaze perception in favour of direct gaze, in line with an ecological perspective that the cost of missing direct gaze signals (such as threat) is higher than the risk of a false alarm (Mareschal et al., 2013, 2014).
Models of face and gaze perception suggest that there does exist an innate predisposition in humans to prioritise faces, more specifically direct gaze, according them greater priority when processing resources are (effectively) limited. These biases are likely the result of accrued evidence for the social consequences of these stimuli. Direct gaze, which is self-referential in nature, can thus be contrasted against averted gaze, which is directed away from the self. The next section examines whether the two gaze types are distinguishable in neurological and psychophysical terms.

1.3 Direct versus Averted Gaze: Are the two gaze types significantly different?

1.3.1 Neurological Evidence

The ability to distinguish between direct gaze and averted gaze is surely of singular adaptive value across species, particularly since a threat signal is only conveyed by direct gaze (Emery, 2000). In humans, the social consequences of direct gaze extend to observer-directed communicative intent, regulation of social interaction, and expression of social control (e.g., Kleinke, 1986; Senju & Csibra, 2008), while averted gaze tends to signal attention away from observers and towards other objects of social relevance in the environment (e.g., Csibra & Volein, 2008; Senju, Csibra, & Johnson, 2008). In general, gaze, arguably a high priority socio-cognitive stimulus, is found to activate the ‘social brain network’, which includes brain regions such as the prefrontal cortex, fusiform face area, superior temporal sulcus, and amygdala (e.g., Adolphs, 2009; Kanwisher, McDermott, & Chun, 1997; Nummenmaa & Calder, 2009; Reddy & Kanwisher, 2007; Wicker, Michel, Henaff, & Decety, 1998). Are the differing social outcomes for direct and averted gaze reflected as differences in activation patterns within this network?

Some evidence from functional neuroimaging suggests that this may be the case, particularly in regions involved in social orienting and face encoding. For example, it has been found that viewing direct gaze live (rather than a photograph) activates the left frontal cortex, which is implicated in the ‘approach’ brain system, relative to viewing averted gaze, which activates the right frontal cortex, linked to ‘avoidance’ motivation (Hietanen et al., 2008). Similarly, direct gaze has been found to generate stronger activity in regions of the amygdala, associated with face encoding and emotional responses respectively, while averted gaze leads to greater activation of the intraparietal sulcus, associated with peripheral attentional shifts (George, Driver, & Dolan, 2001). However, this same work also found that both direct and averted gaze led to activity in the fusiform gyrus, associated with face processing in general. Other studies also find similar activation patterns for both gaze types in the fusiform gyrus (Pageler et al., 2003) or, greater activation for averted gaze in the
amygdala (Hooker et al., 2003), again, reflecting that these brain regions may be more generally responding to gaze stimuli, since both gaze types are of relevance to social cognition. Evidence from Event Related Potential (ERP) studies is similarly mixed, with some studies finding larger amplitudes for direct gaze compared to averted for the face-sensitive N170 component (Burra, Baker, & George, 2017; Conty, N’Diaye, Tijus, & George, 2007), others only finding this when faces were live (Pönkänen, Alhoniemi, Leppänen, & Hietanen, 2010), not at all (McCrackin & Itier, 2019; Taylor, Itier, Allison, & Edmonds, 2001), or in the opposite direction (Puce, Smith, & Allison, 2000). Intriguingly, more recent research suggests that the N170 component may be modulated by top-down influences, perhaps reflecting prediction error processes rather than a stimulus-driven one (Johnston et al., 2017; Robinson, Breakspear, Young, & Johnston, 2018).

1.3.2 Psychophysical Evidence

Behavioural studies suggest that direct gaze, compared to averted, may enhance processing of faces across a range of socio-cognitive dimensions. For example, when presented with photographs of individual forward-facing faces, observers are faster to categorise the gender of direct gaze faces than averted or closed-eye ones, and also faster to categorise lexical strings as words when direct rather than averted gaze faces are presented as a prime (Macrae, Hood, Milne, Rowe, & Mason 2002). Similarly, direct gaze rather than averted is found to facilitate memory for person identity (Hood, Macrae, Cole-Davies, & Dias, 2003; Mason, Hood, & Macrae, 2004). Direct gaze is also found to facilitate emotion processing compared to averted — when presented individually, it speeds up responses to ‘approach’ emotions such as anger and joy and is perceived as more intense (Adams & Kleck, 2003, 2005), and within a visual search paradigm, speeds up target detection of faces with an emotional expression (Doi & Shinohara, 2013). Taken together, these studies suggest that gaze which is directed at observers, rather than away from them, facilitates person perception.

More specifically, there is evidence to suggest that direct gaze is preferentially processed by attention over averted gaze. Recent findings have reported generally faster response times (RTs) to direct gaze than averted within a visual search paradigm, despite gaze not being relevant to task, (Bockler, van der Wel, & Welsh, 2014; Boyer & Wang, 2018). Other findings also suggest that a centrally present direct gaze fixation stimulus is harder to disengage from than a non-direct (downward) one (Senju & Hasegawa, 2005) and slows saccadic latencies to a peripheral target (Ueda, Takahashi, & Watanabe, 2014). Within change blindness paradigms, changes to direct gaze are detected faster than changes to
averted (Lyyra, Astikainen, & Hietanen, 2018; Yokoyama, Ishibashi, Hongah, & Kita, 2011). Previous research also finds that peripherally presented direct and averted gazes are discriminable, while attentional resources are engaged in a centrally presented task, but that two averted gazes (left and right) are not, suggesting that direct gaze does not require additional attentional resources to be processed (Yokoyama, Sakai, Noguchi, & Kita, 2014). Studies that examine self-cueing by gaze find that direct gaze speeds express saccades to itself compared to averted gaze or houses (Mares, Smith, Johnson, & Senju, 2016) and, within a visual search paradigm, leads to greater fixations made overall to direct gazing faces than averted (Boyer & Wang, 2018). Averted gaze, on the other hand, is found to cue attention away from itself, speeding up responses to peripheral targets presented in the cued at direction and slowing responses to targets in the opposite direction (e.g., Driver et al., 1999; Friesen & Kingstone, 1998; Galfano et al., 2012; Slessor, Finnerty, Papp, Smith, & Martin, 2019) and leading to reflexive saccades in the gazed at direction despite task instructions not to (Ricciardelli, Bricolo, Aglioti, & Chelazzi, 2002).

Although these studies reflect differing behavioural effects between direct and averted gazes, they do not offer evidence of whether direct gaze is attentionally prioritised when placed in direct visual competition with averted gaze, a test that would be more representative of direct gaze’s reported attention grabbing properties with respect to averted gaze. The ‘Stare in the Crowd Effect’ (SITCE; Senju, Hasegawa, & Tojo, 2005; von Grünau & Anston, 1995) offers such a test of relative attentional priority for gaze — the phenomenon where direct gaze targets are detected faster and more efficiently from among averted gaze distracters than averted gaze targets are from among direct gaze distracters within a visual search paradigm.

1.4 The Stare in the Crowd Effect

1.4.1 Rationale and Underlying Assumptions in Visual Search

Visual search tasks typically ask observers to detect the presence of a target, if present (usually on half of all trials) from among distracters. The time taken to make a response (i.e., RT) tends to increase linearly with the number of items present on the search display (i.e., the ‘set size’). Search efficiency – the increase in RTs to a target as a function of set size – is considered to be the standard measure of visual search, and searches have classically been distinguished on the basis of the slope of this function. Shallower slopes have traditionally been thought to reflect parallel search in which a single attentional glance suffices to select the target from among distracters, while steeper slopes have been seen to represent serial processing such that attention moves from one (group of) element(s) to the next until a target
decision is made. The relationship of the target absent to target present slope, in particular, has been suggested as a marker of type of search task – a 2:1 ratio believed to characterise serial, self-terminating search (Treisman & Gelade, 1980) – although later investigations into this claim reveal that this ratio varies as a function of both search efficiency and the nature of the search task, whether feature or conjunction (Wolfe, 1998). The initial suggestion of a strict dichotomy between these two types of searches (Treisman & Gelade, 1980) has thus evolved into the notion of a search continuum, ranging from highly efficient search, characterised by flatter slopes (of the order of 10-20 ms/item), to highly inefficient search, characterised by steeper slopes (of the order of 40-50 ms/item, or greater), which might be produced as a result of purely serial or parallel mechanisms, or some combination of both (e.g., Liesefeld, Moran, Usher, Müller & Zehetleitner, 2016; Wolfe, 1998). Thus, while slope per se may serve as a useful distinguishing index between serial and parallel searches, serial and parallel models may always be designed to mimic the behaviour of the other, and a more thorough picture of visual search patterns is often gained from examining the RT x set size interaction.

Von Grünau and Anston (1995) were the first to investigate the SITCE, their innovation lying in applying the basic search format to social stimuli. They presented schematic cartoon eyes randomly distributed across the search display and found that direct gazing targets were detected faster from among averted (both left and right) gazing distracters than averted gazing targets were from among direct and opposite gaze distracters, and that the increment in RTs as the number of display elements increased (i.e., the RT x set size function) was greater for averted gaze targets. At the time of their study, visual search literature was primarily focussed on identifying which basic visual features would capture and guide attention efficiently to allow for target detection and selection. Treisman and Gormican (1988), in their classic paper, investigated stimulus dimensions such as orientation, colour, and texture, and identified which end of a dimension was coded faster by the visual system — for example, a tilted line segment, relative to a vertical line segment, would be coded as having an additional visual feature (the deviation in orientation) and thus could be identified pre-attentively when placed among vertical line segments, but the opposite would not hold true, as detecting the absence of a visual feature would not generate the requisite attention-grabbing activity in the visual system (e.g., Treisman & Souther, 1985). This selection difference between features within the same dimension formed the foundation for visual search asymmetry tasks, with the underlying principle being that a difference in attentional selection would point to the relative attentional priority a particular feature is given by the visual system. For non-social stimuli such as lines, shapes, and colours, this
difference in attentional prioritisation often results in search ‘pop-out’, the phenomenon where a target feature is preferentially coded by the visual system compared to the distracter feature (often thought to be processed in parallel) such that search for a target from among a greater number of distracters is no slower than from among fewer distracters, i.e., the search slope is flat (e.g., Nagy, & Sanchez, 1990). In the case of the SITCE, a search for social stimuli, Von Grünau and Anston (1995) based their predictions on the understanding that direct gaze, as the socially more salient gaze type, could be expected to be preferentially coded by the visual system compared to averted gaze, thus resulting in more efficient search for direct gaze targets over averted.

1.4.2 Models of Visual Search

Simple search for very basic visual features, such as pop-out search, is highly efficient and often believed to reflect parallel processing such that all items in a visual display are simultaneously processed to detect target presence or absence. Treisman and Gelade’s (1980) original Feature Integration Theory suggested that while search for simpler features, or a feature search (e.g., red circle from among green circles), could be detected in parallel, search for more complex targets which were a combination of distracter features, or a conjunction search (e.g., red circle from among green circles and red squares), engaged serial search mechanisms such that each item would be individually scanned to determine target presence, thus resulting in steeper search slopes as the number of display elements increased and when a target was absent as compared to present (2:1 ratio in the case of the latter). Later models of visual search were updated to include ideas such as serial searching through groups of display items which are processed in parallel within their groups (Pashler, 1987) and search efficiency decreasing as function of target-distracter similarity (Duncan & Humphreys, 1989). The influential Guided Search Model (Wolfe, Cave, & Franzel, 1989; Wolfe, 1994, 2007) proposes a two-stage model — the first stage, a parallel mechanism, represents the items in the search display on a feature saliency map and passes this information on to a serial attentional ‘bottleneck’ which filters target saliency on the basis of guidance from both bottom-up activation and top-down input. The key aspect of this model is the coordination between bottom-up effects (perceptual saliency) and top-down ones (prior knowledge of target) to create an activation map which will guide attention to targets. A strict dichotomy between serial and parallel search mechanisms, however, is now seen to be redundant (e.g., Wolfe, 2002). In the case of the SITCE certainly, the complexity of the stimuli involved makes it unlikely to reflect pure parallel search and the current consensus is that either strategy could be engaged depending on task factors (Eimer, 2014). Newer conceptualisations
1.4.3 Visual Search for Gaze

Following the original investigation of the SITCE, Senju, Hasegawa, and Tojo (2005) examined this effect using laterally averted photo-realistic stimuli to control for lower-level confounds of symmetry that forward-facing direct gaze stimuli are susceptible to. Although they were able to replicate the original finding (Senju, Hasegawa, & Tojo, 2005, Experiment 1) — direct gaze was detected faster and more efficiently from among averted and downward gazes than averted gaze was from among the two distracter types — their study raised some methodological concerns. First, as in the original study, they used two types of averted gaze stimuli, rendering the possibility that direct gaze was detected faster not on the basis of its social salience but on the basis of better discriminability from among visually similar distracters. Second, of the three experiments in that study, only one reported both a main effect of gaze direction and an interaction with set size, the other two only reported a main effect, setting the stage for a lack of consensus on what effects constitute the SITCE. Cooper, Law, and Langton (2013) addressed the idea that the SITCE may be a product of the target-distracter relationship rather than an attention grabbing property of direct gaze itself — when direct and averted gazes were isolated and presented among equated distracters, whether homogenous or heterogeneous, the search efficiency advantage for direct gaze was not found, although results were less clear as to attention-grabbing abilities when direct and gazes were presented as homogenous distracters among other gaze types. Although that study was clear on its stance of what would constitute the SITCE (both a main effect and an interaction with set size), it did not, however, investigate direct gaze from among a distracter set of only one averted gaze direction (and vice versa) and had sclera-iris ratio inconsistencies in the eye regions of the stimuli used. Conty Tijus, Hugueville, Coelho, and George (2006) did investigate direct gaze from among homogenous averted gaze distracters, finding a main effect but no interaction with set size, however, those stimuli also had confounds with respect to unequal eye regions between gaze types — the larger area of sclera for those direct gaze stimuli compared to averted may well have supported their more rapid search without any need to process them as eye gaze. A second alternative to the ‘Direct Gaze Salience’ view was suggested by Framorando, George, Kerzel, and Burra (2016) — faster responses to direct gaze targets over averted only emerged when processing gaze was relevant to the task (gaze and gender categorisation), otherwise not (finding the odd-one-out gaze), which the authors
proposed was evidence for the SITCE being a product of task demands. Although that study raised the relevant question of how task goals might influence the SITCE, their stimuli were forward-facing and the study did not investigate the effect of set size. Other investigations of the SITCE have used forward-facing stimuli (Senju, Kikuchi, Hasegawa, Tojo, & Osanai, 2008) or used laterally averted stimuli but did not present these around an imaginary circle, as all studies other than the original had done, and did not investigate set size (Doi & Ueda, 2007; Doi, Ueda, & Shinohara, 2009). Despite there being a lack of standardisation with respect to stimuli used and investigations of set size effects, previous literature on the SITCE revealed one interesting methodological conformity (with the exception of Framorando et al., 2016), with respect to the presentation of direct and averted target gazes within the visual search task — only one target gaze type presented within each block of trials, inadvertently setting up a top-down expectation for upcoming targets.

Thus, a review of the previous literature investigating the SITCE had revealed both methodological inconsistency and consistency, which provided a clear methodological goal for this thesis.

1.4.4 Gaze Cueing Effects

Another’s visual attention serves as a powerful cueing tool to orient observers’ attention, allowing for a refocussing of attention to those aspects of the visual environment which are socially or behaviourally most salient. This attentional orienting may either be overt, in the form of rapid eye movements known as saccades, or covert, where attention is oriented without accompanying eye movements. Gaze cueing paradigms, built on the foundations of the Posner cueing task (Posner, 1980) have revealed the now classic finding that observers are faster to detect targets when cues, both arrows and (averted) eye gaze, congruently indicate target location rather than incongruently (e.g., Driver et al., 1999; Friesen, Ristic, & Kingstone, 2004; Ricciardelli et al., 2002; Quadflieg, Mason, & Macrae, 2004; Tipples, 2002). Such gaze cueing effects may have potential implications for the SITCE — both in terms of observers responding to target gazes as perceptually salient cues rather than socio-cognitively encoding stimuli as eye gaze, and also in terms of rate of search through distracter sets. Particularly in the case of distracter sets, i.e., target absent trials where all gazes present on the search display are of only one type, it may be that observers are slower to search through a group of direct gazing eyes (a target absent trial for averted gaze) due to difficulties with attentional disengagement (e.g., Senju & Hasegawa, 2005), than a group of averted gazing eyes (a target absent trial for direct gaze) which more readily cue attention away, thus rendering the direct gaze target advantage observed in the SITCE (a
concern voiced by Cooper et al., 2013). The present thesis also aimed to answer these questions.

1.5 Autistic Traits and Gaze Processing

Autism Spectrum Disorder (ASD) is a neurodevelopmental condition characterised by difficulties with social interaction and communication, and restricted interests (American Psychiatric Association, 2013). Both observation of early childhood behaviour, retrospective (Osterling & Dawson, 1994; Osterling, Dawson, & Munson, 2002) and longitudinal (e.g., Zwaigenbaum et al., 2005), and experimental evidence (e.g., Dalton et al., 2005; Jones & Klin, 2013; Moriuchi, Klin, & Jones, 2017; Nakano et al., 2010; Senju, Tojo, Yaguchi, & Hasegawa, 2005) suggest that difficulties with gaze processing, particularly direct, are a defining feature of this developmental condition; although it must be noted that evidence is not unequivocal (e.g., Elsabbagh, Gliga et al., 2013; Neumann, Spezio, Piven & Adolphs, 2006). This idea motivates the theoretical standpoint that direct gaze is processed atypically by either sub-cortical or cortical feedback pathways (i.e., the conspec mechanism), thus leading to reduced learning of its consequences by the social brain (Senju & Johnson, 2009a).

The ToMM (Baron-Cohen, 1994, 2005), while it acknowledges difficulties with eye contact and dyadic representations, implicates the mentalising components, ToM and TESS, in atypical gaze processing — suggesting that difficulties arise because individuals with ASD do not derive the same social meaning from direct gaze, i.e., are unable to ‘read the mind’s eye’, as it were. The social motivation theory (Chevallier, Kohls, Troiani, Brodkin, & Schultz, 2012) posits that reduced social experiences in early life lead to a cascade effect of impaired social development, creating a negative reinforcement cycle such that those with ASD are less socially motivated to engage with gaze stimuli.

Evidence from functional neuroimaging finds fair support for the notion that brain areas involved in social attentional processing show atypical functioning in individuals with higher autistic traits (e.g., Dalton et al., 2005; Kleinhans et al., 2008; Pierce, Müller, Ambrose, Allen, & Courchesne, 2001; Nummenmaa, Engell, Von Dem Hagen, Henson, & Calder, 2012) as does evidence from ERP studies which tend to find that viewing direct gaze generates atypical activity (e.g., Kylliäinen et al., 2012; Lauttia et al., 2019). Evidence from gaze cueing paradigms, an index of shared attentional ability, finds that individuals with ASD are able to show reflexive orienting to gaze cues (e.g., Kylliäinen, & Hietanen, 2004; Swettenham, Condie, Campbell, Milne, & Coleman, 2003), although it has been suggested that this apparently intact response may mask a general insensitivity as to the social meaning of such cues, given that individuals with ASD were found to be equally likely to orient to
non-gaze cues (e.g., Chawarska, Klin, & Volkmr, 2003; Ristic et al., 2005; Senju, Tojo, et al., 2005). Similarly, although recent findings suggest that a direct gaze prior may be intact in higher functioning individuals with ASD (Pell et al., 2016), this does not negate the possibility that such priors may be less influential in more real-world situations that call for greater social engagement (Dubey Ropar, & Hamilton, 2015; von dem Hagen & Bright, 2017).

Although higher autistic traits are predictive of superior search abilities, this has most clearly been found with non-social stimuli (e.g., Plaisted, O’Riordan, & Baron-Cohen, 1998; O’Riordan, 2004). Despite some support for relatively intact detection of threatening faces from among arrays of other faces (Ashwin, Wheelwright, & Baron-Cohen, 2006; Krysko, & Rutherford, 2009), evidence is less clear with photo-realistic face stimuli (Farran, Branson, & King, 2011). Of the two studies that have directly compared attentional prioritisation of gaze, i.e., the SITCE, one found a similar tendency for individuals with ASD to demonstrate the effect when stimuli were forward-facing faces (Senju Kikuchi et al., 2008), while the other found this not to be the case when stimuli were laterally averted (Senju, Hasegawa et al., 2005); which, it was suggested might imply difficulties with configural face processing in autistic populations rather than with direct gaze itself. Given the small number of studies investigating this, it remains unclear whether autistic traits influence the preferential processing of direct gaze in visual search.

1.6 Research Questions

1.6.1 Question 1: What effects constitute an SITCE?

A review of previous SITCE literature had highlighted important areas for consideration in understanding the underlying mechanisms driving the SITCE. As a crucial first step, the SITCE task design would first need to be optimised and stimuli well-controlled for to obtain both effects that are known to represent general visual search findings – a main effect (in this case of target gaze type) and an interaction with set size – as had been found in the original study. Chapters 2 and 3 addressed this issue.

1.6.2 Question 2: Do top-down influences play a role in the SITCE?

A literature review on the SITCE had also highlighted an as yet unexplored, but potentially interesting, role of top-down influences on this effect. Previous studies had, inadvertently, set up some manner of top-down influence but this had not been explored in a systematic manner. Chapter 4 investigated how the predictability of top-down cues might influence the SITCE.
1.6.3 Question 3: Does direct gaze attract exogenous attention within the SITCE paradigm?

Previous research, both neurological and psychophysical, provides some evidence for the prioritisation of direct gaze over averted, however its possible attention-grabbing ability within the context of the SITCE has not yet been explored. If this were to be the case, it would go some way in explaining underlying mechanisms in the phenomenon. The simplest index of an ‘attentional pull’ would be initial saccades made to one gaze type over the other. Chapter 5 attempted to answer whether direct gaze attracts exogenous attention when placed within the SITCE paradigm.

1.6.4 Question 4: Is visual search for gaze driven by perceptual ‘templates’ or explicit social processing?

The underlying principle on which the SITCE is based is the greater social salience of direct gaze versus averted gaze, vis-à-vis the observer. A logical follow-up question is whether this effect might simply be stimulus based, reflecting a fixed visual template for direct gaze, or, instead, whether it might reflect more sophisticated coding of gaze-object relations such that any contextually salient gaze type (even non-direct) could be attentionally prioritised from among other gazes. To this end, Chapter 6 studied the visual search for eyes gazing at a contextually salient object versus eyes gazing away.

1.6.5 Question 5: Do individual differences in autistic traits influence gaze processing in the SITCE?

The dearth of studies investigating whether autistic traits influence SITCE task performance, thereby indicating potential differences in direct gaze processing, motivated the final research aim of this thesis, examined in Chapter 7.

All the experiments conducted were approved by the University of Cambridge Psychology Research Ethics Committee.
Chapter 2. The Elusive Stare in the Crowd Effect

1. Introduction

Direct gaze is a salient social signal, signalling communicative intent (Senju & Johnson, 2008) and complex mental states such as emotions and intention (Senju & Johnson, 2009b), and thus would be expected to be attentionally prioritised even in the presence of other faces. This idea forms the underlying principle for the stare in the crowd effect (SITCE), a phenomenon where unique direct gaze targets are often detected faster and more efficiently from among averted gaze distracters than vice versa (e.g., Conty, Tijus, Hugueville, Coelho, & George, 2006; Senju, Hasegawa, & Tojo, 2005; von Grünau & Anston, 1995). The attentional prioritisation of direct gaze stimuli from among other simultaneously presented gazes superficially resembles the search asymmetry for lower-level, basic visual features such as orientation and luminance, for which stimuli of greater salience capture attention in parallel processing of those features (e.g., Treisman & Gormican, 1980; Wolfe & Horowitz, 2004). Thus, as many studies have presumed, it may be the case that the SITCE reflects the attention-capturing properties of direct gaze in parallel processing (e.g., Conty et al., 2006; Senju, Hasegawa, & Tojo, 2005; von Grünau & Anston, 1995). However, others have suggested the effect may be an artefact of stimulus confounds (Cooper, Law, & Langton, 2013) or otherwise enhanced target processing not as a result of guidance by gaze (Framorando et al., 2016).

In the original investigation of the SITCE, von Grünau and Anston (1995) presented schematic cartoons of direct gazing eyes among left and right averted gazing distracters positioned randomly on the search display. Correspondingly, averted gaze targets, whether left or right gazing, were detected from among two types of distracters (direct gaze and opposite-direction averted gaze). Thus, the advantage in detecting direct gaze over averted found in that study may well have been a result of better target discriminability for direct gaze from among visually similar distracters, a shortcoming that is applicable to later studies too (e.g., Senju, Hasegawa, & Tojo, 2005, Senju, Kikuchi et al., 2008). In addition, since gaze stimuli were simple cartoons as opposed to being photo-realistic, observers may not have attributed the same degree of social meaning to them. Later studies did use photographic stimuli, some presenting faces around an imaginary circle, either forward-facing (Senju, Kikuchi et al., 2008, Experiment 2; Framorando et al., 2016) or laterally oriented (Senju, Hasegawa, & Tojo; Cooper et al., 2013), and some presenting stimuli cropped to just the eye region and placed randomly on the display, as in the original study (Conty et al., 2006). Thus, there have been a broad range of stimuli used in the SITCE literature.
Previous studies also reveal a distinct lack of consensus on what findings would constitute an SITCE — merely a faster recognition of direct gaze or the attentional guidance of direct gaze. In visual search tasks behavioural performance is distinguishable from the underlying cognitive processes. Within the SITCE paradigm, the manipulation of gaze direction may affect response times in two respects — as a function of set size and independent of set size. First, the extent to which direct gaze speeds up RTs may be affected by the number of items in a search display (the ‘set size’, e.g., von Grünau & Anston, 1995), typically found for inefficient search such as that for gaze. If the manipulation of gaze direction were to yield larger increments in RTs as set size increases, i.e., a positive search ‘slope’, this would be consistent with the idea that gaze influences the search process; either in parallel, such that direct gaze items are attended to earlier in the search process, or in serial, such that each item is searched through quicker. Second, gaze direction may influence RTs independent of the number of display items, which can reflect efficient parallel processing in very efficient search, but is more likely to reflect a non-search process, such as decision criteria for target presence, in the search for gaze. Either of these effects has been considered as reflecting the SITCE in previous studies — some studies did not manipulate the number of items in a search display (i.e., set size; Framorando et al., 2016; Doi & Ueda, 2007; Doi, Ueda, & Shinohara, 2009) or did not report the influence of gaze direction on manipulating set size (Conty et al., 2006), instead only reporting faster RTs to direct gaze as the SITCE, while others reported effects that scaled with set size only (e.g., Cooper et al., 2013; Senju, Hasegawa, & Tojo, 2005, Experiment 1; Senju, Kikuchi et al., 2008).

Another potentially relevant aspect of the SITCE task is whether top-down variables influence the effect. The majority of previous studies have presented only one type of target gaze within a set block of trials (e.g., Conty et al., 2006; Cooper et al., 2013; Senju, Hasegawa, & Tojo, 2005; Senju, Kikuchi, et al., 2008; von Grünau & Anston, 1995), meaning that observers would have been able to build a reliable top-down expectation for the gaze direction of the target (direct or averted) in each subsequent search display. Only one study (Framorando et al., 2016), to the best of my knowledge, has presented both target gazes within the same block of trials, however, that study did not investigate the effect of set size. It may be the case that the SITCE entirely relies on target predictability, but it may also be that the effect operates in a stimulus-driven manner regardless of top-down expectations, either possibility being consistent with previous findings.

The aim of the experiments here was to develop an optimised task design for the SITCE. Experiment 2.1 presented cropped forward-facing stimuli around an imaginary circle,
with both types of target gaze within a given block of trials (and, in each case, only one type of distracter gaze), i.e., observers would not have been able to set up any kind of expectation for upcoming targets. Experiment 2.2a presented laterally oriented faces in the same format as Experiment 2.1, while Experiment 2.2b presented laterally oriented faces with only target gaze type within each block of trials. All experiments investigated the effect of set size and evidence for the SITCE was determined a priori to be both faster responses to direct gaze targets over averted (i.e., main effect) and more efficient search for direct gaze targets over averted (i.e., RT x set size interaction).
2. Experiment 2.1: In search of the SITCE

2.1 Methods

The aim of this experiment was to demonstrate the presence of an SITCE (i.e., faster and more efficient search for Direct Gaze targets compared to Averted) using novel stimuli. Previous studies on the SITCE, with one possible exception (Framorando et al., 2016), have all presented the same target gaze type within each block of trials (e.g., Conty et al., 2006; Cooper et al., 2013; Senju, Hasegawa, & Tojo, 2005; von Grünau & Anston, 1995). As only one type of target gaze was presented in each block, observers would have known, prior to search displays appearing, which target gaze to search for. It may be the case that the SITCE entirely relies on this predictability. However, in the present experiment, both Averted and Direct target gazes were intermixed and presented within the same block. Were the SITCE to operate in a stimulus-driven manner, rather than rely on observers’ top-down expectations, we would still expect to see effects with the present task design. Thus, here, two effects were expected — a main effect of Target Gaze, such that Direct Gaze targets are detected faster than Averted, and an interaction with Set Size, such that search for Direct Gaze targets is more efficient than Averted.

2.1.1 Power Analysis and Sample Size

Observers were recruited as part of a larger experiment (discussed in Chapter 7). Fifty-three university students were recruited from an existing database and an online volunteer recruitment system. For the purposes of the present experimental analysis, a within-subjects Repeated Measures Analysis of Variance (RM ANOVA) with eight measurements, a power analysis (G*Power 3.0 software; Faul, Erdfelder, Lang, & Buchner, 2007) suggested that 16 observers would provide 80% power to detect medium-sized effects (Cohen’s $f = 0.25$). From the larger sample, 18 observers ($m = 7, f = 11$, ages 18-35) were assigned to the present analysis. Based on their Autism Spectrum Quotient questionnaire (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) scores, observers were designated ‘middle AQ’ (AQ scores 16–27). Observers were compensated £10 for participating.

2.1.2 Apparatus and Stimuli

The visual search task was presented on E-Prime 2.0 software (Psychology Software Tools Inc., 2013) on a 21.5-inch Dell monitor (model number P2414HB, screen resolution 1920 x 1080). Observers were seated roughly 70 centimetres from the screen and made responses via a standard USB keyboard. Search displays consisted of oval-cropped forward-facing faces looking either directly at (direct gaze, Figure 1A) or to the left of the observer (averted gaze, Figure 1B). To create these images, a photograph of a neutral female face
gazing forwards was taken and converted to greyscale to create the direct gaze stimuli. This image was kept as the template onto which the eye region from a similar image of the model gazing to the observer’s left was superimposed to create the averted gaze stimuli. Additionally, the eye region from a similar image of the model’s eyes closed was superimposed to create the placeholder stimuli.

Each individual face fit roughly within an area of 110 x 150 pixels and subtended a visual angle of 2°5’ x 3°4’. As far as possible, individual stimulus dimensions were matched to those of previous studies (e.g., Cooper et al., 2013; Senju, Hasegawa, & Tojo, 2005; Framorando et al., 2016). Faces were arranged in set sizes of either 7 or 13 around an imaginary circle (258 mm diameter approximately) centred on the centre of the visual display and presented against a uniform black background.

2.1.3 Procedure

Figure 1C shows a schematised sequence of displays in a search trial. Each trial began with a brief (250 ms) presentation of placeholder stimuli (faces with eyes closed). These stimuli differed from the subsequently presented stimuli only in eye region, thus giving the naturalistic impression of faces opening their eyes. The placeholder stimuli were included to enhance the relative signal-to-noise ratio of the eye gazes in the search arrays. Previous work has presented faces with their eyes already opened (e.g. Senju, Hasegawa, & Tojo, 2005; Senju, Kikuchi et al., 2008), however, this would have meant the simultaneous onset of open-eye faces (including transient signals from other facial features which tend to misdirect attention) from among which observers would have had to detect task-relevant gaze signals. The addition of placeholder stimuli in these, and subsequent, experiments described in this thesis should have minimised those effects by presenting potentially distracting facial features prior to the eye stimuli themselves, allowing observers to focus their attention on the eyes in particular.

When the eye gaze of the faces was revealed (in the search display) observers searched the display to find a Direct Gaze target from among Averted Gaze distracters, or an Averted Gaze target from among Direct Gaze distracters. On half of all trials a target gaze was present (i.e., odd-one-out) and on the remaining trials no target was present. Observers were instructed to search for the target (defined as the odd-one-out gaze) and make a keyboard response if the target was present (“P”) or not (“Q”) as quickly and accurately as possible. The search display terminated when a response was made.

The visual search task began with a practice block (40 trials, 5 trials of each unique combination) where observers received feedback for their responses (“Correct!” = correct
response, “------” = incorrect response). This was followed by the main experimental blocks (240 trials, presented in two blocks with a 10 second break in between them) for which observers did not receive any feedback. Within each block, half of all trials had a Direct Gaze target and half Averted and half of all trials were presented at Set Size 7 and half at Set Size 13. While all observers saw the same trials per block, these were presented in a pseudo-random order.

As part of the larger study, observers completed a second visual search task (with line stimuli). Those data are summarised in Table 1, but are not discussed further.

Figure 1. A) Direct Gaze stimulus, B) Averted Gaze stimulus, C) Schematised sequence of displays in a typical trial from Experiment 2.1 (Set Size 7, Direct Gaze Target, T = target location).
2.1.4 Results and Discussion

Figure 2. Mean Response Times (accuracy rates in parentheses) for Averted and Direct Gaze Targets, separately at Set Sizes 3 and 7 for Experiment 2.1. Error bars indicate +/-1 SEMpaired diffs.

For each observer (N=18), RT data for accurate responses (M=96.58, SD=2.10) were trimmed to exclude any RTs ±3 standard deviations (for each combination of Target Gaze, Target Presence and Set Size). Figure 2 plots the within-observer mean RTs for each Target Gaze at each Set Size. RTs at Set Size 13 appeared slower than Set Size 7 for both Target Gaze types. Unexpectedly, the plot suggested that Averted Gaze targets were not only detected faster than Direct Gaze ones but also more efficiently (reflected in larger RT increments from Set Size 7 to 13 in Direct Gaze trials compared to Averted).

A three-way repeated measures (RM) ANOVA with factors of Target Gaze (Averted Gaze, Direct Gaze), Target Presence (Present, Absent), and Set Size (7, 13 items) confirmed a main effect of Target Gaze [F (1, 17) = 6.778, p = .019, $\eta_p^2 = .285$] in the opposite direction to that predicted — RTs to Averted Gaze targets were faster than to Direct Gaze. Main effects for Target Presence [F (1, 17) = 113.429, p < .001, $\eta_p^2 = .870$] and Set Size [F (1, 17) = 63.655, p < .001, $\eta_p^2 = .789$], however, were in expected directions: RTs to Target Present trials were faster than to Target Absent and RTs to Set Size 7 trials were faster than to Set Size 13. The key measure of search efficiency, the interaction between Target Gaze and Set Size, was significant [F (1, 17) = 6.192, p = .024, $\eta_p^2 = .267$], again contradicting the initial prediction, such that RT increments from Set Size 7 to 13 were larger for Direct Gaze Target trials. The interaction between Target Presence and Set Size was also significant [F (1, 17) =
52.654, \( p < .001, \eta_p^2 = .756 \), i.e., RT increments from Set Size 7 to 13 were larger for Target Absent trials, as found in previous SITCE studies (e.g., Conty et al., 2006; Senju, Hasegawa, & Tojo, 2005), and would be expected in inefficient search of this kind. The three-way interaction between Target Gaze, Target Presence, and Set Size was marginally significant \([F (1, 17) = 3.752, p = .070, \eta_p^2 = .181]\), however, there had been no predictions for this and thus this was not investigated further.

A corresponding analysis of accuracy revealed only a main effect of Target Presence \([F (1, 17) = 27.103, p < .001, \eta_p^2 = .615]\). No other main effects or interactions were significant (all F values < 2.595, all p values > .126).

Thus, Experiment 2.1 had not been able to demonstrate the SITCE. Instead, a reverse effect was found where Averted Gaze Targets were detected faster and more efficiently than Direct. It was clear that the present stimuli suffered from shortcomings — they were forward-facing, thus more susceptible to physical differences between eye gazes, and were not well-controlled for the sclera-iris ratio between Averted and Direct gazes. Thus, it is likely that observers had not been able to code the stimuli as eye gaze and were simply responding to the light-dark contrast. Experiment 2.2 sought to establish (with newly designed laterally averted stimuli) an SITCE and investigate whether task design played a role in the effect.

<table>
<thead>
<tr>
<th>Target Type</th>
<th>Set Size 7</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Set Size 13</th>
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<th></th>
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<tbody>
<tr>
<td>Vertical</td>
<td>( M = 889.07, SD = 190.49 )</td>
<td>( M = 821.76, SD = 169.86 )</td>
<td>( M = 902.96, SD = 301.73 )</td>
<td>( M = 1005.58, SD = 336.96 )</td>
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<tr>
<td>Tilted Lines (18 degrees left)</td>
<td>( M = 740.31, SD = 130.67 )</td>
<td>( M = 763.56, SD = 148.86 )</td>
<td>( M = 723.59, SD = 118.77 )</td>
<td>( M = 859.76, SD = 183.03 )</td>
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*Table 1.* Mean Response Times for Vertical Line and Tilted Line Targets (second visual search task that observers completed as part of Experiment 1)
3. Experiment 2.2: Does task design play a role in the SITCE?

3.1 Methods

The aim of these experiments was to establish an SITCE with newly designed stimuli that minimised sclera-iris ratio differences between Averted and Direct Gaze stimuli. Additionally, the potential role of task design in the SITCE was investigated. Experiment 2.2a presented Averted and Direct Gaze targets in an intermixed manner within the same block of trials, as in Experiment 2.1. If the SITCE operates irrespective of observers’ top-down expectations, we would expect to find this effect even when observers are not able to predict upcoming targets — odd-one-out gaze information should suffice to guide search. Alternatively, it may be the case that the SITCE only emerges when observers are able to make a clear prediction about upcoming target gaze. Experiment 2.2b tested this assumption by presenting the same target gaze type within each block of trials.

3.1.2 Power Analysis and Sample Size

A power analysis suggested that 32 observers (16 in each study) would provide sufficient power to detect medium-sized effects (Cohen’s $f = 0.25$) for a within-between RM ANOVA with eight measurements. Observers for this study ($m = 13, f = 19$, ages 18-35) were recruited from an existing database and an online volunteer recruitment system and compensated £7 for their time.

3.1.3 Apparatus and Stimuli

The testing apparatus was as described for Experiment 2.1. There, having found a SITCE in the opposite direction when stimuli were forward-facing, cropped faces, it was surmised that those eyes were not being coded as gaze; instead observers had likely responded to the light-dark contrast. In the present experiments, following Senju, Hasegawa, and Tojo (2005), stimuli were faces (comprising head and shoulders) averted approximately 45 degrees to the left of the observer with either direct gazing or averted gazing eyes. Importantly, direct gaze was achieved by the iris moving to one side and averted gaze by the iris moving to the other, by roughly the same amount (Figure 3A and 3B). To construct these images, a photograph of a neutral female face gazing towards the camera (hence, from the observer’s perspective, gazing towards them) was converted to greyscale first. Next, this direct gaze image was used as the template onto which eye regions from similar averted gaze and eyes closed photographs were superimposed to create the averted gaze and placeholder stimulus respectively. Each individual face fit roughly within an area of 200 x 200 pixels, subtending a visual angle of $4^\circ 5' \times 4^\circ 5'$. Face stimuli were arranged around an imaginary circle (258 mm diameter approximately) centred on the centre of the visual display and
presented against a uniform black background. Faces in Set Size 7 were arranged in one configuration while those in Set Size 3 were arranged in three different, roughly equally spaced, configurations to avoid grouping in any one part of the display.

![Figure 3](image)

*Figure 3. A) Direct Gaze stimulus, B) Averted Gaze stimulus, C) Schematised sequence of displays in a typical trial from Experiment 2.2 (Set Size 3, Direct Gaze Target, T = target location).*

### 3.2 Experiment 2.2a: Mixed Design

The aim of this experiment was to investigate whether the SITCE was observed when observers had no specific gaze information for the upcoming target, instead only being given information that the target would be the odd-one-out gaze.

#### 3.2.1 Procedure

Each individual trial procedure was the same as Experiment 2.1. The search task began with a practice block (20 trials, with 5 trials of each unique combination) where observers received feedback (“Correct!” = correct response, “------” = incorrect response),
followed by the main experimental blocks for which observers did not receive any feedback. The main task was presented in 4 blocks of 60 trials each, with 10s breaks between blocks. Within each block, half of all trials had a target present while the other half did not, half of all targets were Averted Gaze and half Direct Gaze, and half of all trials were presented at Set Size 3 and half at Set Size 7. Each observer saw the same trials per block but these were presented unpredictably.

3.2.2 Results and Discussion

![Figure 4. Mean Response Times (accuracy rates in parentheses) for Averted and Direct Gaze Targets, separately at Set Sizes 3 and 7 for Experiment 2.2a. Error bars indicate +/-1 SEM](image)

For each observer (N=16), RT data for accurate responses (M= 95.38, SD= 3.31) were trimmed as before. Visual inspection of Figure 4 did not suggest that there was much difference in RTs between searching for Averted Gaze and Direct Gaze Targets at either Set Size. A three-way ANOVA, in the same format as earlier, revealed main effects for Target Presence \([F(1, 15) = 18.911, p < .001, \eta_p^2 = .558]\) and Set Size \([F(1, 15) = 82.370, p < .001, \eta_p^2 = .846]\) in the expected directions: RTs to Target Present trials were faster than to Target Absent and RTs to Set Size 3 trials were faster than to Set Size 7. However, the main effect for Target Gaze was not significant \([F(1, 15) = 1.031, p = .326, \eta_p^2 = .064]\). The standard Target Presence x Set Size interaction was found \([F(1, 15) = 20.304, p < .001, \eta_p^2 = .575]\), indicating that the new stimuli had worked. However, the Target Gaze x Set Size interaction was not \([F(1, 15) = .441, p = .517, \eta_p^2 = .029]\), confirming impressions from the initial plot inspection.

A corresponding analysis of accuracy showed main effects for Target Presence \([F(1, 15) = 6.241, p = .025, \eta_p^2 = .294]\) and Set Size \([F(1, 15) = 9.389, p = .008, \eta_p^2 = .385]\), but not
for Target Gaze $[F(1, 15) = .733, p = .405, \eta^2_p = .047]$. The Target Presence x Set Size $[F(1, 15) = 15.374, p = .001, \eta^2_p = .506]$ and Target Gaze x Set Size $[F(1, 15) = 13.537, p = .002, \eta^2_p = .474]$ interactions were also significant.

Overall, Experiment 2.2a suggested the absence of a traditional SITCE, i.e., a main effect for Target Gaze and its interaction with Set Size.

### 3.3 Experiment 2.2b: Blocked Design

Experiment 2.2b investigated whether predictability of upcoming targets was a key component in being able to demonstrate a SITCE.

#### 3.3.1 Procedure

The trial procedure was as in Experiment 2.2a. The search task for each gaze target type began with a practice block (20 trials, with 5 trials of each unique combination) where observers received feedback (in the same manner as for Experiment 2.2a), followed by the main experimental blocks for which observers did not receive any feedback. The main search task was presented in 4 blocks of 60 trials each, with 10s breaks between blocks. The first two blocks (120 trials) were of one gaze target type and the next two blocks (120 trials) of the opposite gaze target. The order of which gaze type was seen first was counterbalanced across observers. Within each block, half of all trials had a target present while the other half did not, and half of all trials were presented at Set Size 3 and half at Set Size 7. All observers saw the same trials per block and these were presented in a pseudo-random order.

#### 3.3.2 Results and Discussion

![Figure 5](image)

*Figure 5. Mean Response Times (accuracy rates in parentheses) for Averted and Direct Gaze Targets, separately at Set Sizes 3 and 7 for Experiment 2.2b. Error bars indicate +/-1 SEM.*

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<thead>
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<th>Key Results:</th>
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<tbody>
<tr>
<td>1. Target Gaze: $p = .138$</td>
</tr>
<tr>
<td>2. Target Gaze x Set Size: $p = .042$</td>
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</tbody>
</table>
For each observer \((N = 16)\), RT data for accurate responses \((M = 97.28, SD = 1.69)\) were trimmed as before. One observer was removed because their RTs exceeded the exclusion criterion. Visual inspection of Figure 5 suggested that any advantage for detecting Direct Gaze targets was at Set Size 7. A three-way ANOVA revealed significant main effects for Target Presence \([F (1, 14) = 81.950, p < .001, \eta_p^2 = .854]\) and Set Size \([F (1, 14) = 196.254, p < .001, \eta_p^2 = .933]\) in the expected directions, but no main effect for Target Gaze \([F (1, 14) = 2.480, p = .138, \eta_p^2 = .150]\), as in Experiment 2.2a. The standard Target Presence x Set Size interaction was present \([F (1, 14) = 38.935, p < .001, \eta_p^2 = .736]\). The Target Gaze x Set Size interaction \([F (1, 14) = 8.297, p = .012, \eta_p^2 = .372]\) was significant, such that RT increments from Set Size 3 to 7 were larger for Averted Gaze Targets.

Additionally, a marginal three-way interaction was found \([F (1, 14) = 3.169, p = .097, \eta_p^2 = .185]\), but was not investigated further as it did not fit the primary goal of this experiment.

A corresponding analysis of accuracy revealed significant main effects for Target Presence \([F (1, 14) = 31.573, p < .001, \eta_p^2 = .693]\), Set Size \([F (1, 14) = 9.217, p = .009, \eta_p^2 = .397]\), and Target Gaze \([F (1, 14) = 6.788, p = .021, \eta_p^2 = .327]\). Interactions for Target Presence x Set Size \([F (1, 14) = 9.801, p = .007, \eta_p^2 = .412]\) and Target Gaze x Target Presence \([F (1, 14) = 7.677, p = .015, \eta_p^2 = .354]\) were also observed, but not for Target Gaze x Set Size \([F (1, 14) = .027, p = .871, \eta_p^2 = .002]\).

Experiment 2.2b had found some evidence for a SITCE, i.e., the Target Gaze by Set Size interaction, when each block consisted of only one kind of target. However, a main effect of Target Gaze had not been observed.

### 3.4 Combined Analysis

To investigate whether differences in task design influenced the SITCE, as planned, a combined analysis was run for both experiments. A four-way ANOVA was run with Experiment as a between-subjects factor, and within-subjects factors as before. This analysis revealed that the between-subjects term of Experiment was not significant \([F (1, 29) = 1.689, p = .204, \eta_p^2 = .055]\). The main effects of Target Presence \([F (1, 29) = 76.891, p < .001, \eta_p^2 = .726]\) and Set Size \([F (1, 29) = 227.449, p < .001, \eta_p^2 = .887]\) were significant but there was only a marginal effect for Target Gaze \([F (1, 29) = 3.615, p = .067, \eta_p^2 = .111]\). The key Target Gaze x Set Size interaction was only marginally significant \([F (1, 29) = 3.809, p = .061, \eta_p^2 = .116]\) and was not affected by differences in Experiment condition \([F (1, 29) = .663, p = .442, \eta_p^2 = .022]\). The Target Presence x Set Size interaction was also found \([F (1, 29) = 2.480, p = .138, \eta_p^2 = .150]\).
Attentional Prioritisation of Another’s Direct Gaze

\(29) = 53.215, p < .001, \eta^2_p = .647\). No other interaction terms were significant (all F values < .663, p values > .422) other than a marginal four-way interaction \(F(1, 29) = 3.574, p = .069, \eta^2_p = .110\). However, that was outside the scope of this combined analysis, which had been to see whether differences in search efficiency between gaze types was affected by differences in task design, which appeared not to be the case here.

The aim of this set of experiments had been to investigate, first, whether the new stimuli were able to lead to an SITCE in the expected direction and, second, whether the SITCE relied on the ability of observers making a top-down prediction about the target’s gaze. Experiment 2.2a presented target gazes randomly within a block such that observers were unable to make an expectation about target gaze, instead relying on a finding the odd-one-out strategy. This task manipulation certainly seemed to suggest a lack of the SITCE as evinced by the absence of both the main effect and the interaction term. Experiment 2.2b presented each target gaze type within a block, allowing observers to have a clear expectation about the target’s gaze in each upcoming trial. This manipulation did lead to relatively more efficient search slopes for direct gaze targets compared to averted, however, the lack of a main gaze effect suggested this was not a pure SITCE in a standard understanding of the effect.

Did these results mean that task design, specifically, predictability of target gaze, plays a crucial role in the SITCE? With the current evidence, this was not a conclusion could be made:

1. There was no evidence for the SITCE in the mixed design version of the task. And although the interaction term had been found in the blocked version of the task, the main effect of target gaze had been absent, which did not fit the predetermined effects set as evidence for the SITCE. This suggested that the new stimuli used here had been only somewhat successful in generating an SITCE.

2. A combined analysis for both experiments did not show any main effect or interactions with the between-subjects factor of Experiment, thus suggesting that differences in task design had not led to clear differences in responses to task.
4. Discussion

The goal of the present set of experiments had been to develop an optimised task design for the SITCE. Experiment 2.1 presented forward-facing gaze stimuli with both gaze types appearing in the same block of trials. Results for that experiment were, unexpectedly, in the opposite direction to that predicted — a reverse of the SITCE, as it were. It was surmised that this was most likely to have been due to low-level stimulus confounds as forward-facing gazes would have been more susceptible to differences in symmetry between direct and averted gazes, apart from the fact that the stimuli themselves were not well-controlled for the sclera-iris ratio across gazes. In Experiments 2.2, laterally averted stimuli were used which better controlled for stimulus confounds. Experiment 2.2a investigated whether mixed target presentation within the same block would lead to a SITCE and found that it did not. Experiment 2.2b presented only one target gaze type within a block and found that search slopes to Direct Gaze targets were shallower than to Averted but did not find a main effect of Target Gaze direction. Despite some evidence that the laterally averted stimuli could lead to the SITCE (in the expected direction), some problems with task design still persisted — the stimuli were likely too small, not fully allowing observers to represent the gaze directions accurately, and the blocked design conflated target repetition with target predictability. It was thus not possible to draw any firm conclusions that differences in task design between Experiments 2.2a and 2.2b had an influence on the SITCE, apart from the power limitations inherent in a between-subjects design. Thus, the aim for the next set of experiments was twofold — to optimise task stimuli for the SITCE (Chapter 3) and investigate, more concretely, the role of predictability of target gaze in this effect (Chapter 4).
Chapter 3. Finding the SITCE

1. Introduction

Previous studies investigating the SITCE have used a wide range of stimuli and tasks, as well as differing interpretations of the effect, thus making it difficult to pinpoint which of their SITCE results were due to genuine gaze processes and which due to stimulus/task confounds. The aim of the experiments in Chapter 2 had been to optimise both stimuli and task parameters, but had only partially succeeded in doing so. The laterally averted stimuli used there had minimised differences between direct and averted gaze stimuli, other than a left-right asymmetry, to which search processes are not usually sensitive. However, those stimuli had been too small, demonstrating some evidence for the SITCE but not both effects that had been expected (Experiment 2.2b). Thus, the first goal in this chapter was to demonstrate the presence of the SITCE, both as a main effect of gaze and an interaction with set size, using larger stimuli which should better allow observers to interpret the stimuli as gaze. Experiment 3.1 presented larger stimuli, with only one gaze type within a block of trials, in the same manner as Experiment 2.2b and the majority of previous studies investigating the SITCE (e.g., Cooper et al., 2013; Senju, Hasegawa, & Tojo, 2005, Senju, Kikuchi et al., 2008). As in the previous chapter, evidence for the SITCE was determined to be both faster responses and shallower search slopes to direct gaze targets over averted. Further experiments to more concretely explore the role of target predictability in gaze detection were planned for the next chapter, thus no mixed design of target presentation was included here.

Previous work on the SITCE has not typically assessed whether the gaze stimuli employed were robust to low-level non-gaze effects. For example, the stimuli employed by Conty and colleagues (2006) did not control for the sclera-iris ratio across direct and averted gazes – direct gaze stimuli had a larger area of sclera compared to averted – which may well have supported the more rapid search for direct gaze stimuli that study found, bypassing gaze processing entirely. To preclude any stimulus confounds here (and in subsequent experiments) in generating an SITCE and exploring its components, it was crucial to include a control condition in which gaze coding was disrupted but key task elements remained the
same. In the gaze search literature, this has typically involved inverting the eye or face stimulus (e.g., Senju & Hasegawa, 2006; Senju, Hasegawa, & Tojo, 2005; Senju, Kikuchi et al., 2008, Experiment 2), while in the non-search gaze literature this has involved reversing the contrast polarity of the just the eye region (Senju & Hasegawa, 2005) or reversing the contrast polarity of the faces themselves (Ricciardelli, Baylis, & Driver, 2000; Ricciardelli, Betta, Pruner, & Turatto, 2009). Experiment 3.2 presented observers with both standard contrast and reversed polarity contrast versions of the same task as Experiment 3.1. If the SITCE were to rely on low-level differences between direct and averted gaze stimuli, we would expect the effect to hold even in the reversed contrast polarity condition. However, if the SITCE relies on gaze processing, we would not expect to not see any effects in this condition.
2. Experiment 3.1: The SITCE

2.1 Methods
Experiment 3.1 sought to establish an SITCE using larger stimuli to better allow observers to process them as gaze. Both a main effect of Target Gaze and an interaction with Set Size were expected here.

2.1.1 Power Analysis and Sample Size
As in Chapter 1 experiments, a power analysis suggested that 16 observers would suffice to power a medium-sized effect (Cohen’s d = 0.25) for a within-subjects RM ANOVA with eight measurements (G*Power 3.0 software; Faul, et al., 2007). The present experiment tested 17 observers (m = 5, f = 12, ages 18-35), having booked a person extra. Observers were recruited as before and compensated £7.50 for their participation.

2.1.2 Apparatus, Stimuli, and Procedure
The laterally averted stimuli used in Chapter 2 were enlarged such that each individual face fit within an area of roughly 279 pixels$^2$, subtending a visual angle of approximately 6° 3’ x 6° 3’ (Figure 1A and 1B). The apparatus and procedure were the same as that in Experiment 2.2b (Figure 1C shows a schematic display of trial procedure).

Figure 1. A) Direct Gaze stimulus, B) Averted Gaze stimulus, C) Schematised sequence of displays in a typical trial from Experiment 3.1 (Set Size 7, Direct Gaze Target, T = target location).
2.1.3 Results and Discussion

![Figure 2: Mean Response Times (accuracy rates in parentheses) for Averted and Direct Gaze Targets, separately at Set Sizes 3 and 7 for Experiment 3.1. Error bars indicate +/-1 SEMpaireddiffs.](image)

For each observer (N=17), RT data for accurate responses (M=96.69, SD=2.45) were trimmed in the standard manner. Visual inspection of Figure 2 suggested that, as expected, RTs were faster when detecting Direct Gaze and that this advantage got somewhat bigger at the larger set size. A three-way, RM ANOVA, with factors of Target Gaze (Direct Gaze, Averted Gaze), Target Presence (Present, Absent) and Set Size (3, 7), yielded significant main effects of Target Gaze \( F(1, 16) = 6.192, p = .024, \eta_p^2 = .279 \), Target Presence \( F(1, 16) = 62.779, p < .001, \eta_p^2 = .797 \), and Set Size \( F(1, 16) = 141.795, p < .001, \eta_p^2 = .899 \) in the expected directions: Direct Targets were detected faster than Averted, Target Present trials were faster than Target Absent, and responses in Set Size 3 trials were faster than Set Size 7.

The standard two-way interaction between Target Presence and Set Size \( F(1, 16) = 45.146, p < .001, \eta_p^2 = .738 \) was observed. The Target Gaze by Target Presence interaction was not significant \( F(1, 16) = .448, p = .513, \eta_p^2 = .027 \). Contrary to expectations, the two-way interaction between Target Gaze and Set Size was only marginal \( F(1, 16) = 3.309, p = .088, \eta_p^2 = .171 \).

Corresponding analyses of accuracy yielded a main effect of Target Presence \( F(1, 16) = 22.078, p < .001, \eta_p^2 = .580 \) and a marginal effect of Set Size \( F(1, 16) = 4.405, p = .052, \eta_p^2 = .216 \), following the RT patterns. No main effect of Target Gaze \( F(1, 16) = 2.901, p = .108, \eta_p^2 = .153 \) or significant interactions were noted, though the Target Gaze by
Target Presence interaction was marginal \( F(1, 16) = 4.531, p = .049, \eta^2_p = .221 \). Again, following the RT patterns the Target Presence by Set Size interaction was significant \( F(1, 16) = 5.976, p = .026, \eta^2_p = .272 \).

Experiment 3.1 had thus established the presence of the SITCE using novel stimuli, for faces that were laterally-verted, and for displays comprising only one kind of distracter per display, and for blocks of trials that comprised only one type of target and one type of distracter.
3. Experiment 3.2: SITCE with Reversed Contrast Polarity

3.1 Methods

Experiment 3.2 had two primary aims. First, to establish whether the overall RT advantage observed in Experiment 3.1 was reliable, and to gather further evidence on whether the marginal Target Gaze by Set Size interaction there was a real effect. Second, to assess whether any such effects could be ascribed to local shape and contrast elements of the images, rather than coding of gaze per se. Experiment 3.2, therefore, replicated the conditions of Experiment 3.1 twice, within the same observers — once with standard face stimuli and once with the images’ contrast polarity reversed to disrupt gaze processing.

3.1.1 Sample Size

On the basis of the previous sample, 17 new observers ($m = 6, f = 11$, ages 18-35) were recruited in the same manner as before, and compensated £10.

3.1.2 Apparatus, Stimuli, and Procedure

The apparatus and the standard face stimuli were the same as in Experiment 3.1. To create the reverse contrast stimuli, the polarity of the standard stimuli was inverted, such that dark regions (e.g., iris) became light, and light regions (e.g., sclera) became dark (Figure 3A and 3B). While negative contrast eyes retain the low-level physical and spatial properties of standard contrast eyes, the reversal of light and dark regions changes high-level viewer judgments about where the eyes are gazing. This manipulation reversed the contrast polarity of both the stimuli and their luminance relative to the background, to control for confounds that could arise from the magnitude of luminance contrasts between one or more elements of the stimulus and background. In non-search literature, reversed contrast polarity eyes have been successfully used to disrupt gaze processing (Ricciardelli et al., 2000; Ricciardelli et al., 2009). Thus this condition was included as a control of whether the SITCE is a low-level effect (in which case we would find a difference in detecting Direct versus Averted gaze, despite a change in polarity) or not.

The procedure was the same as Experiment 3.1 except for the addition of a fixation cross prior to the placeholder stimuli (250 ms), as it was felt that trials were perceptually better demarked from one another by the addition of a fixation cross rather than placeholder stimuli alone (Figure 3C). With the addition of the reversed contrast stimuli, the total number of trials doubled to 480. The order of seeing the two types of Contrast stimuli (Standard Contrast and Reversed Polarity Contrast, presented as two separate search tasks of 240 trials each) as well as the order of seeing the two types of Target Gaze (Direct and Averted, presented as in Experiment 1), were counterbalanced across observers.
3.1.3 Results and Discussion

Figure 3. A) (Reversed) Direct Gaze stimulus, B) (Reversed) Averted Gaze stimulus, C) Schematised sequence of displays in a Reversed Contrast Polarity trial from Experiment 3.2 (Set Size 3, Direct Gaze Target, T = target location).
Figure 4. Mean Response Times (accuracy rates in parentheses) for Averted and Direct Gaze Targets, separately at Set Sizes 3 and 7 for the (A) Standard Contrast condition and (B) Reverse Contrast Polarity condition of Experiment 3.2. Error bars indicate +/-1 SEM_{paired diffs}.

For each observer (N= 17), RT data for accurate responses (M= 97.35, SD= 1.91) were trimmed in the standard manner. One observer had to be excluded because even post trim, their RTs fell outside 3 standard deviations of the group mean. Analysis was as for Experiment 3.1, but with the addition of a new factor, Contrast Polarity (Standard, Reverse). Visual inspection of the plots suggested the presence of an SITCE for the Standard Polarity but not Reverse Contrast Polarity condition, as had been predicted. These impressions were confirmed in a four-way RM ANOVA that yielded main effects of Contrast Polarity [F (1, 15) = 21.504, p < .001, \(\eta_p^2 = .589\)], Target Gaze [F (1, 15) = 5.706, p = .030, \(\eta_p^2 = .276\)], Target Presence, [F (1, 15) = 25.147, p < .001, \(\eta_p^2 = .626\)], and Set Size [F (1, 15) = 87.731, p < .001, \(\eta_p^2 = .854\)], all in the expected directions. As in Experiment 3.1, the Target Presence by Set Size interaction was significant [F (1, 15) = 27.232, p < .001, \(\eta_p^2 = .645\)], a classic visual search finding. In addition, the interactions of Contrast Polarity with Set Size [F (1, 15) = 30.372, p < .001, \(\eta_p^2 = .669\)] and with Target Presence [F (1, 15) = 9.918, p = .007, \(\eta_p^2 = .398\)] were also significant , as was the Target Gaze by Target Presence one [F (1, 15) = 6.043, p = .027, \(\eta_p^2 = .287\)]. There were also marginal interactions between Contrast Polarity, Target Presence, and Set Size [F (1, 15) = 3.979, p = .065, \(\eta_p^2 = .210\)], and between Target Gaze, Target Presence, and Set Size [F (1, 15) = 3.211, p = .093, \(\eta_p^2 = .176\) . Crucially, however, there was a three-way interaction between Contrast Polarity, Target Gaze, and Set
To reveal the source of the main three-way interaction, two two-way ANOVAs for each Contrast Polarity condition were run. The Standard Contrast condition ANOVA yielded both a main effect of Target Gaze \( F(1, 15) = 12.635, p = .003, \eta^2_p = .458 \) and a Target Gaze by Set Size Interaction \( F(1, 15) = 12.908, p = .003, \eta^2_p = .463 \), strongly showing evidence of Direct Gaze advantages. In sharp contrast, the Reverse Contrast condition showed neither of these effects — main effect of Target Gaze \( F(1, 15) = .564, p = .464, \eta^2_p = .036 \), the interaction with Set Size \( F(1, 15) = .915, p = .354, \eta^2_p = .057 \).

An accuracy analysis yielded a main effect of Target Presence \( F(1, 15) = 32.036, p < .001, \eta^2_p = .681 \) an interaction between Target Presence and Set Size \( F(1, 15) = 5.906, p = .028, \eta^2_p = .282 \), but no other evidence of main effects or interactions that would go against the RT analysis (all \( F \) values < 2.561, \( p > .130 \)).

Experiment 3.2 greatly strengthened evidence for two types of effects involving search for gaze direction. In the Standard Contrast condition, strong evidence for a Direct Gaze advantage was found — a main effect of Target Gaze in favour of Direct Gaze targets and a Target Gaze by Set Size interaction such that the search slopes when searching for Direct Gaze targets were shallower (more efficient) than when searching for Averted Gaze. If such effects had indeed reflected subtle differences in local visual elements making up those stimuli (direct gaze stimuli always differ from averted gaze stimuli in terms of low-level features) rather than gaze coding per se, we would have expected to see the same patterns in the Reverse Contrast condition. No such effects were seen, suggesting that the direct gaze biases (SITCEs) observed reflected coding of gaze direction in those stimuli (highly disrupted by contrast reversal).
4. Discussion

The aim of the present chapter had been to optimise the task design and stimuli to be used in subsequent experimental investigations in this thesis. Experiment 3.1 first established an SITCE, using large laterally averted faces (with direct and leftward averted gaze) arranged in a circle, that could not readily be ascribed to stimulus confounds (e.g., Conty et al., 2006) or potential issues with using multiple distracter types (e.g., Senju, Hasegawa, & Tojo, 2005; Senju, Kikuchi et al., 2008). Experiment 3.2 replicated these conditions and included, within the same observers, a reversed contrast polarity condition. The markedly different findings in these two conditions strongly suggested that the SITCE observed was not a function of simple contrast features in the images (which were preserved but inverted in the control condition), but rather of gaze perception (greatly disrupted by the manipulation).
This chapter has been published as part of the following paper:

**Chapter 4. The Influence of top-down target templates on the SITCE**

**1. Introduction**

With the foundation in place for two observable effects when searching for eye gaze, the aim of this next chapter was to investigate the influence of top-down target templates on SITCE performance. With the possible exception of Framorando et al. (2016), a review of the SITCE literature revealed no studies that directly studied the role of top-down influences on this effect. Although that study did not manipulate set size, and suffered from stimulus confounds associated with forward-facing faces, it did highlight the potentially important role of top-down variables in the SITCE. Experiments 2.2a and 2.2b had attempted to investigate whether top-down variables played a role in the SITCE, however, that design had been between-subjects and had conflated target repetition with target predictability.

The experiments here sought to more explicitly elucidate the role of top-down trial-by-trial predictions. Within each block of trials some targets were direct gaze, others averted gaze, in a random, unpredictable order. However, in some blocks of trials, a pre-cue at the beginning of each trial signalled in a reliable (predictive) or unreliable (nonpredictive to varying extents) manner whether the subsequent target was direct or averted gaze — i.e., allowing or not allowing the formation of a top-down search template for a particular gaze direction. By comparing performance across predictive cue blocks and nonpredictive cue blocks, the present experiments sought to reveal those aspects of the SITCE that reflect observers’ top-down target templates, i.e., internal representations that guide attention toward targets and speed recognition of those items (e.g., Goldstein & Beck, 2018; Berggren & Eimer, 2018). While bottom-up, stimulus-driven or otherwise fixed, processes of priming (Theeuwes, 2013), and patterns of targets/nontargets across trials (e.g., Geng, DiQuattro, & Helm, 2017) were equivalent in the predictive and nonpredictive cue conditions, the potential to pre-specify, top-down, the exact nature of the target item was enhanced in the predictive cue conditions.

The conceptual distinction between set-size-dependent and -independent effects is relevant empirically in terms of the possible effects of predictive cues. Establishing a top-down target template would be expected to have either, or both, of two effects — biasing
attention toward elements in an array that match the template and/or speeding decisions about target presence. The influence of the former effect on RTs would be expected to scale with the number of items in a display, thus affecting search slope. However, the latter effect may speed responses in a way that need not scale with set size. Different models of visual search may conceive of these effects differently. Irrespective of whether top-down templates do or do not scale with set size, some basic views of top-down processing and the SITCE make differing predictions for expected effects:

1. **General Enhancement** — If top-down templates for gaze processing work in the same manner as they do for other visual stimuli, we should expect general performance enhancement following a reliable cue as to the next target’s identity. Simply, a cue to expect a direct gaze target will speed up responses to direct gaze targets and a cue to expect an averted gaze target will similarly speed responses to averted gaze targets. This need not affect the magnitude of the SITCE.

2. **SITCE Reduction** — If the SITCE reflects a tendency for observers to adopt a default template for direct gaze, and one that can be influenced or counteracted by top-down target templates, we should expect to find that the SITCE is reduced by predictive cues. If a default direct gaze template operated even in the absence of predictive cues, a cue to establish that same direct gaze template should benefit performance little. In contrast, a cue to establish a template to search for averted gaze should benefit performance more, reducing the performance gap between direct and averted gaze targets (the SITCE).

3. **Flexible SITCE Increase** — If top-down templates for gaze were to operate in a cue-predictability-dependent manner (e.g., Conci, Müller, Geyer, 2018), the magnitude of the SITCE would be modulated by observers’ ability to make predictions about the reliability of the cue. Thus, for example, if cues were reliable on only 20% of trials, this would lead to weak/no effect of the SITCE, whereas if cues were reliable on 80% of all trials this would lead to a stronger effect.

4. **Inflexible SITCE Increase** — If top-down templates were to operate like a fixed Bayesian prior for direct gaze (e.g., Mareschal et al., 2013, 2014), i.e., a fixed bias toward processing direct gaze that is applied regardless of whether observers attempt to establish a target template for direct or averted gaze, we could expect predictive cues to increase the magnitude of the SITCE in an all or none fashion. In contrast to a flexible SITCE increase, only 100% reliable cues would increase
the magnitude of the SITCE, while differing degrees of cue predictability, whether 20% or 80%, would all be treated as unreliable.

Experiment 4.1 examined the influence of 100% predictive versus nonpredictive pictorial cues when searching for target gaze, while Experiment 4.2 examined the influence of 80% predictive versus 20% predictive pictorial cues. Experiment 4.3 investigated the influence of 100% predictive versus nonpredictive semantic cues, while Experiment 4.4 was a replication of 4.3.
2. Experiment 4.1: The Influence of Predictive Pictorial Cues on the SITCE

2.1 Methods

To investigate the influence of (100% valid) top-down target templates on SITCE performance, observers were presented with pictorial cues that informed them, prior to each search display, which target gaze they would be asked to search for. This new manipulation required a change to the task — within each block of trials, trials with direct gaze targets and trials with averted gaze ones were now mixed. They were presented in a pseudo random order, such that, in the absence of a cue, observers could not predict which type of target they would next be asked to search for. The search task thus consisted of two types of blocks of trials — blocks in which trials contained non-predictive cues prior to the display, providing a baseline performance for observers, and blocks in which 100% valid cues signalled, at the beginning of each trial, which type of target observers would have to search for. In these latter blocks of trials, observers could confidently establish a single top-down search template in each trial to improve their search performance.

2.1.1 Observers and Sample Size

An average effect size of $\eta_p^2 = .317$ for the key Target Gaze x Set Size interaction (based on the experiments in Chapter 3) suggested that 16 participants would suffice to power the interaction. However, since that effect had been variable and the present experiment aimed to investigate a higher-order interaction, with four factors in the experiment, the sample size was increased to 20 observers ($m = 9, f = 11$, ages 18-35, sample size estimated using PANGEA software, jakewestfall.shinyapps.io/pangea). Observers were recruited an online volunteer recruitment system and compensated £10.

2.1.2 Apparatus, Stimuli, and Procedure

All aspects of methods were as for Experiment 3.2 (Standard Contrast condition) with the following exceptions. As detailed above, trials with Direct Gaze targets and trials with Averted Gaze targets were now randomly intermixed within the same blocks. Prior to each placeholder and search display, a cue was now presented (see Figure 1 for Direct Gaze example). This cue was an image of the eye region of an Averted or Direct Gaze target, with a cross underneath (200 pixels$^2$, subtending a visual angle of approximately $4^\circ 5' \times 4^\circ 5'$). In Predictive Cue blocks the cue reliably predicted which of two targets observers would have to search for. In Nonpredictive Cue blocks, the cue comprised no predictive information as to the likely gaze direction of the target – half the trials had a Congruent cue (i.e., Direct Gaze target preceded by Direct Gaze cue) and half had an Incongruent cue (i.e., Direct Gaze target preceded by Averted Gaze cue).
preceded by Averted Gaze cue). The run order of these blocks was counterbalanced across observers. Observers were instructed to pay attention to cue information in the Predictive cue condition, but ignore this information in the Nonpredictive Cue condition. Each cue condition was presented as one search task, consisting of 240 trials presented in 5 blocks, with 10 second breaks between blocks. Each trial was any one of a combination of Target Gaze (Direct or Averted), Target Presence (Present or Absent), and Set Size (3 or 7); and observers saw 30 trials of each unique combination. Within each block, all observers encountered the same trials, but these were presented in a pseudo-random order that differed across observers.

Figure 1. Schematised sequence of displays in a typical trial from Experiment 4.1 (Set Size 7, Direct Gaze Target, Predictive Cue, T = target location).
2.1.3 Results and Discussion

Figure 2. Mean Response Times (accuracy rates in parentheses) for Averted and Direct Gaze Targets, separately at Set Sizes 3 and 7 for (A) Predictive Cue condition and (B) Nonpredictive Cue condition of Experiment 4.1. Error bars indicate +/- 1 SEM_paired differences.

For each observer (N= 20), RT data for accurate responses (M= 94.67, SD= 4.09) were trimmed for each combination of Target Gaze, Target Presence, and Set Size, within each Cue Predictiveness condition. Figure 2 plots mean RTs for each Set Size and Target Gaze, separately for Predictive Cues (Figure 2A) and Nonpredictive Cues (Figure 2B). Visual inspection of the plots suggested that there was a tendency toward a shallower search slope for Direct Gaze than Averted Gaze Targets for Nonpredictive cues, whereas for Predictive Cues the advantage appeared to take the form of a general advantage for Direct Gaze Targets,
irrespective of Set Size. A four-way RM ANOVA with the factors Cue Predictiveness (Predictive, Nonpredictive), Target Gaze (Direct Gaze, Averted Gaze), Target Presence (Present, Absent) and Set Size (3, 7) clarified which of these effects were reliable. There were main effects of Target Gaze \(F(1, 19) = 17.445, p = .001, \eta^2_p = .479\], Target Presence \(F(1, 19) = 16.903, p = .015, \eta^2_p = .471\], and Set Size \(F(1, 19) = 116.505, p < .001, \eta^2_p = .860\] as expected, as also the expected Target Presence by Set Size interaction \(F(1, 19) = 28.538, p < .001, \eta^2_p = .600\]. Though the interaction between Target Gaze and Set Size was marginal \(F(1, 19) = 3.151, p = .092, \eta^2_p = .142\], the corresponding pattern in accuracy scores \(F(1, 19) = 4.428, p = .049, \eta^2_p = .189\] and in the previous experiments in Chapter 3, bolstered the assumption that this was a genuine effect.

Most importantly, a two-way interaction between Cue Predictiveness and Target Gaze \(F(1, 19) = 7.217, p = .015, \eta^2_p = .275\] was observed — the advantage for Direct Gaze versus Averted Gaze Targets was greater in the Predictive Cue condition than the Nonpredictive. This interaction, however, was not reliably influenced by Set Size \(F(1, 19) = 1.424, p = .247, \eta^2_p = .070\]. No other two-way or three-way interactions were significant (all F values ≤ 1.424, p > .247). Thus, contrary to impressions from visual inspection of the plot, Cue Predictiveness did not reliably alter the two-way interaction between Target Gaze and Set Size. On the basis of this one null result, there could be no confidence that there was no effect, as opposed to a small, undetected effect to which the data were insensitive. However, there was initial evidence that the set size dependent and set size independent components of the SITCE were differently affected by Cue Predictiveness — any numerical trend in the data was toward Predictive Cues reducing the Target Gaze x Set Size interaction, and, in contrast, significantly increasing the main effect of Target Gaze.

The use of pictorial cues in this experiment presented a potential complication with regard to interpretation. In the Predictive cue blocks, the cue always was physically similar to the target, whereas in Nonpredictive cue blocks, it was only so on half of the trials. In principle, therefore, the effects of cues on the SITCE may have been the result of perceptual priming of the target by the cue, which would benefit responses for all trials of Predictive cue blocks, but only half those of Nonpredictive cue blocks, yielding a benefit. However, anticipating this possibility prior to running the experiment, a planned supplementary analysis was run to rule this out, which would also serve to demonstrate that the effect was not due to masking by the cue. First, from the Nonpredictive cue blocks, only those 50% of trials in which the cue did match the target were selected. In terms of perceptual priming, these trials
were physically identical to the Predictive cue blocks. With priming effects thus removed, the analysis was re-run to check whether key findings regarding Cue Predictiveness remained. Consistent with an effect of prediction/top-down templates, and no effect of perceptual priming, the interaction between Cue Predictiveness and Target Gaze remained \( F(1, 19) = 11.573, p = .003, \eta^2_p = .379 \), was not influenced by Set Size \( F(1, 19) = 1.022, p = .325, \eta^2_p = .051 \), and overall, there was a marginal Target Gaze by Set Size interaction \( F(1, 19) = 3.063, p = .096, \eta^2_p = .139 \).

Applying the same analysis as for RTs to accuracy data revealed significant effects of Target Gaze \( F(1, 19) = 9.391, p = .006, \eta^2_p = .331 \), Target Presence \( F(1, 19) = 22.315, p < .001, \eta^2_p = .540 \), and Set Size \( F(1, 19) = 9.470, p = .006, \eta^2_p = .333 \) — all in the same direction as the RT findings. As with the RTs, the Target gaze by Set Size interaction was marginal \( F(1, 19) = 4.428, p = .049, \eta^2_p = .189 \), and the Target Presence by Set Size interaction was significant \( F(1, 19) = 6.111, p = .023, \eta^2_p = .243 \). In addition, the Target Gaze by Target Presence interaction was significant \( F(1, 19) = 8.339, p = .009, \eta^2_p = .305 \), though qualified by a three-way interaction with Set Size \( F(1, 19) = 7.240, p = .014, \eta^2_p = .276 \) such that the Target Gaze by Set Size effect was significant only in the Target Present condition \( F(1, 19) = 7.083, p = .015, \eta^2_p = .272 \) as opposed to Target Absent \( F(1, 19) = .065, p = .802, \eta^2_p = .003 \). No other interactions were significant (all F values ≤ 2.095, \( p > .164 \)), in line with main RT results.

More generally, the presence of predictive cues tended to increase the RT advantage for Direct Gaze Targets at least as much at Set Size 3 as at Set Size 7. Indeed, the Predictive cues did not affect search slopes at all, or performance in general. Experiment 4.1 had therefore provided evidence of an SITCE, and of a rather selective effect of top-down target templates in this task. There was clearly no general performance enhancement – top-down templates for gaze-processing do not simply operate in the manner one would expect from, for example, templates for red or green items – thus, the first General Enhancement prediction could be excluded. Further, any influence of such templates on components of the SITCE that are independent of set size, tended to increase rather than decrease the SITCE. To further explore this component, Experiment 4.2 investigated the influence of 80% valid versus only 20% valid pictorial cues on the SITCE. The outcome was less clear, however, for the set-size-dependent element of SITCE, the shallower search slopes often found for direct gaze targets. Experiments 4.3 and 4.4 investigated this by replicating the conditions of
Experiment 4.1 but presenting word cues in place of pictorial ones to preclude any potential bottom-up, perceptual priming effects of the pictorial cues on search.
3. Experiment 4.2: The Influence of Variable Cue Predictability on the SITCE

3.1 Methods

Experiment 4.1 suggested that 100% valid top-down templates gaze preferentially sped up responses to direct gaze independent of set size. Experiment 4.2 investigated how flexible these direct-gaze-biased templates might be — is it the case that templates act on direct gaze in an all or none manner such that only 100% cue validity leads to the cue being used, or, is top-down evidence accrued across search trials such that greater instances of template validity lead to greater application of it. To this end, Experiment 4.2 presented pictorial cues before the SITCE display across two conditions — one where cues were valid 80% of the time, and one where they were valid only 20% of the time. Each condition of predictiveness was presented within a block, such that observers had the chance to build an expectation about the likelihood of a cue validly predicting the target gaze. The key terms of interest were the Target Gaze x Set Size interaction and the Cue Predictiveness x Target Gaze interaction.

3.1.2 Observers and Sample size

Based on the sample size for Experiment 4.1, 20 new observers (m = 4, f = 16, ages 18-35) were recruited in the same manner as before, and compensated £10 for their participation.

3.1.3 Apparatus, Stimuli, and Procedure

All aspects of methods were the same as in Experiment 4.1, with the following exception — observers now saw one condition where cues were 80% congruent and 20% incongruent (80% Predictive) and another condition where cues were only 20% congruent and 80% incongruent (20% Predictive). Observers were told that cues would only be accurate 80% and 20% of the time respectively. The run order of both conditions was counterbalanced across observers.
3.1.4 Results and Discussion

Figure 3. Mean Response Times (accuracy rates in parentheses) for Averted and Direct Gaze Targets, separately at Set Sizes 3 and 7 for (A) 80% Predictive Cue condition and (B) 20% Predictive Cue condition of Experiment 4.2. Error bars indicate +/-1 SEM. 

Key Results:
1. Target Gaze: p = .003
2. Target Gaze x Set Size: p = .012
3. Cue Pred x Target Gaze: p = .977

For each observer (N= 20), RT data for accurate responses (M= 97.06, SD= 2.44) was trimmed as before. One observer had to be removed as their accuracy scores failed to satisfy the exclusion criterion. Fig 3 plots, in the same format as earlier, the mean RTs for conditions in Experiment 4.2. A four-way RM ANOVA was conducted, identical to that in Experiment 4.1, with Cue Predictiveness levels either 80% Predictive or 20% Predictive and all other factors as before. There were main effects of Target Gaze [$F(1,18) = 11.797, p = .003, \eta^2_p = .396$], Target Presence [$F(1,18) = 163.777, p < .001, \eta^2_p = .901$], and Set Size [$F(1,18) =$...
In terms of interactions of interest, a significant effect of Target Gaze x Set Size \( [F(1, 18) = 7.759, p = .012, \eta^2_p = .301] \) was found, providing further evidence for this component of the SITCE. However, there was no main effect of Cue Predictiveness \( [F(1, 18) = 1.770, p = .200, \eta^2_p = .090] \), nor was there an interaction with Target Gaze \( [F(1, 18) = < .001, p = .977, \eta^2_p = .000] \). There were, marginal effects of Cue Predictiveness x Set Size \( [F(1, 18) = 4.171, p = .056, \eta^2_p = .188] \) and Cue Predictiveness x Target Gaze x Set Size \( [F(1, 18) = 4.324, p = .052, \eta^2_p = .194] \), although both were qualified by an overall four-way interaction \( [F(1, 18) = 3.509, p = .077, \eta^2_p = .163] \). However, two separate three-way ANOVAs for each condition of Cue Predictiveness revealed a significant Target Gaze x Set Size interaction for both 80\% Predictive \( [F(1, 18) = 7.449, p = .014, \eta^2_p = .293] \) and 20\% Predictive Cue conditions \( [F(1, 18) = 6.021, p = .025, \eta^2_p = .251] \), suggesting that cue variability did not differentially affect the key two-way interaction.

A corresponding analysis of accuracy revealed a main effect only for Target Presence \( [F(1, 18) = 10.981, p = .004, \eta^2_p = .379] \), not for Target Gaze \( [F(1, 18) = 1.002, p = .330, \eta^2_p = .053] \) or Set Size \( [F(1, 18) = 2.209, p = .155, \eta^2_p = .109] \). The Target Presence x Set Size was marginally significant \( [F(1, 18) = 4.611, p = .046, \eta^2_p = .204] \) but no other interaction terms were (all \( F \) values < 2.875, all \( p \) values > .107).

Thus, it appeared that observers were not treating the two cue predictiveness conditions differently and that any cue validity less than 100\% had the same effect — both were treated as unreliable and did not selectively speed up the set-size-independent response to Direct Gaze. Instead, overall, there appeared to be shallower search slopes for Direct Gaze Targets compared to Averted. This pattern of results thus excluded the *Flexible SITCE Increase* and, by default, the *SITCE Reduction* hypotheses.
4. Experiment 4.3: The Influence of Predictive Semantic Cues on the SITCE

4.1 Methods

Experiment 4.1 had found evidence for two dissociable components of the SITCE that were differently affected by top-down cues. However, that experiment could not entirely preclude a selective masking/priming effect that might only arise for Predictive cue blocks due to greater attention to the cue there, than in Nonpredictive blocks. Accordingly, in Experiment 4.3 (and Experiment 4.4, the pre-registered replication of the present experiment), the pictorial cue was replaced by a verbal description cue (with negligible target-feature overlap), to be certain that the effect of predictive cues found in Experiment 4.1 was not simply an effect of perceptual priming or some other masking effect of the cue.

4.1.2 Observers and Sample size

Sample-size was based on that employed for the previous experiments. Twenty observers ($m = 6, f = 14$, ages 18-35) were recruited and compensated for their time (£10) as before.

4.1.3 Apparatus, Stimuli, and Procedure

The apparatus, stimuli and procedure were as for Experiment 4.1, with one exception. Now, the cues in Predictive Cue condition blocks, rather than being a pair of direct or averted gazing eyes, were simply the words “Direct” or “Averted” printed centrally in white text (font: Courier New, size: 18) on a black background. The cue in Nonpredictive blocks was a string of the letter X repeated six times, for a length that was visually roughly the average length of the words ‘Direct’ and ‘Averted’, again with a fixation cross beneath.

Figure 4. Schematised sequence of displays in a typical trial from Experiment 4.3 (Set Size 7, Direct Gaze Target, Nonpredictive Cue, $T =$ target location).
### 4.1.4 Results and Discussion

![Graphs showing mean response times for Averted and Direct Gaze Targets](image)

**Figure 5.** Mean Response Times (accuracy rates in parentheses) for Averted and Direct Gaze Targets, separately at Set Sizes 3 and 7 for (A) Predictive Cue condition and (B) Nonpredictive Cue condition of Experiment 4.3. Error bars indicate +/- 1 SEM paired diffs.

For each observer (N= 20), RT data for accurate responses (M= 95.45, SD= 3.80) were trimmed in the standard manner. Figure 4 plots, in the same format as before, mean RTs for conditions in Experiment 3. Inspection of the plot again suggested that in the Predictive blocks, the overall advantage in RT for Direct versus Averted Gaze Targets was increased following Predictive Cues, even though these now bore no physical relationship to the targets or nontargets themselves. Identical analyses to those for RTs in Experiment 4.1 yielded expected main effects of Target Gaze [$F (1, 19) = 21.441, p < .001, \eta_p^2 = .530$].
Attentional Prioritisation of Another’s Direct Gaze

Presence \( [F(1, 19) = 25.965, p < .001, \eta^2_p = .577] \), Set Size \( [F(1, 19) = 327.562, p < .001, \eta^2_p = .945] \), and the standard two-way interaction between Target Presence by Set Size \( [F(1, 19) = 268.252, p < .001, \eta^2_p = .934] \). In terms of interactions of interest, the two-way interaction between Target Gaze and Set Size was significant \( [F(1, 19) = 8.401, p = .009, \eta^2_p = .307] \), suggesting that a strong SITCE that scaled with set size was present, and that such an effect was generally present throughout our experiments. The other crucial two-way interaction between Cue Predictiveness and Target Gaze was significant \( [F(1, 19) = 5.611, p = .029, \eta^2_p = .228] \). As in Experiment 4.1, the SITCE was increased by the presence of predictive cues. The absence of a three-way interaction between Cue Predictiveness, Target Gaze direction and Set Size \( [F(1, 19) = 1.152, p = .297, \eta^2_p = .057] \) again suggested that the top-down search template effects on the SITCE were independent of set size and acted to increase the magnitude of a set-size-independent component of the SITCE as had been concluded for Experiment 4.1.

In corresponding analysis of accuracy scores, main effects of Target Gaze \( [F(1, 19) = 9.425, p = .006, \eta^2_p = .332] \), Target Presence \( [F(1, 19) = 21.064, p < .001, \eta^2_p = .526] \) but not Set Size \( [F(1, 19) = 2.660, p = .119, \eta^2_p = .123] \) were found. Two-way interactions between Target Gaze and Target Presence \( [F(1, 19) = 10.402, p = .004, \eta^2_p = .354] \) and Target Presence and Set Size \( [F(1, 19) = 20.185, p < .001, \eta^2_p = .515] \), with no higher-order interactions, other than a four-way interaction between Cue Predictiveness, Target Gaze, Target Presence, and Set Size \( [F(1, 19) = 9.049, p = .007, \eta^2_p = .323] \) were found. Two three-way ANOVAs \( [2 \times (\text{Target Gaze Direction}) \times 2 \times (\text{Target Presence}) \times 2 \times (\text{Set Size})] \), conducted for each cue condition, found a three-way interaction for the Nonpredictive Cue condition \( [F(1, 19) = .5.515, p = .030, \eta^2_p = .225] \), but not the Predictive Cue condition \( [F(1, 19) = .289, p = .597, \eta^2_p = .015] \), the former effect reflecting a marginal two-way (Target Gaze by Set Size) interaction \( [F(1, 19) = 3.103, p = .094, \eta^2_p = .140] \) and significant for Target-Absent trials \( [F(1, 19) = 5.218, p = .034, \eta^2_p = .215] \). As these effects reflected error differences in very small numbers of trials and did not adversely impact the RT analyses, these were not analysed further.

Overall, these results increased confidence in the conclusions from Experiment 4.1 — that top-down search templates related to gaze direction (encouraged in conditions with 100% predictive cues) had selectively increased a component of the SITCE that was relatively independent of set size, favouring the Inflexible SITCE Increase hypothesis. Further, a
component of SITCE that did scale with set size (reflecting shallower search slopes for direct
gaze targets) appeared to be unaffected by top-down search templates. This core element of
the SITCE, which likely reflects search processes, may not be susceptible to top-down
influences.
5. Experiment 4.4: Replication of Experiment 4.3

5.1 Methods

Experiment 4.3 was replicated to have more evidence for the interaction between Target Gaze and Set Size, a key aspect of the SITCE. The pre-registration of this replication is available at https://aspredicted.org/dg8j9.pdf.

5.1.2 Sample Size, Apparatus, Stimuli, and Procedure

Effect sizes for the Target Gaze by Set Size interaction from Experiments 4.1 to 4.3 yielded $\eta_p^2 = 0.29$. Thus the sample size was kept the same as Experiment 4.3. Twenty observers ($m = 3, f = 17$, ages 18-35) were recruited from an online volunteer database, and paid for their time (£10) as before. The apparatus, stimuli, and procedure were exactly as for Experiment 4.3.

5.1.3 Results and Discussion

\[\text{Figure 6. Mean Response Times (accuracy rates in parentheses) for Averted and Direct Gaze Targets, separately at Set Sizes 3 and 7 for (A) Predictive Cue condition and (B) Nonpredictive Cue condition of Experiment 4.4. Error bars indicate +/-1 SEM}_{\text{paired}}.\]
For each observer (\(N=20\)), overall RT data and accuracy rate were calculated and any observers whose RT or accuracy means exceeded ± 3 SDs of the group mean was excluded. Two observers had to be excluded, one failed to satisfy the RT criterion and the other, accuracy. For the remaining 18 observers, individual RTs for accurate responses (\(M = 95.6, \ SD = 1.01\)) were trimmed as for Experiment 4.3. Figure 6 plots mean RTs for conditions in Experiment 4.4, in the same format as Figure 5. Visual inspection of the plots suggested that results were largely parallel to those in Experiment 4.4 — RT slopes for Averted Gaze were shallower than Direct across both cue predictiveness conditions, while predictable cues seemed to increase the overall Direct Gaze advantage regardless of Set Size.

Identical analyses as that for Experiment 4.3 showed main effects for Target Gaze [\(F(1, 17) = 35.574, p < .001, \eta_p^2 = .677\)], Target Presence [\(F(1, 17) = 55.461, p < .001, \eta_p^2 = .765\)], and Set Size [\(F(1, 17) = 289.841, p < .001, \eta_p^2 = .945\)], and the standard visual search interaction of Target Presence by Set Size [\(F(1, 17) = 116.115, p < .001, \eta_p^2 = .945\)]. With respect to interactions of interest, the Target Gaze by Set Size interaction was replicated [\(F(1, 17) = 20.549, p < .001, \eta_p^2 = .547\)], and, crucially, this interaction was not influenced by Cue Predictiveness [\(F(1, 17) = .791, p = .386, \eta_p^2 = .044\)], as expected. The Cue Predictiveness by Target Gaze interaction did not reach significance [\(F(1, 17) = 2.774, p = .114, \eta_p^2 = .140\)]. However, as this effect was in the same direction as Experiments 4.1 and 4.3, it increased our confidence further that the effect existed (in the population of scores, if not clearly in the sample). The Cue Predictiveness by Set Size interaction was marginal [\(F(1, 17) = 3.824, p = .067, \eta_p^2 = .184\)], and no other interactions were significant (all F values ≤ 2.948, \(p > .104\)).

A corresponding analysis of accuracy rates showed main effects of Target Gaze [\(F(1, 17) = 6.073, p = .025, \eta_p^2 = .263\)], Target Presence [\(F(1, 17) = 11.604, p = .003, \eta_p^2 = .406\)], and Set Size [\(F(1, 17) = 9.290, p < .007, \eta_p^2 = .353\)] — all in the same direction as the RT findings. In addition, the Target Gaze by Target Presence interaction [\(F(1, 17) = 22.779, p < .001, \eta_p^2 = .573\)] as well as the standard Target Presence by Set Size interaction [\(F(1, 17) = 18.939, p < .001, \eta_p^2 = .527\)] were significant. The Cue Predictiveness by Target Gaze by Target Presence interaction was marginal [\(F(1, 17) = 3.837, p = .067, \eta_p^2 = .184\)], and so was the Cue Predictiveness by Target Gaze by Set Size [\(F(1, 17) = 3.615, p = .074, \eta_p^2 = .175\)] one. As these two marginal terms were not in the primary dependent variable, very small, and not found in Experiment 4.3, they were not analysed further.
5.2 Combined Analyses

It was planned (as detailed in our pre-registration description) to combine results from Experiment 4.3 and 4.4 to further increase power. A five-way within-between RM ANOVA was run, with Experiment as a between-observers factor and all other within-observers factors as before.

This combined analysis found main effects of Target Gaze \[ F(1, 36) = 50.753, p < .001, \eta^2_p = .585 \], Target Presence \[ F(1, 36) = 74.807, p < .001, \eta^2_p = .675 \], and Set Size \[ F(1, 36) = 614.292, p < .001, \eta^2_p = .945 \] in the expected directions. The key Target Gaze by Set Size interaction was also found \[ F(1, 36) = 25.636, p < .001, \eta^2_p = .416 \], and, as before, was not influenced by the factor of Cue Predictiveness \[ F(1, 36) = .001, p = .973, \eta^2_p = .000 \]. The standard Target Presence by Set Size interaction was also present \[ F(1, 36) = 345.656, p < .001, \eta^2_p = .906 \]. In addition, the Cue Predictiveness by Target Gaze interaction was significant \[ F(1, 36) = 8.121, p = .007, \eta^2_p = .184 \], suggesting that across both experiments faster detection of Direct Gaze was influenced by the presence of predictive cues. The interaction between Cue Predictiveness and Target Presence was also significant \[ F(1, 36) = 4.208, p = .048, \eta^2_p = .105 \], such that responses to Target Absent trials were slowed by the presence of predictive cues. The Cue Predictiveness by Experiment interaction was marginal \[ F(1, 36) = 3.627, p = .065, \eta^2_p = .092 \], such that response times to predictive cues were slower in Experiment 4.3 than in Experiment 4.4. The between-observers factor of Experiment was not significant \[ F(1, 36) = .186, p = .669, \eta^2_p = .005 \]. No other interaction terms were significant (all F values \( < 1.895, p > .177 \)).
6. Multiple-Experiment Analyses and Discussion

Standard Null Hypothesis Significance Testing (NHST) statistics had been used to analyse each of the four experiments. These analyses identified three key terms of interest. First, there were two two-way interactions involving Target Gaze — Target Gaze x Set Size and Target Gaze x Cue Predictiveness. Each of these was ascribed to a different process — the first, a Target Gaze effect that varied with Set Size but not with Cue Predictiveness (Process 1), and the second, a Target Gaze effect that varied with Cue Predictiveness but not with Set Size (Process 2). Both interactions yielded clearly significant ($p<0.02$) or marginal effects ($0.02<p<0.11$), varying across experiments as would be expected for a medium to large effect. It was concluded that these two interaction terms might reflect dissociable processes, particularly as there was no three-way interaction involving all three terms (Target Gaze x Set Size x Cue Predictiveness) in any individual experiment, other than a marginal effect in Experiment 4.2 (which could be treated as a nonpredictive condition in its entirety) that was qualified by a four-way interaction, further analysis of which revealed the two-way interaction for both cue conditions.

For each of the key terms identified, combining data across experiments would provide a much more powerful test. However, for the null results pertaining to the three-way interaction, NHST statistics do not distinguish whether null results reflect the genuine absence of an effect or, instead, insensitivity of the data (e.g., Dienes, 2014). In contrast, corresponding Bayesian analyses yield an index of the relative evidence for the null hypothesis (zero effect) versus a range of non-zero effects (Gronau, Ly, & Wagenmakers, 2017). For terms such as the three-way interaction, for which there is little or no evidence of an effect, Bayesian alternatives provide a framework for deciding whether evidence overall actively supports the absence of any effect versus where more data is required.

Accordingly, Bayesian analyses of the two two-way interactions and the three-way interaction were conducted next, which was of importance for the interpretation of results (discussed below). To simplify the analyses, two-way (2x2) and three-way (2x2x2) within-observers interactions of interest were reduced to a single value per observer, according to which term was being analysed. For example, to analyse the Target Gaze x Set Size interaction, first, average RTs for each combination of Target Gaze and each Set Size (averaging across levels of Cue Predictiveness and Target Presence) were calculated. Next, to find the two-way interaction, the Direct Gaze advantage at each Set Size was computed by subtracting the average RT (for each observer) for Direct Gaze targets from that for Averted Gaze targets. Finally, the resulting Direct Gaze advantage at Set Size 3 was subtracted from
that for Set Size 7. The same logic was applied to the other terms of interest. The resulting scores were then subjected to one-sample Bayesian t-tests (JASP Team, 2018; Wagenmakers et al., 2018, JZS prior, centred on zero, Cauchy’s Width = 0.707. These analyses are reported and discussed below for each of the two-way interactions and the three-way interaction.

6.1 Overall Evidence for ‘Process 1’: Target Gaze x Set Size interaction

First, the two-way interaction revealing an SITCE component that scaled with Set Size (i.e., Target Gaze x Set Size) was investigated. This interaction had been significant in three experiments and marginal in one experiment. Overall, there was very strong evidence for the presence of this effect when collapsing across experiments ($BF_{10} = 85762$). There are two broad classes of cognitive mechanisms to which one might appeal to explain the effect of gaze direction on search slopes — serial and parallel search models. First, the effect may reflect more rapid serial search in one condition compared to the other, i.e., searching faster through averted gaze nontargets (one at a time, or several at a time) to find a direct gaze target than through direct gaze nontargets to find an averted one, yielding shallower search slopes when looking for direct gaze targets. This is an intuitively appealing account, and need only assume that disengaging attention from direct gaze nontargets is slower than from averted gaze ones. However, this account could be effectively excluded on the basis of current findings (by fortunate accident, rather than by design). Purely serial, self-terminating search models, without parallel guidance of attention, predict substantially larger effects of set size on target absent trials versus target present trials (as was the case here, and in other SITCE studies). In such models, fewer items will be searched on target present trials as only half the items will typically be searched before encountering the target, whereas all items need to be searched to ensure no target is present. If more items are searched on target absent trials, any speeding up of serial search through non-targets should yield substantially larger measured effects for target absent than target present trials (given the presence of the present/absent slope difference described above).

However, across the present four experiments, a Bayesian t-test on scores computed for this term (by calculating the Target Gaze x Set Size interaction term separately for Target Present trials and Target Absent trials for each observer, then subtracting the Target Present score from the Target Absent score) yielded moderate evidence in favour of $H_0$ ($BF_{10} = 0.184$) — providing evidence that the SITCE effect on search slopes was the same for Target Present and Target Absent trials. Therefore, the effects of gaze direction on purely serial search elements of search could be excluded as an explanation for the effect of gaze direction on search slopes.
Accordingly, it was concluded that gaze direction must have affected noisy, parallel guidance of attention toward the target, more efficiently (though still inefficiently, given our steep search slopes) toward Direct Gaze Targets among Averted Gaze Nontargets than Averted Gaze Targets among Direct Nontargets. This conclusion does not depend upon search being either strictly parallel or serial — the present findings are more consistent with an effect of gaze on parallel guidance, than on any serial components of search (i.e., recognition of, or attentional disengagement from, individual items).

6.2 Overall Evidence for ‘Process 2’: Target Gaze x Cue Predictiveness interaction

Next, the second component of the SITCE was investigated, which, it is proposed here, is influenced by Cue Predictiveness, but not Set Size. As discussed in the introduction to this chapter, if gaze-related target templates, encouraged by the presence of predictive cues, were to behave as one might expect for standard search templates, we would expect both averted gaze and direct gaze top-down templates to enhance the detection of their respective targets. This would yield an overall benefit in performance for trials following a predictive cue, relative to those with no predictive cue, irrespective of whether the target was direct or averted gaze. Contrary to this assumption, a one-sample Bayesian t-test (on scores computed for Experiments 4.1, 4.3 and 4.4, using the same logic as described for the first two-way interaction) provided strong evidence that predictive cues selectively augmented the Target Gaze component of the SITCE ($BF_{10}= 58.660$). That is, irrespective of whether the observer sought to adopt a direct gaze template or an averted gaze template, the template tended to speed their responses regarding direct gaze targets and (relatively) to slow their responses to averted gaze targets. This is consistent with any gaze-related, top-down template (whether for averted gaze or direct gaze) favouring direct gaze, irrespective of the observer’s intention – i.e., a mandatory specification of direct gaze by top-down gaze templates.

6.3 Overall Evidence against a Target Gaze x Set Size x Cue Predictiveness interaction

Finally, it was sought to establish whether there was evidence against a three-way interaction between Target Gaze, Set Size and Cue Predictiveness. Such evidence would bolster conclusions that the two processes above, each identified with a two-way interaction term, were dissociable. To compute the single scores for this analysis, the Target Gaze x Set Size interaction was calculated (as described above) separately for Predictive Cue and Nonpredictive Cue trials, for each observer in Experiments 4.1, 4.3, and 4.4, then subtracted one set of scores from the other. When analysed using a one-sample Bayesian t-test, as for the previous analyses, moderate evidence was found in favour of the null hypothesis ($BF_{10}=0.181$), i.e., the evidence from these experiments favoured the absence of a three-way
interaction. It was concluded, accordingly, that the two processes identified above (both favouring direct gaze) were dissociable — one involving parallel processing of gaze that biased attention to direct over averted gaze targets irrespective of top-down influences of the kind employed here, and a second, sensitive to top-down manipulations that was not influenced by set size.

In sum, these analyses confirm the existence of two distinct biases toward direct gaze in search for eye gaze. The first process (i.e., Target Gaze by Set Size interaction) was unaffected by top-down cues, but sensitive to changes in set size; reflecting an effect of gaze direction on attentional guidance in noisy parallel processing that is weighted more toward direct gaze, and is consistent with the idea of a direct gaze prior in human vision (Mareschal et al., 2013). A second process (i.e., Cue Predictiveness by Target Gaze interaction) did vary as a function of predictive cues but was independent of set size. A simple interpretation of this is that top-down templates specify response criteria regarding the presence or absence of a target. This may either reflect an effect of perception of the target (it could be modelled as speeded recognition of direct gaze eyes versus averted gaze ones) or an effect of response criteria. This effect parallels findings of Bayesian priors for direct gaze in individual faces (which similarly cannot distinguish perceptual from decision-making influences; Mareschal et al., 2013; Mareschal et al., 2014).
7. Discussion

The present set of experiments investigated how predictive cues (both 100% valid and unreliably valid), intended to encourage the formation of top-down target templates, would influence the SITCE. Two relevant previous studies have studied potential SITCEs when gaze is ‘task irrelevant’ and the target is defined by gender (Framorando et al., 2017) or emotion (Doi & Shinohara, 2013). However, both of these used forward-facing faces and were thus subject to likely luminance confounds related to the eye region (as discussed previously). Moreover, even that work had not manipulated the likelihood of a direct or averted gaze target in a particular trial, but rather tried to make it task-irrelevant. Observers would have expected to see direct gaze stimuli in those trials, even if the observer’s intention was to suppress attention toward those features. For both 100% valid pictorial cues (Experiment 4.1) and semantic cues (Experiments 4.3 and 4.4), predictability of cues influenced a component of the SITCE that did not scale with set size. In the case of less than 100% valid pictorial cues (Experiment 4.2), there was no influence on this set-size-independent component — observers treated any variability in cue predictability as nonpredictive. We could thus conclude that this component of the SITCE likely related to certainty about the target item when it was encountered (or its absence if it was not present); i.e., the perceptual or response criteria relating to target-presence or absence. Thus, this effect, sensitive to top-down templates and insensitive to set size manipulations, was distinct from a second component of the SITCE that was affected by set size but that was not affected by top-down templates in the present set of experiments.

From these findings, it would appear that the SITCE observed both in the present experiments and in Chapter 3, comprised at least two distinct processes. Both involved an obligatory bias toward direct gaze over averted gaze. In terms of preferential guidance of attention toward direct gaze eyes versus averted gaze eyes, ‘Process 1’ – revealed by a Target Gaze by Set Size interaction that was not affected by top-down search templates – seems to reflect a bias to attend to direct gaze stimuli even if they are not looking for those patterns. This makes functional sense if we consider that such processes could serve to highlight threats in the observer’s environment (e.g., Mareschal et al., 2013) — such a process would have greatly reduced adaptive value if it only operated when the observer was already actively searching for a threat. The second component, ‘Process 2’, unaffected by Set Size, but enhanced by the presence of predictive cues – revealed by the Cue Predictiveness by Target Gaze interaction – was consistent with top-down gaze-direction templates enhancing the bias toward direct gaze. In this respect, attempting to apply a gaze-related top-down
template (either direct or averted gaze) may be readily modelled as a fixed Bayesian prior, rather than something under effective voluntary control — a bias of fixed direction even if only applied following informative cues. This interpretation fits with the findings that humans have a prior internal representation to see eye gaze as direct, particularly when facing visual uncertainty (Mareschal et al., 2013; Mareschal et al., 2014). In the present case, predictable cue conditions enhance a prior bias for direct gaze, leading to the main Target Gaze effect. Why should direct gaze be a fixed prior? From an ecological perspective, correctly interpreting gaze stimuli as direct gaze leads to social benefits such as joint attention, imitation, and referential communication, which form the building blocks of social cognition. Models for the socio-cognitive consequences of direct gaze (e.g., Conty, George, & Hietanen, 2016; Senju & Johnson, 2009) propose that attention to direct gaze is a two-step model where attention capture by direct gaze, including in face-processing tasks, is the first step and the role of direct gaze on social cognition is the second. Incorrectly interpreting gaze to be self-directed would thus make more ecological sense, rather than missing out on direct gaze altogether (Mareschal et al., 2013).

In summary, the present conclusions distinguish two direct gaze advantages in visual search which differed in terms of their dependence on top-down influences and on set size — one which was independent of top-down templates but scaled with set size, and another which varied as a result of target templates but was independent of set size. These findings suggest that (obligatory) direct gaze biases in search can be differentiated into at least two constituent components, and reflect a first step toward decomposing the process.
Chapter 5

This chapter has been submitted for publication:

Chapter 5. The Gaze Paradox

1. Introduction

Eye gaze is a powerful social signal, which, through a process of evolution and adaptive learning is subjectively distinguished in human vision between two salient types — direct gaze and averted gaze. Underscoring the pivotal role gaze plays in social attention and perception, evidence from functional neuroimaging suggests that eye gaze activates a network of brain areas that are together known as the ‘social brain’, which prioritise stimuli for attention (e.g., Carlin & Calder, 2013; Calder et al., 2002; McCrackin & Itier, 2019). While all gaze cues are of importance, surely another person’s gaze directed at you, i.e., direct gaze, is of the highest priority for visual attention (e.g., Hamilton, 2016) — what could be considered a Direct Gaze Salience view. Consistent with this intuition, studies measuring reaction times and other manual response measures find that direct gaze is given attentional priority by the visual system over averted gaze when presented as an irrelevant fixation stimulus (Senju & Hasegawa, 2005), as an irrelevant peripheral stimulus (Yokoyama, Sakai, Noguchi, & Kita, 2014), in change blindness paradigms (Lyyra, Astikainen, & Hietanen, 2018; Yokoyama, Ishibashi, Hongah, & Kita, 2011), and in facilitating target detection when gaze is irrelevant to task (Böckler, van der Wel, & Welsh, 2014; Doi & Shinohara, 2013). Eye-tracking studies also find that direct gaze slows saccadic latencies to a peripheral target compared to averted (Ueda, Takahashi, & Watanabe, 2014), speeds express saccadic responses to itself compared to averted gaze faces or houses (Mares, Smith, Johnson, & Senju, 2016), and leads to greater fixations made overall to direct gazing faces than averted (Boyer & Wang, 2018). Perhaps the best documented evidence of direct gaze’s reported salience over averted gaze is the SITCE (e.g., Senju, Hasegawa, & Tojo, 2005; Senju, Kikuchi, et al., 2008).

At first glance these studies all seem to suggest that direct gaze is prioritised by attentional processes over averted gaze. By analogy with attention-capturing properties of more basic environmental features such as luminance and contrast, for which stimuli of greater salience capture attention more effectively, we could conceive of this increased attentional ‘pull’ of direct gaze in terms of increased perceptual salience. However, this
Attentional Prioritisation of Another’s Direct Gaze

Prioritisation of direct gaze is not purely stimulus-driven – it can be abolished following frontal lobe damage (Vecera & Rizzo, 2006) – rather, is a result of learnt association between direct gaze and its social consequences, such as self-awareness, emotions, and intentionality (e.g., Conty et al., 2016; Senju & Johnson, 2009b), perhaps resulting in a top-down prior which feeds back to earlier visual processing layers (Mareschal, et al. 2013, 2014).

How could we explain more exogenous or ‘bottom-up’ effects of gaze then? An influential line of thinking sees the brain as a hierarchical predictive coding processor, in which higher layers of networks send predictions down to representations in lower layers. These predictions – in Bayesian terms, ‘priors’ – are often modelled as a distribution of probabilities and may exert two primary effects on processing in those lower layers — first, they may speed processing of items that conform to likely interpretations on the basis of the prior and may bias interpretation of noisy input toward more probable interpretations; second, when input in lower layers is compared with the top-down prediction from higher layers, this generates prediction error signals that are passed up to higher layers to fine-tune subsequent predictions (e.g., Kanai, Komura, Shipp, & Friston, 2015; Rao & Ballard, 1999). Central to this principle is the understanding that stimuli that conform to prior expectations will elicit little prediction error response, while those that diverge markedly from predictions, a much larger response. It follows that stimuli that are in line with prior expectations are associated with a dampened attentional response, while those that are unexpected generate a sufficiently large error signal to exogenously attract attention and engage learning mechanisms to update predictions (e.g., Stefanics, Heinzle, Horváth, & Stephan, 2018; Summerfield & Egner, 2009). Within such a framework, direct gaze need not necessarily be prioritised over averted gaze exogenously. In fact, a Predictive Coding (PC) viewpoint would assume the opposite — averted gaze, as the unexpected stimulus weighted away from a direct gaze prior, is more likely to attract exogenous attention.

At face value, it seems as though the two approaches outlined above are caught in a ‘paradox of prediction in visual perception’ (e.g., Press, Kok, & Yon, 2019). This supposed contradiction may, at least, be constrained by examination of test cases in which there is clear reason to suppose the existence of a prediction — a biased prior. The apparent prior for direct gaze provides one such test case. Mareschal and colleagues (2013), using Bayesian principles, found that observers were more likely to judge ambiguous gaze as direct in the face of visual uncertainty (high stimulus noise) and that this was true regardless of head orientation (Mareschal et al., 2014), taking this as evidence for the existence of a direct gaze prior in human vision. Additionally, Chapter 4 had found that providing top-down templates
(both pictorial and semantic) for gaze acted in an all or none manner, i.e., only 100% predictive cues worked to speed responses selectively to direct gaze rather than both gaze types. In terms of attention, the ‘Direct Gaze Salience’ view, outlined above, predicts that direct gaze eyes should exert a greater exogenous pull on attention than averted gaze — in Bayesian terms, due to speeding of its detection/recognition as a function of conforming to a direct gaze prior. Conversely, the PC view – that attention is strongly biased toward stimuli that yield large prediction errors – predicts that attention should be biased toward averted gaze stimuli, given that they yield a prediction error when a direct gaze prior is applied.

How could we experimentally test for gaze prioritisation in the visual system, and the model that best describes this? A critical element of the task design would require direct and averted gazes to be placed in visual competition with each other to measure the relative ability of one gaze type to attract attention over the other. The visual search for gaze literature already has such a paradigm, the SITCE. Some exceptions to this view aside (e.g., Cooper, et al., 2013; Framorando et al., 2016), the large majority of literature on the SITCE has tended to favour the Direct Gaze Salience approach (e.g., Conty et al., 2006; Senju, Hasegawa, & Tojo, 2005), as does the interpretation in Chapter 4. A previous study has also shown that unique direct gaze facilitates target detection even when not relevant to the search task (Doi & Shinohara, 2013). However, traditional investigations of the SITCE, whether in favour of or against the notion of prioritisation of direct gaze, have not explicitly tested for a Direct Gaze Salience versus Predictive Coding approach.

Typically, previous work on the SITCE has measured manual responses to the target in the form of reaction times (RTs; e.g., Senju, Hasegawa, & Tojo, 2005; Senju, Kikuchi et al., 2008; von Grünau & Anston, 1995) — faster RTs indicating more effective response criterion to determine target presence and shallower search slopes indicating better attentional guidance. However, RTs are not a pure measure of initial attentional allocation, instead reflecting stages such as stimulus processing, target selection and verification, and finally, manual response production (e.g., Pashler, 1994; Taylor, 1976; Wolfe, Oliva, Horowitz, Butcher, & Bompas, 2000). Eye movements, on the other hand, particularly initial saccades, are a more direct measure of initial attentional allocation and guidance (e.g., Eckstein, Guerra-Carrillo, Singley, & Bunge, 2017). To the best of my knowledge, previous studies that have looked at eye movements in the search for gaze have not used the standard visual search format usually associated with the SITCE (Crehan & Althoff, 2015; Palanica & Itier, 2012) thus making it hard to draw conclusions about preferential attentional allocation from those studies.
Chapter 5 investigated, more formally, whether direct gaze is indeed preferentially attended to, or not, when placed in visual competition with averted gaze, thereby elucidating which of the two models, Direct Gaze Salience or PC, best fit observed effects. The same stimuli as in Chapter 4, that control for stimulus confounds of facial symmetry and sclera-iris ratio, were used here and allocation of initial overt attentional allocation and guidance was indexed in the form of proportion of initial saccades to gaze type. Experiment 5.1 explored the exogenous self-cueing ability of direct gaze versus averted gaze when gaze was task irrelevant. The search display was set up in standard SITCE format, with one unique gaze face and three gazes of the same type. However, the target was defined as a lighter mouth present on one of the non-unique faces, with the idea being that unique gaze would act as an ‘active nontarget’ to exogenously cue attention towards itself.

Experiment 5.2 asked whether uniqueness of gaze was a pre-requisite for exogenous cueing by gaze — gaze was still task irrelevant and the target was a lighter mouth, but now, both gaze types were always balanced in the display such that gaze was no longer unique. Experiments 5.3 and 5.4 investigated whether predictability in stimulus patterns played a role in exogenous cueing of unique gaze — one half of the task set up unique gaze to be task-irrelevant unique gaze, as in Experiment 5.1, while the other half of the task set up unique gaze to be task-relevant by placing it on the same face as the unique lighter mouth. Finally, Experiment 5.5 examined the role of semantic top-down templates in exogenous cueing by unique gaze — observers always searched for the unique gaze in each display and each trial was preceded by a semantic cue indicating which gaze type was the target.

Given that the vast majority of previous literature has favoured a Direct Gaze Salience approach, and that the experiments in Chapter 4 had shown a top-down prior for direct gaze, initial predictions were based on this view. Thus, in Experiment 5.1 we would expect unique direct gaze to preferentially cue exogenous attention over averted gaze, reflected as a greater proportion of first fixations. Predictions for subsequent experiments were updated based on observed effects.
2. Experiment 5.1: Exogenous Self-Cueing by Direct versus Averted Task-Irrelevant Gaze

2.1 Methods

Experiment 5.1 explored the exogenous self-cueing ability of direct gaze versus averted gaze when gaze was task-irrelevant. Observers were tasked with searching displays of two or four face stimuli, detecting which of them had a lighter mouth than the others (the target) and clicking on it using the cursor and mouse. When two faces were presented, one a target and the other a nontarget, each had a different gaze (one averted, one direct gaze; see Figure 1, left panel). When four faces were presented, one (nontarget) had an odd-one-out (unique) gaze; this was designated the ‘active’ nontarget as it was the only one that could pull attention on the basis of its gaze difference to the other faces. When two faces were presented, the ‘active nontarget’ was the only nontarget. In each case the proportion of initial saccades directed to the active nontarget, following display onset, could be compared.

2.1.1 Observers and Sample Size

It was estimated that 16 observers would provide sufficient power (~80%) to detect medium to large effects of interest (Cohen’s $f = 0.32$) for a 2x2 repeated measures ANOVA (G*Power 3.0 software; Faul, et al., 2007). This experiment was run with 17 volunteers ($m = 5, f = 12$, ages 18-35, one person having been booked extra due to a booking error). Observers were recruited from an online volunteer recruitment system and were paid £5 for their time.

2.1.2 Apparatus and Stimuli

Participants were seated approximately 70 cm from the screen (same computer model as all previous studies) and had their head in a chin rest, with their right eye tracked using an SR EyeLink 1000 eye-tracker (SR Research Ltd., 2005-2009) with a five-point calibration procedure (for all points, errors were limited to 0.5° of visual angle). The search display comprised stimulus faces that could appear in either two or four locations, centred 7.79° of visual angle to the right, left, above, and below the fixation. Faces in the search display could differ in two ways — in terms of eye gaze direction (gazing towards the observer ‘direct gaze’, or away ‘averted gaze’) and by colour of mouth (lighter grey or darker grey) Figure 1, right panel shows an example of display at Set Size 4 with four stimuli. The stimuli were modified versions of the stimuli used in Chapter 4. The lighter shade of mouth was constructed by adjusting the luminance of the mouth region in the original greyscale images.
2.1.3 Procedure

Each trial began with a fixation cross (250 ms) followed by the search display (presented until response made), which comprised either two or four faces, each identical save for variations in gaze direction and the luminance of the mouth region (see Figure 1). Only one face in each display had a lighter mouth, which had been defined as the target; observers were instructed to ignore the eye gaze of all images and ‘click on the target’ as quickly as possible using the mouse and cursor. Thus, the only task-relevant features of the search displays were the mouths, not the gaze direction of each face. Additionally, however, one of the faces in each display also differed from the target in terms of gaze. For displays in which only two faces were presented, this was simply the other display item. For displays comprising four faces, two of the nontarget faces had the same gaze as the target and one nontarget differed in gaze from the target. As mentioned above, only the nontarget that differed from the target in terms of gaze might draw attention away from the nontarget on the basis of gaze. In terms of the analyses and discussion the nontarget was termed ‘active’ as the terms ‘unique’ or ‘odd-one-out’ gaze were not unambiguously applicable for Set Size 2.

The search task began with a practice block (12 trials, with 3 trials of each combination) and observers were given feedback about target location after each trial. The main experimental blocks followed for which no feedback was given. The search task was presented in 5 blocks of 24 trials each, with a 10 second break between blocks. Trial order
was randomised within each experimental block, but all participants saw the same 24 trials in each block. Within a block, the positions of target and active nontarget faces were randomised across set sizes. Half of all trials had two faces presented on the display and half had four. Within each ‘set size’ (i.e., number of items in each display), half of all trials had the lighter mouth target on a direct gazing face and half on an averted gazing one. The display was constructed such that there were always two types of unique faces in the display — the Target (with unique mouth) and Active Nontarget (with unique gaze). If the Target was a lighter mouth on an averted gazing face the Active Nontarget was always a direct gazing face, and vice versa.

2.1.4 Measures and Predictions

The primary dependent variable of interest was the proportion of initial saccades directed to the Active Nontarget in each display, i.e., the stimulus face that differed in gaze from the Target (RTs to ‘click’ on the Target were also recorded). Initial saccades, rather than overall number/duration of saccades, were chosen as this intuitively mapped onto notions of the Active Nontarget’s ‘attentional pull’ — its exogenous ability to summon attention to itself. At Set Size 2, the Active Nontarget was the only Nontarget, while at Set Size 4, this was one out of three Nontargets, the other two of which shared the same gaze as the Target. The proportion of initial saccades was calculated separately for each Set Size (2 and 4) and for each Active Nontarget Gaze type (Direct and Averted). Based on previous literature, prior to Experiment 5.1, it was expected that a greater proportion of initial saccades would be made to the Direct Gaze Active Nontarget than Averted, contradicting the PC premise. Additionally, the proportion of initial saccades to a lighter mouth Target and other Nontargets was calculated. Any such effects were expected to be weak, given the subtle difference between Target and Nontarget luminances. Average RTs (Table 1) and proportions of initial saccades to the lighter mouth Target (Table 2) were collected for completeness.
2.1.5 Results and Discussion

![Initial Saccade Patterns for Active Nontargets](image)

Figure 2. Proportion of initial saccades to Active Nontargets – an index of cueing by task-irrelevant gaze – for each Set Size and Gaze in Experiment 5.1. Error bars indicate +/- 1 SEM paired differences.

### 2.1.5.1. Bias toward Active Nontargets

Saccades with latencies shorter than 70 ms were excluded as anticipatory. One observer’s data was excluded from analysis of the basis of extreme (>3SD from sample mean) saccade measures at Set Size 2. Figure 2 plots proportions of initial saccades, separately for each Gaze direction and Set Size. Visual inspection of the plot suggested little or no effect of gaze direction at Set Size 2. At Set Size 4, the plot suggested, contrary to initial expectations and current consensus, more saccades to Averted than Direct Gaze Active Nontargets. To be able to compare Set Size 2 proportions on the same scale as those at Set Size 4 (in which an Active Nontarget saccade by chance alone, was half as likely as at Set Size 2) the values at Set Size 2 were halved before running the ANOVA. A two-way repeated measures ANOVA with factors Gaze (Averted, Direct) and Set Size (2, 4) revealed main effects of Gaze $[F(1, 15) = 7.317, p = .016, \eta^2_p = .328]$, Set Size $[F(1, 15) = 20.216, p < .001, \eta^2_p = .574]$ and an interaction between the terms $[F(1, 15) = 5.244, p = .037, \eta^2_p = .259]$.

Follow-up t-tests were run to investigate the source of this interaction. A paired sample t-test showed that at Set Size 2, there was no difference in proportion of first fixations to Averted Active Nontargets ($M = 0.47, SD = 0.09$) compared to Direct Active Nontargets ($M = 0.47, SD = 0.06$), $[t(15) = -0.042, p = 0.820]$. However, a paired sample t-test confirmed that at Set Size 4, a greater proportion of first fixations was made to Averted Active Nontargets ($M = 0.36, SD = 0.10$) than Direct Active Nontargets ($M = 0.28, SD = 0.06$), $[t(15) = 2.635, p = .019]$. 


Gaze effects at Set Size 4 were *broadly speaking*, more consistent with predictions of PC models, contrary to what had been hypothesised. However, the basic formulation of such models would also have predicted an effect of the factor Gaze at Set Size 2. To investigate the cause of the different findings in the two set sizes, two key differences between them are noted — first, the number of items differed and second, only Set Size 4 comprised a unique, ‘odd-one-out’ gaze (i.e., a unique gaze accompanied by multiple other faces sharing different gaze). To assess which, if either, of these differences was responsible for the effect at Set Size 4, Experiment 5.2 replicated the conditions of Experiment 5.1, but with one crucial alteration. At Set Size 4, one of the nontargets now had the same gaze as the target, the other two having a different gaze. Accordingly, there was no unique, odd-one-out gaze. If the effects of gaze direction at Set Size 4 in Experiment 5.1 had reflected a unique gaze in those displays, we should not observe the same effects now. Conversely, if those effects had reflected the number of items in those displays (four) we should observe the same pattern of effects as in Experiment 5.1.
3. Experiment 5.2: Gaze Bias in the Absence of Unique Gaze

3.1 Methods

Experiment 5.2 was designed to confirm whether gaze uniqueness was required to see the averted gaze advantage observed in Experiment 5.1, Set Size 4. Across both set sizes, the only unique element was the lighter mouth on the target. No specific predictions were made regarding the presence of an averted gaze bias at Set Size 4, but it was expected not to detect one at Set Size 2, following the results of Experiment 5.1.

3.1.1 Observers and Sample Size

Sixteen observers ($m = 4$, $f = 12$, ages 18-35) were recruited and compensated for their time as in Experiment 1. On the basis of an expected effect size at Set Size 4 from Experiment 5.1 (Cohen’s $d \approx 0.8$), the power analyses from Experiment 5.1 did not need updating.

3.1.2 Apparatus, Stimuli, and Procedure

All aspects of Stimuli, Apparatus and Procedure were as for Experiment 5.1, with the sole exception that each Set Size 4 display now comprised two faces with direct gaze and two with averted (see Figure 3).

![Figure 3](image-url)  
*Figure 3. Example of search display in Experiment 5.2 with Direct Gaze Target. T = Target, ANT = Active Nontarget, NT = Nontarget*
3.1.3 Results and Discussion

Figure 4. Proportion of initial saccades to Active Nontargets separately for each Set Size and each Gaze type in Experiment 5.2. Error bars indicate +/- 1 SEM_paired diffs.

3.1.3.1 Bias Toward Active Nontargets

Figure 4 plots the proportion of initial saccades in the same format as Figure 2. Visual inspection of the plot suggested weak or no effect of Gaze to the Active Nontargets at both Set Size 2 and 4. A two-way, repeated measures ANOVA with factors of Gaze (Averted, Direct) and Set Size (2, 4) revealed only a significant Set Size effect \[ F(1, 15) = 496.948, p < .001, \eta_p^2 = .971 \]. There was no main effect of Gaze \[ F(1, 15) = .001, p = .970, \eta_p^2 = .000 \] or an interaction between these two factors \[ F(1, 15) = .149, p = .705, \eta_p^2 = .010 \]. A planned follow-up t-test at Set Size 2 showed, as in Experiment 5.1, that there was no difference in proportion of initial saccades between Averted Active Nontargets \( (M = 0.45, SD = 0.05) \) and Direct Active Nontargets \( (M = 0.47, SD = 0.07) \), \[ t(15) = -0.835, p = 0.417 \]. There was also no difference at Set Size 4 (Averted Active Nontargets: \( M = 0.54, SD = 0.10 \), Direct Active Nontargets: \( M = 0.53, SD = 0.07 \), \( t(15) = .207, p = 0.839 \)).

One limitation when interpreting Experiments 5.1 and 5.2 was that, in both cases, gaze uniqueness was task-irrelevant and observers may either have sought actively to suppress processing of gaze or may not have done so. It is well-documented that attempted suppression of salient nontargets may, paradoxically, cause increased attentional bias towards them (Moher & Egeth, 2012; Tsal & Makovski, 2006). To clarify whether the unexpected effect in Experiment 5.1, Set Size 4 had reflected attempted suppression of gaze related information in those displays, or instead reflected more typical processing of them, Experiment 5.3 investigated attentional biases for unique (odd-one-out) direct versus averted
gazes in two conditions — (i) when gaze was task irrelevant – *uninformative* regarding the target’s location as in Experiment 5.1, or (ii) when the unique gaze was highly task-relevant and *informative*, i.e., a 100% valid cue to the target’s location. To ensure that these conditions were directly comparable, each observer participated in both.

One aspect of this manipulation is particularly important, but not necessarily obvious — in the Informative Gaze condition, the *position of the unique gaze* was relevant, but the gaze of that face (or any individual face) was not. Accordingly, while the task relevance of the uniqueness of one face’s gaze would have engaged endogenous attention rather than exogenous attention, as it was part of the instructions, the dimension of interest (direct versus averted gaze) remained outside these instructions and must reflect an inherent bias in the observer’s response to the stimuli (as in Experiments 5.1 and 5.2). Accordingly, the predictions of PC models remained the same as for Experiment 5.1.

Contrary to PC model assumptions, a specific prediction was made for the *Informative* Unique Gaze condition – that initial saccades would be more biased toward direct gaze targets than averted – based on previous findings in Chapter 4. Conversely, in the *Uninformative* Unique Gaze condition, it was predicted that attention would be biased toward the averted gaze nontargets, as in Experiment 5.1.
4. Experiment 5.3: Informative versus Uninformative Unique Gaze

4.1 Methods

Experiment 5.3 was designed to investigate the attention cueing properties of unique gaze, direct or averted, in informative and uninformative cue conditions. Observers again searched for a lighter mouth target from among darker mouth faces. In the Informative condition, unique (odd-one-out) gaze and unique mouth were on the same face and observers were told that gaze information would guide their search, such that observers could reliably use unique gaze information to identify the target more rapidly. In the Uninformative context, unique gaze did not provide information about the location of the target mouth (as in Experiments 5.1 and 5.2).

As outlined previously, a model which only took into account the competing effects of stimulus-based spatial cueing and top-down expectation of target features did not suffice to explain findings in the first two experiments. However, a model that, additionally, took into account predictability of stimulus patterns had the potential to elucidate those effects. Importantly, this model would assume that Informative condition effects were in the opposite direction to Uninformative condition effects. Such a model would predict one of two effects — stronger cueing by direct gaze in the Informative Unique Gaze condition and stronger attentional pull by averted gaze in the Uninformative Unique Gaze condition or stronger cueing by averted gaze in the Informative Unique Gaze condition and stronger attentional pull by direct gaze in the Uninformative one.

With respect to RTs, based on previous literature on the SITCE (e.g., Senju, Hasegawa, & Tojo, 2005) and findings from Chapters 3 and 4, we would expect faster RTs to unique direct faces when among averted nontargets than vice versa. In the Informative condition, observers had been told that unique gaze information would reliably aid target search and only for this condition, we made a prediction that responses would be faster to direct targets than to averted ones. Previous findings have been less clear on whether direct gaze facilitates non-gaze target search (Doi & Shinohara, 2013) or not (Framorando et al., 2016) when told to ignore gaze, and thus there were no specific predictions for the Uninformative condition when unique gaze and unique mouth are on different faces.

4.1.1 Observers and Sample Size

Based on the sample size and power calculated in Experiments 5.1 and 5.2, 16 observers (m = 5, f = 11, ages 18-35) were recruited and compensated for their time, as before.
4.1.2 Apparatus, Stimuli, and Procedure

All aspects of the experiment were as described for Experiments 5.1 and 5.2, with the following exceptions. Since this experiment was investigating unique gaze effects, all trials only comprised set size 4 displays (see Figure 5). Observers were again instructed to ‘click on’ the face with the lighter mouth. In the Informative Unique Gaze condition, the lighter mouth was always placed on the face with unique gaze, whether direct or averted. Observers were informed of this and instructed to use the unique gaze to find the target (the lighter mouth). In the Uninformative Unique Gaze condition, observers were informed that the unique gaze did not provide information as to the target’s location. By chance, three-quarters of the trials had unique (odd-one-out) gaze and unique mouth on different faces, while a quarter of all trials had (again, by chance) unique gaze and unique mouth on the same face. The latter quarter of trials were excluded from the main analysis of active nontarget effect as attention might be biased to the target in those displays either on the basis of the nontarget’s unique gaze, or that same face’s lighter mouth.

The search task was presented in 4 blocks of 30 trials each, with a 10 second break between blocks. Depending on counterbalance order, if the first two blocks were of Informative Unique Gaze, the next two were of Uninformative, and vice versa. Trial order was randomised within each experimental block, but all participants saw the same 30 trials in each block. Prior to each condition began with a practice block (Informative, 8 trials; Uninformative, 8 trials), comprising feedback as in Experiments 5.1 and 5.2.

Figure 5. Examples of search displays in Experiment 5.3. Left panel: Example of an Uninformative display with Direct Gaze Target and Averted Gaze Active Nontarget; Right panel: Example of an Informative display with Direct Gaze Target and Averted Gaze Nontargets. T = Target, ANT = Active Nontarget, NT = Nontarget
4.1.3 Results and Discussion

4.1.3.1 Bias toward Unique Gaze

Figure 6. Proportion of initial saccades to Active Nontargets in the Uninformative condition (left pair of bars) and to Targets in the Informative condition (right pair of bars) separately for each Gaze type in Experiment 5.3. Error bars indicate +/- 1 SEMpaireddiffs.

The proportion of initial saccades to the unique gaze in each condition was calculated — this was an Active Nontarget in the Uninformative Unique Gaze condition and a Target in the Informative Unique Gaze condition. Figure 4 plots these separately for the two conditions and for each direction of the unique gaze (Averted, Direct). Visual inspection of the plot suggested little or no effect of Gaze on Active Nontargets in the Uninformative Unique Gaze condition, but, contrary to our predictions, a clearer effect in the Informative Unique Gaze condition, a clearer bias toward Averted Gaze than Direct. A two-way Unique Gaze Informativeness (Informative, Uninformative) x Gaze (Averted, Direct) repeated measures ANOVA revealed a substantial main effect of Gaze \( [F(1, 15) = 13.592, p = .002, \eta^2_p = .475] \), but not of Gaze Informativeness \( [F(1, 15) = 2.166, p = .162, \eta^2_p = .126] \) and no evidence of an interaction between the terms \( [F(1, 15) = .540, p = .474, \eta^2_p = .035] \).

These results provided no statistical basis to examine the effects of Unique Gaze separately in the two conditions. Nonetheless, there was an a priori reason to do so (opposite effects were expected in the two Gaze Informativeness Conditions). Paired samples t-tests confirmed that Averted Targets (\( M = .31, SD = .10 \)) were looked at significantly more than Direct Targets (\( M = .25, SD = .05 \)), \( [t(15) = 2.342, p = .033] \) in the Informative Unique Gaze Condition, but no such bias was detected for Active Nontargets in the Uninformative Unique Gaze Condition (Averted: \( M = .26, SD = .10 \), Direct: \( M = .23, SD = .09 \), \( [t(15) = 1.047, p = \)...
As inspection of the plot had suggested, the effect was reliable only in the Informative Unique Gaze condition, yet the mean effect was not significantly larger than the Uninformative Condition. Accordingly, the existence of averted gaze bias was uncertain when unique gaze was uninformative — it had been evident in Experiment 5.1, but was not clearly evident here.

4.1.3.2 Manual Responses

RT data were only considered for accurate responses (i.e., when the correct item was ‘clicked’; $M = 97.7$, $SD = .04$). For each participant, data within each Gaze Informativeness condition and Gaze Type were trimmed to exclude any RTs that were $\pm 3$ SDs from these means. A two-way ANOVA, with the same factors as for eye movement analyses, revealed no significant effects for Gaze [$F(1, 15) = 0.768, p = .395, \eta^2_p = .049$], Gaze Informativeness [$F(1, 15) = 2.808, p = .115, \eta^2_p = .158$] or their interaction [$F(1, 15) = .881, p = .363, \eta^2_p = .055$]. As with eye movements, planned follow-up paired sample t-tests were run to compare key differences. A paired samples t-test found no difference in RTs between Averted Active Nontargets ($M = 1911$, $SD = 517.5$) and Direct Active Nontargets ($M = 1910$, $SD = 465.9$) in the Uninformative condition, [$t(15) = 1.891, p = .078$]. Neither was there a difference between RTs to Averted Targets ($M = 2167$, $SD = 695.3$) compared to Direct ones ($M = 2093$, $SD = 513.5$) in the Informative condition. Thus, RTs in the Informative condition had not been in the expected direction, although they had not been in favour of Averted Targets either, despite eye movements patterns being in that direction.

Consistent with Predictive Coding model predictions, observers made a greater proportion of initial saccades to a unique averted gaze than direct. This was even the case (in fact, especially clearly so) for the Informative Condition, indicating that an averted gaze bias was not only observed when unique gaze is irrelevant. There was no clear evidence that Uninformative and Informative Unique Gaze conditions differed, though the effect was only evident in the Informative Unique Gaze condition when they were analysed independently. RT findings had also not shown any difference between the two conditions. One potential reason for the absence of such a difference might simply have been that the manipulation was too subtle. Observers searched, in both conditions, for a lighter-mouth target, and gaze was of secondary importance, even when informative. To remedy this, Experiment 5.4 replicated the conditions of Experiment 5.3, except that in the Informative Unique Gaze condition, the observer was instructed to ignore the mouths of the faces and simply to click directly on the unique gaze — now, the primary task-relevant feature dimension. It is important to note that
while the position of the unique gaze in each display was of primary task relevance, gaze direction itself (of the target or of any individual face) remained task-irrelevant.
5. Experiment 5.4: Unique Gaze as the task-relevant dimension

5.1 Methods

Experiment 5.4 aimed to enhance target selection on the basis of gaze and encourage active nontarget inhibition to more clearly examine potential differences between the Informative and Uninformative conditions. In the Informative condition, observers were explicitly told to look for the odd-one-out gaze while ignoring the mouths of the faces. In the Uninformative Unique Gaze condition, trials in which the unique gaze fell on the same face as the target, were now removed, the better to replicate conditions of Experiment 5.1. Here, a larger difference was expected between the Informative and Uninformative Unique Gaze Conditions, compared with Experiment 5.3.

5.1.1 Observers and Sample Size

The Unique Gaze Informativeness manipulation in Experiment 5.3 had resulted in a weaker-than-expected effect. Although the effect here was expected to be stronger, the sample size was also slightly increased to twenty observers ($m = 8, f = 12$, ages 18-35), to increase power to detect those effects. Volunteers were recruited and compensated for their time as in the previous experiments. An error in the recording of eye tracking data for one participant excluded them from analysis.

5.1.2 Apparatus, Stimuli, and Procedure

Stimuli, apparatus, and procedure were as for Experiment 5.3 with the following modifications — all trials in the Uninformative condition now had the odd-one-out gaze and lighter mouth target on different faces (60 trials), to encourage active suppression of gaze information, with task instructions to look for unique mouth while ignoring gaze, while task instructions in the Informative condition (60 trials) were to explicitly look for unique gaze while ignoring the mouth. The run order for Uninformative and Informative conditions was counterbalanced across observers.
5.1.3 Results and Discussion

5.1.3.1 Bias toward Unique Gaze

Figure 7. Proportion of initial saccades to Active Nontargets in the Uninformative condition (left pair of bars) and to Targets in the Informative condition (right pair of bars) separately for each Gaze type in Experiment 5.4. Error bars indicate +/- 1 SEM paired differences.

Figure 7 plots the proportion of initial saccades to Unique Gaze Faces in Experiment 5.4 in the same format as Figure 6. Visual inspection of the plot suggested that the pattern of results in both Uninformative and Informative conditions mirrored that of Experiment 5.3. A two-way (Gaze Informativeness (Informative, Uninformative) x Gaze (Averted, Direct) repeated measures ANOVA revealed only a marginal main effect of Gaze Informativeness $[F(1, 18) = 4.358, p = .051, \eta_p^2 = .195]$, a clear effect of Gaze $[F(1, 18) = 11.689, p = .003, \eta_p^2 = .394]$, and no interaction between the two terms $[F(1, 18) = 2.665, p = .120, \eta_p^2 = .129]$. Paired t-tests revealed no differences in proportion of first saccades to Averted Active Nontargets ($M = .27, SD = .08$) versus to Direct ones ($M = .25, SD = .07$), $[t(18) = 1.022, p = .320]$ in the Uninformative Unique Gaze condition, but a difference favouring Averted Targets ($M = .32, SD = .10$) over Direct Targets ($M = .26, SD = .06$), $[t(18) = 3.104, p = .006]$, in the Informative Unique Gaze condition. These findings closely paralleled those of Experiment 5.3, providing strong evidence for an averted gaze bias of attention when it was informative for observers. There was again no clear effect for Uninformative Unique Gaze conditions and yet no clear difference between Informative and Uninformative conditions in terms of gaze bias.
5.1.3.2 Manual Responses

RT data for accurate responses ($M = 98.7$, $SD = .01$) were entered into a two-way repeated measures ANOVA (Gaze Informativeness (Informative, Uninformative) x Gaze (Averted, Direct)). This revealed a main effect of Gaze Informativeness [$F(1, 18) = 4.999, p = .038$, $\eta^2_p = .217$], but no main effect of Gaze [$F(1, 18) = .019, p = .892$, $\eta^2_p = .001$] or an interaction [$F(1, 18) = .042, p = .839$, $\eta^2_p = .002$]. Thus, as in Experiment 5.3, RT patterns did not yield evidence that direct gaze was detected faster from among averted gaze nontargets, or vice versa.

5.1.4 Combined Analysis of Experiments 5.3 and 5.4

To maximise power to detect an effect of gaze predictiveness and any potential influence on the size/presence of an averted gaze bias, a three-way repeated measures ANOVA was conducted, with Experiment as a between-subjects factor and Unique Gaze Informativeness (Informative, Uninformative) and Gaze (Averted, Direct) conditions as within-subject factors. There was neither a main effect of Experiment (Experiment 5.3 versus 5.4), nor any interaction involving the term Experiment (all $F$ values < .000, all $p$ values > .777), suggesting that the two experiments might be combined. As expected, this found a main effect of Informativeness [$F(1, 33) = 5.870, p = .021$, $\eta^2_p = .151$] and of Gaze [$F(1, 33) = 24.696, p < .001$, $\eta^2_p = .428$]. However, even with power maximised across these two studies, no clear evidence of their interaction [$F(1, 33) = 2.410, p = .130$, $\eta^2_p = .068$] emerged. That is, there was no clear influence of predictability on the (overall, very clear) tendency for unique averted gaze to attract attention (initial saccades) more than unique direct gaze.

Experiment 5.4 exhibited the same pattern of eye movement and RT results as Experiment 5.3 — very clear evidence that unique (odd-one-out) averted gaze exerted a stronger initial pull on attention than direct gaze, and no clear evidence that this was influenced by Gaze Informativeness. What these conditions had in common with Experiment 5.1, Set Size 4, but not with Experiment 5.2, Set Size 4 (or either of the Set Size 2 conditions in Experiments 5.1 and 5.2) was unique gaze. Only under these circumstances did the tendency to attend more to averted than to direct gaze (nontargets or targets) emerge, otherwise, the effect was absent.

The effects of Unique Gaze Informativeness (whether or not it benefitted participants to deliberately attend to the unique gaze in a display, or alternatively to ignore this information) in Experiments 5.3 and 5.4 had been weaker (as main effects) than expected and
had not significantly influenced the substantial averted-gaze bias observed there. However, the informativeness of gaze in those experiments was limited to the position of the unique gaze in each display — no information was provided by the particular direction of gaze in either case, which remained task-irrelevant. Accordingly, Experiment 5.5 was designed to investigate, more concretely, the role that informativeness about a particular gaze might exert on the robust averted unique gaze bias observed in those experiments. This new experiment therefore replicated the conditions of the Informative Unique Gaze condition in Experiment 5.4, but with a crucial further manipulation. Each search display would now be preceded by, in one condition, a predictive word cue signalling which gaze type the target would be (‘Direct’ or ‘Averted’), and a nonpredictive string of X’s (in the same manner as Experiments 4.3 and 4.4).

We would expect to find faster responses and a greater proportion of initial target saccades, in the predictive condition. We would also expect to find faster RTs to direct gaze than averted gaze targets following a predictive cue, as Chapter 4 had found this using the same face stimuli (though at Set Sizes 3 and 7). It is to be noted that, in the Predictive Cue condition at least, attention toward one gaze direction was now endogenous in the sense that it was manipulated by cue-target probabilities and instructions, rather than a function of the stimulus and the observer’s inherent bias. Accordingly, PC models need no longer make the same prediction of an averted gaze bias as in the previous experiments (at the time of conducting the experiment, it was unclear as to what, if any, predictions predictive coding might make).
6. Experiment 5.5: The role of top-down templates in Unique Gaze cueing

6.1 Methods

Observers were now always asked to search for unique gaze as a target (all trials had unique gaze and unique mouth on the same face for stimulus consistency across experiments, though no mention was made of the mouth here). Top-down prior information regarding the target face’s (unique) gaze was provided in the form of word cues indicating which gaze type to look for in the Predictive Condition. No such information was available in the Nonpredictive Condition.

6.1.1 Observers and Sample Size

Based on sample size and power estimates for Experiment 4.4, 20 observers (m = 3, f = 17, ages 18-35) were recruited and compensated for their time as in previous experiments.

6.1.2 Apparatus, Stimuli, and Procedure

Stimuli, apparatus, and procedure were as for the Informative Unique Gaze condition in Experiment 4.4, with the addition of word cues at fixation, for a duration of 1500 ms. The words ‘Direct’ and ‘Averted’ (Courier font, 18 point) were presented just above the fixation cross in the Predictive condition and were replaced by a letter string of X repeated six times in the Nonpredictive condition (based on Experiments 4.3 and 4.4). The run order of Predictive and Nonpredictive conditions was counterbalanced across participants.

6.1.3 Results and Discussion

6.1.3.1 Bias toward Unique Gaze

![Initial Saccade Patterns for Unique Gaze](image)

Key Results:
1. Cue Pred.: p = .023
2. Gaze: n.s.
3. Gaze x Cue Pred.: n.s.

*Figure 8.* Proportion of initial saccades to Targets in the Nonpredictive condition (left pair of bars) and Predictive condition (right pair of bars) separately for each Gaze type in Experiment 5.5.
Figure 8 plots the proportion of initial saccades to targets of each Gaze type separately for Predictive and Nonpredictive conditions. Visual inspection of the plots did not suggest any difference between proportion of initial saccades to either Gaze type in either condition. However, the plot did suggest that, overall, providing informative cues increased the number of saccades made to a target regardless of its gaze. A two-way, repeated measures ANOVA, Cue Predictiveness (Nonpredictive, Predictive) x Gaze (Averted, Direct), revealed a main effect of Cue Predictiveness \( F(1, 19) = 6.162, p = .023, \eta^2_p = .245 \) — observers made a greater proportion of target saccades in the Predictive condition than Nonpredictive. However, there was neither a main effect of Gaze condition itself \( F(1, 19) < .01, \text{n.s.} \) nor an interaction between the terms \( F(1, 19) = .007, \text{n.s.} \).

Providing 100% valid top-down cues was associated with no effect of Gaze Type, suggesting that the unique averted gaze tendency had been reduced or abolished by a top-down direct gaze prior in the Predictive condition. And although a lesser proportion of initial saccades was made, suggesting that observers had treated the two conditions differently, the Nonpredictive condition showed the same pattern of lack of gaze prioritisation. This latter finding was contrary to results from Experiments 5.3 and 5.4, and likely involved the presence of an uninformative cue prior to each search display. Speculatively, seeing an uninformative cue (in the presence of other informative cues) may have prompted observers to guess the gaze of the subsequent target, rather than simply detecting a unique gaze on the basis of its uniqueness. That something more fundamental differed in this condition, relative to Experiments 5.3 and 5.4, and not just a failure to get the same averted-gaze bias, was evident in two respects. First, observers now looked at targets (in their initial saccade) less than chance, rather than substantially greater than chance when gaze uniqueness was informative in Experiments 5.3 and 5.4. Second, RTs (discussed in section 6.1.3.3) showed a different pattern to those in Experiments 5.3 and 5.4.

6.1.3.2 Additional Analysis of Total Fixations to Target Gaze

To better understand underlying mechanisms driving target selection, and whether these differed between Predictive and Nonpredictive conditions, an additional analysis of overall fixations made to each Gaze type was conducted. To determine this, the ordinal position of fixations was calculated — the number of fixations an observer took to reach the target without repeating an already looked at region. The maximum number of fixations to reach the target would be 4, exactly half that number of fixations would indicate guidance at chance, and any numerical value less than half would indicate some degree of guidance to
target. A two-way ANOVA with the same factors as before revealed no significant effects of Cue Predictiveness \( F(1, 19) = 0.635, p = .435, \eta^2_p = .032 \), Gaze \( F(1, 19) = .475, p = .499, \eta^2_p = .024 \) or the interaction term \( F(1, 19) = .393, p = .538, \eta^2_p = .020 \), suggesting that there were no significant differences between gaze types in the number of fixations it took to reach the target in either Cue Predictiveness condition.

6.1.3.3 Manual Responses

RT data for accurate responses \((M = 97.8, SD = .04)\) were subjected to a two-way repeated-measures ANOVA, with the same factors as before. This analysis revealed significant main effects of Cue Predictiveness \( F(1, 19) = 23.665, p < .001, \eta^2_p = .555 \) and Gaze \( F(1, 19) = 12.586, p = .002, \eta^2_p = .398 \), but not the interaction between both terms \( F(1, 19) = 1.195, p = .288, \eta^2_p = .059 \). Paired sample t-tests revealed that RTs to Direct Targets were marginally faster than Averted in the Nonpredictive Cue condition (Averted \((M = 1985, SD = 535.4)\), Direct \((M = 1893, SD = 431.9)\), \( t(19) = 1.844, p = .081 \)) and significantly faster in the Predictive Cue condition (Averted \((M = 1567, SD = 560.9)\), Direct \((M = 1419, SD = 431.0)\), \( t(19) = 4.470, p < .001 \)). As predicted, RTs in the Predictive Cue Condition were faster for Direct Gaze than Averted Gaze Targets.

In marked contrast to conditions in Experiments 5.3 and 5.4, in which gaze uniqueness had been informative, Experiment 5.5 found no evidence of any averted gaze bias, now that gaze direction itself was task relevant. Also in contrast to those other conditions, where no difference in RTs to direct versus averted gaze targets had been detected, there was now a clear RT benefit for Direct Gaze Targets, in both Predictive Cue and Nonpredictive Cue conditions. These patterns in the Predictive Cue condition were highly consistent with the findings from Chapter 4 that top-down influences on the basis of instructions always favour RTs to direct gaze targets relative to averted, but not search, i.e., ‘Process 2’. This same influence in the Nonpredictive Cue condition, but a complete absence of such effects in the Informative Gaze conditions of Experiments 5.3 and 5.4, indicated that the presence of a cue had eradicated evidence of an averted gaze bias that was otherwise robustly evident under comparable conditions without the cue. It was concluded that both types of cue (predictive and nonpredictive) had elicited top-down influences. This is intuitively plausible given that predictive cues (either indicating direct or averted gaze) had previously yielded effects in RT exclusively to direct gaze targets (Chapter 4) — establishing an explicit expectation of any particular gaze speeds responses only to direct gaze.
7. Supplementary Bayesian Analysis

Standard NHST analyses had revealed a clear overall bias to averted gaze, as predicted by PC models, and in direct contradiction of the current consensus. This appeared not to reflect a greater attentional pull of averted gaze over direct, as no evidence for this bias had been found when there was no ‘odd one out’ gaze (Set Size 2 conditions and Experiment 5.2, Set Size 4) or when observers were prompted to look for a specific gaze type rather than searching for generic unique gaze (Experiment 5.5). However, NHST statistics did not distinguish whether those findings reflected a genuine absence of an averted gaze effect, or alternatively, insensitivity of the data (e.g., Dienes, 2014). To weigh the relative evidence for these two possibilities, NHST statistics were supplemented with Bayesian t-tests (JASP team, 2018, Wagenmakers et al., 2018, JSZ prior centred on zero, Cauchy’s width, 707).

7.1 Displays with no unique gaze

In displays with no unique gaze – Set Size 2 displays comprising one direct, one averted gaze, or Set Size 4, comprising two of each gaze (Experiment 5.2) – no evidence had been found for an averted gaze bias. Pooling Set Size 2 scores from Experiments 5.1 and 5.2 to maximise power to detect any bias, the proportion of initial saccades to Averted versus Direct Gaze Active Nontargets were compared, subjecting this to a one-sample Bayesian t-test as described above. This found moderate evidence in favour of the null hypothesis ($BF_{10} = 0.238$), concluding that no gaze bias had arisen for those displays. Similarly, for Experiment 5.2, Set Size 4, evidence moderately supported the null hypothesis ($BF_{10} = 0.260$). Thus, in both types of display without a unique gaze significant, evidence had been found for no gaze bias.

7.2 When observers are prompted to search for a particular gaze

There had also been no evidence of a gaze bias when there was a unique gaze, but the presence of a pre-display cue encouraged observers to think about a specific gaze type rather than applying an odd-one-out-strategy. A Bayesian t test, for proportion of initial saccades to Averted versus Direct gaze pooled across Predictive and Nonpredictive conditions in Experiment 5.5 revealed moderate evidence in favour of the null hypothesis ($BF_{10} = 0.232$). Again, this suggested that there had been no averted gaze bias.

7.3 An uncertain case: irrelevant unique gaze

Although an averted gaze bias had been observed for Unique, task-irrelevant gaze in Experiment 5.1, similar conditions in the Uninformative Gaze Conditions of Experiments 5.3 and 5.4 found no such evidence. Pooling this data across Experiments 5.3 and 5.4, revealed that the data were insensitive ($BF_{10} = 0.488$). Thus, here, there was less evidence to support
the absence of an averted gaze bias. It is possible either that the intermixture of Set Size 2 trials in Experiment 5.1 (with no unique gaze), but not in Experiments 5.3 and 5.4, highlighted gaze uniqueness in Set Size 4 trials in Experiment 5.1, or equally, that the initial finding may have been a Type 1 Error. None of this would detract from the strong averted gaze biases detected in Experiments 5.3 and 5.4 (with informative unique gaze).

To summarise the outcomes of this supplementary Bayesian analyses, no evidence for an averted gaze bias was found if: (1) no gaze in a display was unique (i.e., no odd-one-out gaze), (2) observers were prompted to look for a particular gaze rather than to search for gaze on the basis of its uniqueness. That is, the averted gaze bias, predicted to arise by PC models on account of yielding prediction error, was only observed when an odd-one-out gaze was present and its uniqueness highlighted. In terms of a given display, searching for the odd-one-out gaze could be interpreted as searching for within-display prediction error. These findings suggested therefore, that there was no overall bias toward direct gaze or averted gaze, except when observers were searching for within-display prediction error regarding gaze.
8. Discussion

It is often presumed that direct gazing eyes cue attention to themselves more powerfully than do averted gazing eyes. The mechanism for such an attentional ‘pull’ might be described as an innately specified preference for direct gaze (e.g., Farroni et al., 2002), given its obvious importance across species, or as the result of a direct gaze Bayesian prior (e.g., Mareschal et al., 2013, 2014) that speeds processing of direct gaze eyes (Chapter 4), biasing competition for attention toward them. In contrast, PC models more naturally support the opposite prediction, that averted eyes, deviating from the predictions of a direct gaze prior distribution, generate larger prediction error signals and should therefore attract attention more than direct gaze. These opposing predictions render an apparently simple question – whether it is direct gaze or averted that exerts the greater pull on attention – a pivotal battleground for opposing predictions of two much larger perspectives (a recent review by Press et al., 2019 terms this opposition a ‘perceptual prediction paradox’).

The aim in this chapter had been to experimentally test for gaze prioritisation within the visual system and gain insight into which model might best describe this. The previous chapters had demonstrated a clear benefit for detecting direct gazing eyes from among averted gazing ones than vice versa, a finding consistent with a greater attentional pull of direct gaze. These findings, however, could not speak to whether direct gaze would exert increased self-cueing when gaze was rendered irrelevant. Experiment 5.1 investigated the cueing ability of odd-one-out gaze, when that gaze was task-irrelevant, measuring rapid allocation of overt attention (and, by extension, covert attention) in first fixations. On the basis of previous literature, stronger exogenous cueing by direct gaze was predicted, i.e., a greater proportion of first fixations to Direct Gaze Active Nontargets than Averted, at both Set Sizes 2 and 4. However, results showed the opposite pattern — observers had made a greater proportion of first fixations to Averted Active Nontargets, only at Set Size 4. Thus, in contrast to the large majority of previous literature suggesting an attentional prioritisation for direct gaze over averted, Experiment 5.1 had found initial evidence for an averted gaze cueing effect that fit better with PC models than the Direct Gaze Salience view.

Next, Experiment 5.2 investigated whether a gaze must be unique within a display in order to observe the effect seen in Experiment 5.1. That would offer one account of why no effect had been evident at Set Size 2 in that study. In Experiment 5.2, the Set Size 4 displays comprised two faces with direct gaze, two with averted (i.e., no gaze was unique). Now, no gaze bias was observed at either Set Size 2 or 4. Whatever the explanation for this pattern, it
was already clear that despite clear evidence of direct gaze priors in previous findings, neither direct nor averted gaze exerted a stronger pull on attention in Experiments 5.1 and 5.2.

One important assumption of PC and other Bayesian models is that predictability of stimulus patterns within an experiment plays a key role in mediating effects of longer-term representations (e.g., Geng & Behrmann, 2005; van Moorselaar & Slagte, 2019; Wang & Theeuwes, 2018). To investigate the possibility of such predictions having played a role in Experiment 5.1, Experiments 5.3 and 5.4 explicitly manipulated this variable. Observers searched for gaze in two different conditions — Informative, where unique gaze predicted target location, and Uninformative, where unique gaze was not a reliable indicator of target location. Across both experiments results found that when unique gaze reliably predicted target location (i.e., the target had a unique gaze in each display), it was unique averted gaze that exerted a stronger attentional pull rather than direct. When, instead, unique gaze was irrelevant to the target’s location, this effect was no longer reliable; though, unexpectedly, the averted gaze advantage was only marginally greater in the task-relevant condition versus task-irrelevant condition, even combining the two experiments’ data. It is speculated that in the task-irrelevant conditions, some participants may have spontaneously treated gaze as task-relevant (this was not affected by run order), whereas this would be uniformly the case in task-relevant conditions.

Despite not finding a clear unique gaze advantage for Informative versus Uninformative conditions, it was apparent that opposing attentional processes had operated in the present set of experiments — one, perhaps guided by prediction error, that resulted in exogenous cueing by unique averted gaze and another, guided by prior expectations, which facilitated attention to direct gaze targets. The former process, interestingly, did not seem, in isolation, to influence RTs overall — observers were no faster to respond to one target gaze type over the other in the Informative condition for both Experiments 5.3 and 5.4. However, the absence of an averted gaze bias was associated with an RT benefit (evident in Experiment 5.2, Set Size 4; see Appendix, Table 1). It is speculated that the differing RT effects associated with the averted versus direct gaze biases were simply a function of a gaze-related top-down template (‘Process 2’ as described in Chapter 4), that speeds recognition of individual direct gaze faces as targets when there is no averted gaze bias, obscuring an RT advantage when there is an averted gaze bias.

Also requiring clarification were the incongruent results between the near-identical conditions of Experiment 5.1, Set Size 4 and the Uninformative conditions of Experiments 5.3 and 5.4 (a clear averted gaze bias only in the former case). One key point of difference
was that Experiment 5.1 had Set Size 2 trials intermixed with Set Size 4. At Set Size 2, with only two faces in the display, one direct gazing face would not have represented enough instances of the norm against which one averted gazing face could set up a prediction error, and thus averted gaze would have been unable to exert an exogenous pull on attention. Equally, a single direct gaze would not have been able to guide attention, resulting in observers having had to look at both faces to make a target decision. This inability to apply a search strategy at Set Size 2 may have then interfered with the chance to employ a direct gaze biased search strategy at Set Size 4, leading to prediction error processes creating the averted gaze pull instead.

In Experiments 5.3 and 5.4, even when gaze was informative regarding the target’s location, it was only on the basis of gaze uniqueness — whether any given face had direct or averted gaze had no predictive value. To assess the importance of this latter source of predictability, Experiment 5.5 investigated the potential role of prior knowledge of target gaze direction on whether averted or direct gaze exerted a stronger pull on attention. When observers were provided with explicit information regarding the (again, unique) gaze of the subsequent target no difference was found in proportion of first fixations to either gaze type in both the Predictive and Nonpredictive conditions. However, the proportion of initial saccades made to targets overall, irrespective of gaze type, was greater in the Predictive condition. This suggested that while observers had been able to treat the two instructions separately, precise predictability played no role in driving initial attention.

Across both conditions, RTs to Direct Gaze Targets were faster than to Averted, this advantage corresponding to a SITCE. In the case of the Predictive condition, it may have been that top-down templates facilitated greater prior evidence weighted towards direct gaze, obviating any predication error from being set up; however, RTs to Direct Gaze were preferentially sped up in the Nonpredictive condition as well where no gaze-relevant template had been presented. Again, it appeared that precise predictability was not a factor in speeding responses to Direct Gaze over Averted. It may be the case that the RT advantage in the Nonpredictive condition was as a result of viewing the nonpredictive cue for the same time duration as the predictive one — seeing a string of the letter ‘X’ may have encouraged observers to guess the likely target gaze rather than looking for uniqueness.

Across five experiments, results suggest that neither direct nor averted gaze exert a uniformly strong pull on attention. A paradigm that accounts only for Direct Gaze Salience or one that takes into account PC models does not suffice to explain the complex interplay of processes that guide attention in these experiments. The addition of implicit learning to a PC
framework was also inadequate to explain results — neither prediction benefits nor an effect of prediction error seemed to accrue for items independently. Instead, prediction error seemed to play a much greater role when unique (odd-one-out) gaze was present, particularly when observers were searching for the target on the basis of that uniqueness. This process of searching for prediction error appeared to be disrupted/obscured when search conditions encouraged observers to make specific predictions about target features.

![Figure 9](image)

**Figure 9.** Density plots for initial saccade onset latencies in the Informative Gaze conditions of Experiments 5.3 and 5.4, separately for saccades directed to Averted Gaze and Direct Gaze Targets.

A recent paper (Press et al., 2019) has proposed an insightful resolution to the apparent opposition between the two theoretical frameworks — that different mechanisms use the same priors first, to bias perception toward stimuli that conform to the likeliest prior, and subsequently to drive processing of those stimuli that yield larger prediction errors — which can be termed a timing view. On the basis of this view, we could potentially expect to see a direct gaze bias at shorter saccade latencies and an averted gaze bias at longer latencies. In contrast, the present results suggest an alternative — the direct or averted gaze bias should be observed irrespective of saccade latency, but entirely as a function of gaze uniqueness (within
a display). This view is based on the finding that a clear benefit for objects eliciting larger prediction error signals (unique, averted gaze) was observed only when the task prompted observers to attend to within-display prediction error, which would be consistent with the idea that the crucial determinant of whether predictions will favour processing of expected or unexpected stimuli is task demand, i.e., information required to perform the task.

To examine this question, rapid initial saccades toward the face stimuli (typical of those observed for repeated face stimuli and limited spatial saccade targets, e.g., Crouzet et al., 2010; Visconti & Gobbini, 2015) were analysed. These results are plotted in Figure 9—a striking evidence for the averted gaze bias from the most rapid (short latency) saccades in the Informative Gaze conditions in Experiments 5.3 and 5.4. Thus, in the case of the present results, at least, whether expectation or prediction error has the greater enhancing effect upon attention, appears to be a function, not of timing nor of stimulus-visibility (equated in the present experimental conditions), but of the information selected within particular layers of a network by top-down attention—i.e., by the demands of the task.

Thus, it must be assumed that predictions are dynamic processes that evolve as a display is processed. Indeed, nuanced conceptualisations of PC models (e.g., Friston, 2010; Bastos et al., 2012; Kanai et al., 2015) propose that a prediction error being set up depends on the extent to which priors are released from their restrictions—if top-down representations are afforded greater priority, prediction error at lower levels is re-weighted towards zero, and if top-down representations are released from their limits, prediction error signals are then set up. Based on the experiments here, it is proposed that the mechanism for top-down representations to either be released or strengthened lies in the mode of processing activated by observers—a between-gaze difference signal, which sets up prediction error (observed in Experiment 5.1 and Informative conditions of Experiments 5.3 and 5.4) or a within-gaze comparison, which strengthens top-down representations, and can speed responses to target (observed in Experiment 5.5).

To summarise, across five experiments, a clear bias toward averted gaze was found when the task called for observers to pay attention to within-display prediction error; in all other cases, this effect was weak or absent. These findings are in contradiction to current consensus on the preferential allocation of attention to direct gaze and an intuitive understanding of its socio-cognitive importance. The few predictive coding perspectives that make a clear prediction for this example fared somewhat better but were still inadequate. The present results suggest that in these gaze-coding examples, the information sought by top-
down attention, not stimulus timing, determined whether predicted or unpredicted stimuli were preferentially processed.
9. Appendix

### Table 1

RTs to Odd-one-out Gaze

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Averted</th>
<th>Direct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Experiment 5.1, Set Size 2</td>
<td>1479</td>
<td>275.4</td>
</tr>
<tr>
<td>Experiment 5.1, Set Size 4</td>
<td>2288</td>
<td>613.8</td>
</tr>
<tr>
<td>Experiment 5.2, Set Size 2</td>
<td>1299</td>
<td>296.2</td>
</tr>
<tr>
<td>Experiment 5.2, Set Size 4</td>
<td>2206</td>
<td>712.5</td>
</tr>
<tr>
<td>Experiment 5.3, Uninformative condition</td>
<td>1911</td>
<td>517.5</td>
</tr>
<tr>
<td>Experiment 5.3, Informative condition</td>
<td>2167</td>
<td>695.3</td>
</tr>
<tr>
<td>Experiment 5.4, Uninformative condition</td>
<td>1832</td>
<td>391.3</td>
</tr>
<tr>
<td>Experiment 5.4, Informative condition</td>
<td>1991</td>
<td>373.3</td>
</tr>
<tr>
<td>Experiment 5.5, Nonpredictive condition</td>
<td>1985</td>
<td>535.4</td>
</tr>
<tr>
<td>Experiment 5.5, Predictive condition</td>
<td>1567</td>
<td>560.9</td>
</tr>
</tbody>
</table>

*Note: odd-one-out gaze is the Active Nontarget in the uninformative cases (Experiments 5.1, 5.2, and 5.3 and 5.4 Uninformative) and the Target in the informative cases (Experiments 5.3, 5.4, and 5.5)*

Table 1. Reaction times to odd-one-out gaze (Active Nontarget or Target depending on experiment and condition) across all experiments

### Table 2

Proportion of initial saccades to Targets in Experiments 5.1, 5.2, 5.3, and 5.4

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Averted</th>
<th>Direct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment 5.1, Set Size 2</td>
<td>0.45</td>
<td>0.46</td>
</tr>
<tr>
<td>Experiment 5.1, Set Size 4</td>
<td>0.25</td>
<td>0.24</td>
</tr>
<tr>
<td>Experiment 5.2, Set Size 2</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Experiment 5.2, Set Size 4</td>
<td>0.22</td>
<td>0.24</td>
</tr>
<tr>
<td>Experiment 5.3, Uninformative condition</td>
<td>0.21</td>
<td>0.27</td>
</tr>
<tr>
<td>Experiment 5.4, Uninformative condition</td>
<td>0.24</td>
<td>0.27</td>
</tr>
</tbody>
</table>

Table 2. Proportion of initial saccades to Targets in Experiments 5.1, 5.2, 5.3, and 5.4
This chapter has been written-up for publication:
Ramamoorthy, N., Jamieson, O., Imaan, N., & Davis, G (to be submitted). Enhanced search for eyes gazing at an object: Evidence for explicitly social processing in visual search


1. Introduction

The human eye’s unique darker-iris lighter-sclera morphology (Kobayashi & Kohshima, 1997) renders it the only sensory modality that it is able to both perceive social information and communicate this to others (e.g., Cañigueral & Hamilton, 2019; Gobel, Kim, & Richardson, 2015). The special status accorded to gaze, believed to form the foundation for social development (e.g., Charman et al., 2000; Tomasello, Carpenter, Call, Behne, & Moll, 2005), is emphasised by gaze stimuli activating a network of brain regions associated with social perception and cognition, often referred to as the ‘social brain’ (e.g. Carlin & Calder, 2013; McCrackin & Itier, 2019). Given their crucial importance, visual attention would be expected to be drawn toward eyes, when they are present. But not all eyes need be of equal priority — those gazing toward us (direct gaze) or at other important objects and events may hold particularly important information and may be prioritised over other gazes during search.

Previous work on this topic has largely compared *direct* gaze with *averted* gaze, which differ from each other in terms of both physical properties and social implications. Direct gaze, intuitively assumed to be of greater importance, has been reported to engage attention more effectively (Senju & Hasegawa, 2005; Ueda et al., 2014), even when task irrelevant (Bockler et al., 2014; Doi & Shinohara, 2013; Yokoyama, et al. 2014). Perhaps the best-known example of the reported preferential processing for direct gaze relative to averted is the SITCE, which suggests that attention is more readily guided toward direct gaze than averted gaze targets; however, the mechanisms underpinning such attentional guidance remain unclear. On one hand, this may reflect explicit social processing in search mechanisms that guide attention across multiple-gaze displays, i.e., processes that explicitly code eye gaze as looking at an object of salience, whether that be the observer or another object (e.g., Baron-Cohen, 1994, 2005 (the Eye Direction Detector model); Becchio, Bertone, & Castiello, 2008; Mareschal et al., 2013, 2014; Pantelis & Kennedy, 2016). However, two simpler possibilities exist. First, direct gazing eyes may simply be *intrinsically* more salient than averted gazing ones, even to a visual system not sensitive to gaze information. The
human eye’s unique morphology may give rise to a stronger luminance-contrast signal for direct gaze than averted, guiding attention without the observer needing to code gaze at all. Human eyes seem to have evolved to be salient signals (to communicate with direct gaze). Accordingly, human direct gaze may simply be a more physiologically salient signal than averted gaze, and human vision need incorporate no special biases to attend it, other than a standard bias toward more salient stimuli — gaze studies employing cartoon stimuli (e.g., Lyyra et al., 2018, Yokoyama et al., 2011) and those with naturalistic eyes that do not control for iris-sclera ratio (e.g., Conty et al., 2006; Mares et al., 2016) are automatically subsumed within this explanation. Second, given direct gaze’s presumed importance, human vision may incorporate a perceptual template — perhaps unconscious (e.g., Madipakkam, Rothkirch, Guggenmos, Heinz, & Sterzer, 2015), perhaps innately specified (e.g., Farroni et al., 2002; Senju & Johnson, 2009b) — that need only specify direct gaze’s physical properties (circular iris often with similar areas of sclera evident either side), without the need to code spatial relationships between gazing eyes and objects in a display.

The question, then, is which is the underlying mechanism that drives preferential gaze processing — whether simpler perceptual templates tuned to visual, rather than social, features of gaze, or, instead, more sophisticated socio-cognitive coding. Some evidence has been found for gaze-object relations being able to cue attention to targets — e.g., observing eye contact between two faces presented at fixation speeds up response times to subsequently presented targets as compared to both faces looking away from each other (Böckler, Eskenazi, Sebanz, & Rueschemeyer, 2016; Böckler, Knoblich, & Sebanz, 2011), viewing congruent attentional shifts to targets by direct gazing rather than averted gazing eyes speeds response times (Bristow, Rees, & Frith, 2007) — although these do not answer whether such processes can guide search. A separate body of literature suggests that visual search for objects can be influenced by contextual cues. The contextual cueing hypothesis (first put forth by Chun & Jiang, 1998) proposes that repeated exposure to a specific spatial arrangement of target and distracters, i.e., the visual context, progressively speeds up target search (Brockmole & Henderson, 2006; Chua & Chun, 2003; Jiang & Chun, 2001; Olson & Chun, 2002). However, other work finds that repeated spatial arrangements may only partially lead to contextual cueing (Schlagbauer, Müller, Zehetleitner, & Geyer, 2012) and that contextual cues do not influence search efficiency in a standard visual search task, typically, salient targets would be expected to show shallower search slopes, (Kunar, Flusberg, Horowitz, & Wolfe, 2007). Thus, this literature only partially points to contextual cues being able to influence search and certainly does not do so for social stimuli.
A key assumption made in the SITCE, but one that has not yet been explicitly investigated, is that direct gaze is contextually more salient than averted because observers intuitively understand themselves to be the socially relevant object being looked at or looked away from. A formal test of this suggestion would require not only direct gaze to be detected faster from amongst averted gaze distracters, but any contextually salient target gaze (including non-direct) to be detected from amongst contextually non-salient gaze distracters. The present set of experiments examined visual search for eyes *gazing at* a prominent object versus *gazing away* (i.e., not gazing at any prominent object), thus allowing for the same stimuli to be both target and distracter, differing only in terms of which side the object was presented. Such an approach uniquely enables a distinction between stimuli on the basis of mental state attribution, but not on the basis of their physical characteristics; providing a basis to untangle the differing explanations outlined above. Experiment 6.1 presented only averted gazes within the visual search format, defining the target by its relationship to a salient object (an image of the Statue of Liberty), whether looking toward it (congruent) or away from it (incongruent). An explicit social processing view would predict faster and more efficient response times to congruent gaze than incongruent, while a simpler perceptual template approach would not distinguish between the two gaze conditions. Experiment 6.2 was designed to clarify the pattern of results found in Experiment 6.1, making gaze relevant to the task, rather than merely the odd-one out.
2. Experiment 6.1: Visual search for contextually defined eye gaze

2.1 Methods

The aim of this experiment was to investigate whether visual search for gaze could be driven by a salient social context (rather than a simpler perceptual difference between target and distracter gazes). Drawing a parallel between the SITCE and the present, ‘stare at the object’, paradigm, it was predicted that search would be more efficient for congruent gaze eyes (looking toward the contextually salient image) than incongruent gaze ones (looking away from the image); the effect represented by shallower search slopes.

2.2 Observers and Sample Size

It was estimated that 24 observers would suffice to detect medium-large effects (Cohen’s $f = 0.33$ / Cohen’s $d = 0.65$) of interest in an RM ANOVA with one group and three measurements (G*Power 3.0 software; Faul et al., 2007). University students ($m = 18, f = 6$, ages 18-35) were recruited from posters and an online volunteer recruitment system, and paid £7 for participating.

2.3 Apparatus and Stimuli

Observers sat 70 centimetres from a 24-inch Dell monitor (model number SE2416H, screen resolution 1920 x 1080), and made responses using a standard USB keyboard. Stimuli were presented using E-Prime 2.0 software (Psychology Software Tools Inc., 2013). Search displays were arrays of oval-cropped, forward-facing faces looking either to the left or right of the observer (same stimuli as those used in Experiment 2.1 but made larger). A Statue of Liberty image (hereon ‘SoL’, downloaded from an open source image database) was converted to greyscale and formed the prominent object toward which, or away from which, eyes might gaze in a display.

Each individual face (279 x 370 pixels) subtended a visual angle of approx. $6^\circ \times 8^\circ$ retinal angle. Faces were arranged in groups of 7 and 3 centrally around an imaginary circle of approximately 258 mm diameter. The faces at Set Size 7 were all arranged in the same configuration, while those at Set Size 3 were arranged in three, equal-spacing configurations to counter effects of clustering in any one region of the display. A snapshot of the eye region from the left or right gazing faces (105 x 96 pixels), subtending an angle of approximately $2^\circ$ square, was used as the pictorial cue preceding cued trials. An image of the Statue of Liberty (329 x 839 pixels), subtending a visual angle of approximately $7^\circ \times 18^\circ$, was placed either to the left or right of the faces.
2.4 Procedure

Figure 1. Schematised sequence of displays in a typical trial from Experiment 6.1 (Set Size 7, Congruent Gaze Target, T = target location).

Figure 1 schematises a typical display sequence in trials from Experiment 6.1. Each trial presented a fixation cross (1500 ms), then a ‘placeholder’ display of three or seven faces with eyes closed (250 ms) followed by a search display of the same faces with eyes opened, lending a naturalistic impression of eyes opening. At the same time that the placeholder stimuli appeared, the SoL image also appeared on screen, either to the right or left of the faces. A tall object was chosen such that faces at any position on the screen might conceivably be looking at the object. Observers were instructed to find the odd-one-out, unique target gaze in the display (present, unpredictably on half of trials) when the eyes opened and make one of two keyboard responses as quickly as possible to indicate whether a target was present or not. Targets were either left averted gaze among right averted faces or right averted gaze among left averted faces.

As shown in Figure 1, on 75% of trials, a pictorial target cue signalling the gaze of the unique target face in the subsequent search display informed observers as to which direction (left or right) the unique target gaze would gaze (no cue on remaining 25%). Orthogonally to this task, whether the target, if present, gazed toward a prominent object or not was manipulated — whether it gazed toward the SoL (and the distracters gazed away) or vice versa. The former condition was termed ‘congruent’ target gaze, the latter, ‘incongruent’ target gaze. This congruency in Experiment 6.1 was entirely task-irrelevant — observers were only instructed to detect the unique gaze in each display. The search task began with a
practice block (12 cued trials, 3 trials of each unique combination, and 4 uncued trials, 1 trial of each unique combination). Observers received feedback on their responses (“Correct!” = correct response, “------” = incorrect response). The main experimental trials followed, with no feedback, and were presented as 5 blocks of 64 trials, with each block having the same ratio of cued to uncued trials. Each block was followed by a 10 second break.

2.5 Results and Discussion

![Figure 2](image)

**Figure 2.** Mean Response Times (accuracy rates in parentheses) for Congruent and Incongruent Gaze Targets in Target Present and Absent conditions, separately at Set Sizes 3 and 7 for (A, B) Cued condition and (C, D) Uncued condition of Experiment 6.1. Error bars indicate +/-1 SEMpairediffs.

For each observer (N= 24), RT data for accurate responses (Cued, $M= 93.48$, $SD= 0.04$; Uncued, $M= 93.59$, $SD= 0.06$) were trimmed to exclude any RTs ±3 standard deviations for Cued and Uncued trials separately, for each combination of Target Presence, Congruence, and Set Size. Since accuracy was generally high, these data were not analysed any further. One participant had to be removed as even post trim their RTs exceeded limits in both Cued and Uncued trials, while another’s data was lost due to a technical error during acquisition. As the key factor being investigated was context salience (i.e., where the target eyes were looking in relation to the SoL), the Target Gaze condition was collapsed.

Figure 2 plots mean RTs for Congruent and Incongruent trials at each Set Size, separately for Target Present and Target Absent Trials (2A and 2B: Cued Trial RTs, 2C and
2D: Uncued Trial RTs). While search slopes (increases in RT from Set Size 3 to 7) appeared similar for Congruent and Incongruent trials in the Target Absent condition, the same could not be said for the Target Present one. Instead, there appeared to be no effect of Congruence for Cued trials, but the predicted effect of Congruence for Uncued trials (shallower search slopes for Congruent than Incongruent trials).

A four-way ANOVA with factors of Cue (Cued, Uncued), Congruence (Congruent or Incongruent), Target Presence (Present or Absent), and Set Size (3 or 7) yielded main effects of Target Presence \[ F(1, 21) = 23.198, \ p < .001, \ \eta_p^2 = .525 \] and Set Size but not of Congruence \[ F(1, 21) = .2.730, \ p = .113, \ \eta_p^2 = .115 \] or Cue \[ F(1, 21) = .328, \ p = .573, \ \eta_p^2 = .015 \]. The standard Target Presence x Set Size interaction was significant \[ F(1, 21) = 46.483, \ p < .001, \ \eta_p^2 = .689 \], as was the Cue x Set Size one \[ F(1, 21) = 7.549, \ p = .012, \ \eta_p^2 = .264 \]. The three-way interactions which were significant were all qualified by the significant four-way interaction \[ F(1, 21) = 5.217, \ p = .033, \ \eta_p^2 = .199 \].

Since all terms of interest involved search efficiency, the dependent variable for the follow-up analyses was simplified by calculating search slopes for each condition and observer (RT for Set Size 7 minus RT for Set Size 3). The resulting three-way interaction was first analysed by Target Presence – independent two-way ANOVAs for Target Present and Target Absent trials – as this could make clear assumptions about the search process. For Target Present trials, a two-way ANOVA revealed a marginal effect of Cue \[ F(1, 21) = 4.088, \ p = .056, \ \eta_p^2 = .163 \], a main effect of Congruence \[ F(1, 21) = 8.299, \ p = .009, \ \eta_p^2 = .395 \], and, as expected, an interaction of the two factors \[ F(1, 21) = 7.116, \ p = .014, \ \eta_p^2 = .253 \]. For Target Present trials, this interaction reflected shallower search slopes (more efficient search) for Congruent than Incongruent Gaze targets in Uncued trials \( (t(21)= -2.518, \ p = .020) \), but not for Cued trials \( (t(21)= 1.051, \ p = .305) \). Corresponding analyses for Target Absent trials revealed no main effect or interaction (all \( F \) values < 0.4, \( p \) values > .539). Together these findings indicated that for Uncued Target Present trials, search had been more efficient for Congruent than Incongruent Gaze, as had been predicted, and that this effect was reduced or absent when a prior cue was provided as to the target’s gaze. There was no evidence of such effects in Target Absent trials, consistent with the effect in Target Present trials reflecting biased attentional guidance toward Congruent Gaze targets when they were present, rather than faster serial rejection of (congruent or incongruent) distractors — the latter would be typically associated with larger absolute effects of Congruence on RTs in Target Absent trials than Target Present ones.
A second route to investigating the three-way interaction was to split the analysis into Cued and Uncued trials. This alternative analysis was perhaps less powerful, and harder to interpret, given the greater variability of Target Absent search slopes, but was nevertheless conducted to thoroughly investigate the pattern underlying the three-way interaction. The two-way ANOVA for Cued trials revealed only a main effect of Target Presence \( F(1, 21) = 8.817, \ p = .007, \ \eta^2_p = .296 \), and no main effect of Congruence \( F(1, 21) = 1.652, \ p = .213, \ \eta^2_p = .073 \), or interaction of the two \( F(1, 21) = 0.138, \ p = .714, \ \eta^2_p = .007 \). For Uncued trials, there was a significant main effect of Target Presence \( F(1, 21) = 51.813, \ p < .001, \ \eta^2_p = .712 \), only a marginal main effect of Congruence \( F(1, 21) = 2.972, \ p = .099, \ \eta^2_p = .124 \), and a marginal interaction of the two factors \( F(1, 21) = 3.480, \ p = .076, \ \eta^2_p = .142 \). While these findings were consistent with the clear patterns in the more powerful, primary analysis, this would require confirmation in further experiments.
3. Experiment 6.2: Task-relevant versus Task-irrelevant Contextual Salience

3.1 Methods
Experiments 6.2a and 6.2b largely replicated the conditions of Experiment 6.1, but with two important exceptions. First, each observer now only experienced Cued (Experiment 6.2a) or Uncued (Experiment 6.2b) trials, yielding a far more powerful index of Congruence effects within each Cue condition individually. Second, to maximise the opportunity to see Target Gaze Congruence effects (target gazing toward the SoL, versus gazing away), this feature was now task-relevant — that is, the side on which the SoL was presented was 100% informative as to which side the target would gaze in any block of trials (half of the blocks of trials comprised only Congruent Gaze targets, the remainder, only Incongruent Gaze ones). Based on results from Experiment 6.1, it was predicted that Experiment 6.2a would find little or no effect of Congruence (or, at least, reduced, relative to Uncued conditions), but that Experiment 6.2b would find an effect, likely stronger than Experiment 6.1 now that Congruence was task-relevant. Again, these effects were expected to arise in Target Present rather than Target Absent trials.

3.2 Observers and Sample Size
For Experiments 6.2a and 6.2b, the same calculations as for Experiment 6.1 were applied (24 observers per study). They were run consecutively, but the total sample (48 observers, \( m = 29, f = 19 \)) was estimated to be sufficient for cross study of within-between interactions (Cohen’s \( f = 0.33 \), two groups, four measures, power = 0.8).

3.3 Apparatus, Stimuli, and Procedure
Experiments 6.2a (Cued) and 6.2b (Uncued) replicated the conditions of Experiment 6.1, with the following exceptions. First, trials were now divided into two blocks of 120 trials each, with each block of only one Congruence type (run order for Congruent and Incongruent blocks counterbalanced across observers). The side on which the SoL appeared (only 250 ms prior to the search display, along with placeholder faces) provided entirely valid cueing as to where the unique target gaze would be directed, thus making Target Gaze Congruence task-relevant in the present experiments. Second, while Experiment 6.2a supplemented this information with a prior cue as to the direction of target gaze (left or right, as in Cued trials of Experiment 1), Experiment 6.2b did not (as in Uncued trials of Experiment 6.1).
### 3.4 Results and Discussion

**Figure 3.** Mean Response Times (accuracy rates in parentheses) for Congruent and Incongruent Gaze Targets in Target Present and Absent conditions, separately at Set Sizes 3 and 7 for (A, B) Cued condition and (C, D) Uncued condition of Experiment 6.2. Error bars indicate +/-1 SEM_{paired}.

Accuracy was again high for both experiments (6.2a: $M = 96.6$, $SD = 0.02$, 6.2b: $M = 96.5$, $SD = 0.02$) and not analysed further. One participant had to be removed from each experiment, as even post trim their RTs exceeded limits. Figure 3 plots RTs for conditions in Experiments 6.2a and 6.2b in the same format as Figure 2. Inspection of the plots suggested that search slopes were shallower for Congruent than Incongruent Gaze targets in the Target Present trials of Uncued conditions (Experiment 6.2b), as in Experiment 6.1; however, this also appeared to be the case for Target Absent trials of that condition. This pattern was, again, as in Experiment 6.1, not evident for Target Present trials in the Cued condition (Experiment 6.2a), although this was not as clear for Target Absent trials.

Following Experiment 6.1, analyses were conducted on search slopes as the dependent variable, calculated in the same manner as before. An omnibus three-way ANOVA (factors of Congruence and Target Presence as for Experiment 6.1, Cue now between observers) revealed standard effects of Target Presence [$F (1, 44) = 111.669, p < .001, \eta^2_p = .717$], Congruence [$F (1, 44) = 12.087, p < .001, \eta^2_p = .215$] and a marginal Congruence by...
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Cue interaction \([F (1, 44) = 2.914, p = .095, \eta^2_p = .062]\) but no other main effects or interactions (all \(F\) values < 1.2 , \(p\) values > .278). This pattern of findings supported conclusions from Experiment 6.1 that search for Uncued Congruent Gaze targets is more efficient than for Incongruent Gaze targets.

To thoroughly explore the pattern of findings underpinning this confirmation, follow-up analyses were repeated motivated by findings from Experiment 6.1. Analysis was first split by Target Presence. A two-way mixed ANOVA on Target Present trials (factors of Cue and Congruence only) yielded a marginal effect of Congruence \([F (1, 22) = 3.538, p = .067, \eta^2_p = .074]\), no main effect of Cue \([F (1, 22) = 1.682, p = .201, \eta^2_p = .037]\), and a clear interaction between the two-factors \([F (1, 22) = 5.484, p = .024, \eta^2_p = .111]\). This reflected substantially more efficient search for Congruent than Incongruent targets for Uncued trials \([t(22)= -2.833, p=.010]\) but not for Cued trials \([t(22)= .346, p=.733]\). An identical ANOVA on Target Absent trials yielded only a main effect of Congruence \([F (1, 22) = 9.419, p = .004, \eta^2_p = .176]\), but no main effect of Cue \([F (1, 22) = 1.171, p = .285, \eta^2_p = .026]\), or evidence of an interaction between the two factors \([F (1, 22) = .072, p = .789, \eta^2_p = .002]\). Accordingly, both Target Present and Target Absent trials now showed evidence of Congruence effects in Experiments 6.2a and 6.2b.

Finally, to confirm patterns of search efficiency within Cued and Uncued trials individually, two-way repeated-measures ANOVAs were conducted for each experiment individually. First, this was run for Uncued trials (Experiment 6.2b) for which there were clear reasons to expect an effect of Congruence on search efficiency. This yielded clear main effects of Congruence \([F (1, 22) = 10.609, p = .004, \eta^2_p = .325]\) and Target Presence \([F (1, 22) = 46.104, \eta^2_p = .507]\), with no evidence of an interaction between the two \([F (1, 22) = .030, p = .863, \eta^2_p = .001]\). That is, search for Congruent targets was clearly more efficient than for Incongruent targets — now, seemingly, irrespective of Target Presence.

Corresponding analyses of Cued trials (Experiment 6.2a) yielded no main effect of Congruence \([F (1, 22) = 2.134, p = .158, \eta^2_p = .037]\) a main effect of Target Presence \([F (1, 22) = 1.682, p = .201, \eta^2_p = .088]\), and a marginal interaction \([F (1, 22) = 3.658, p = .069, \eta^2_p = .143]\) such that search was marginally more efficient in Congruent than Incongruent trials, but only in the Target Absent condition.

Experiments 6.2a and 6.2b therefore provided strong confirmation of findings from Experiment 6.1, that search for congruent gaze (looking at a prominent object) is more efficient than incongruent gaze (looking elsewhere), yielding shallower search slopes. This
effect was, again, particularly clear in Target Present, Uncued trials, and not so in Target Present, Cued trials. Overall, search was, additionally, more efficient in Target Absent trials of the blocks comprising Congruent Gaze targets than those comprising Incongruent Gaze targets; for the current purposes, this marginal effect was unimportant — only an effect in the other direction might potentially impact interpretation of the findings for Target Present trials.
4. Discussion

The present set of experiments were motivated by a large body of work, including the findings in this thesis, on greater search efficiency for direct gaze than averted (e.g., Senju, Hasegawa, & Tojo, 2005, Senju, Kikuchi, et al., 2008; Chapters 3 and 4). It may be the case that effects observed in the SITCE are as a result of greater perceptual salience of direct gaze compared to averted, whether as a result of intrinsic salience as a result of evolutionary association with the consequences of direct gaze or as a result of physical salience based on luminance contrasts and symmetry. Alternatively, previous findings on the SITCE are consistent with a specifically social coding view in which search for direct gaze is enhanced because it is explicitly coded as ‘looking at me’ (versus averted gaze coded as ‘looking away from me’).

This latter hypothesis, although a core assumption made by the SITCE, is constrained by the fact that direct and averted gazes differ from each other both physically and in terms of social significance. The present experiments attempted to distinguish between these approaches by examining the search for eyes gazing at or away from another salient object (as opposed to observer), such that target and distracter gazes were differentiated not in terms of physical characteristics but on the basis of mental state attribution — i.e., target gaze was defined by its social salience (target gaze looking at or away from the contextually relevant object) rather than it being defined by its perceptual salience (target gaze being of one gaze type or the opposite gaze type). Results found that attention is guided more efficiently toward congruent gaze (eyes looking toward an object) than to incongruent gaze (eyes gazing away). This effect was particularly clear in target present trials, even when not evident in target absent trials, suggesting that it reflects biased competition between target and distracters in parallel coding, rather than speeded serial search through distracters. Although parallel and serial computational models may always be constructed to imitate the behaviour of the other, any simple serial model of the shallower search slopes for congruent gaze (than incongruent gaze) targets, would more naturally predict larger absolute effects in target absent trials, which were generally not evident or less marked here. The effect was also not evident when a pictorial cue signalled which way a target face would look (left or right) prior to the onset of the search display. This suggests that the gaze congruence effect, when present, may have reflected biasing of attention toward left gazing versus right gazing eyes in a display on the basis of which eyes gazed toward the prominent object (here, the Statue of Liberty image) and that a prior cue could overwhelm that bias. This speculation, however, was not core to the primary conclusion, which pertains to gaze processing in the absence of prior cues.
As the face-stimuli were identical across trials for congruent and incongruent conditions, neither differences in intrinsic salience nor fit to a perceptual template could account for them. Rather, any effect would appear to demand an explanation in terms of the spatial relationship between the gaze stimulus and the prominent object. This could not be an arbitrary relationship specified by the observer and task — if it were, observers would have been able to use the relationship between eyes gazing away from an object just as effectively as eyes gazing toward the object. Instead, these findings strongly suggest that visual search mechanisms incorporate an explicit coding of gaze as is and its relationship to other relevant objects in a scene.
Chapter 7. Individual Differences in the SITCE

1. Introduction

The work described in the previous chapters developed measures of a key aspect of social cognition – processing of gaze directed toward the self or other objects – and its relationship to attention in the visual search paradigm. The current chapter sought to apply this work to understanding how this phenomenon might, if at all, differ with respect to traits associated with Autism Spectrum Disorder (ASD) in the typical population.

Addressing the relationship between autistic traits and social attentional processing might be particularly promising in two respects. First, the ASD spectrum is characterised by atypical social cognition and interaction, as well as by restricted/repetitive interests (American Psychiatric Association, 2013). Second, a large body of literature increasingly suggests that atypical attention is a shared underlying feature of its diagnostic markers. For example, difficulty with attentional disengagement (Landry & Bryson, 2004; Elsabbagh et al., 2009; Elsabbagh, Fernandes et al., 2013), though possibly compensated for in adulthood (e.g., Luna, Doll, Hegedus, Minshew, & Sweeney, 2007), and attention to detail (e.g., O’Riordan, Plaisted, Driver, & Baron-Cohen, 2001) are thought to underlie restricted patterns of interest (Keehn, Müller, & Townsend, 2013). Importantly, difficulty with looking at eyes (e.g., Dalton et al., 2005; Hadjikhani et al., 2017) and gaze processing (e.g., Freeth, Chapman, Ropar, & Mitchell, 2010; Senju, Tojo, Dairoku, & Hasegawa, 2004) is thought to have adverse consequences for a wide range of socio-cognitive processes such as emotion, language, and intentionality (e.g., Baron-Cohen, 2005; Senju & Johnson, 2009a).

Given that crucial social information is provided by gaze cues with regard to objects that are the focus of gaze (e.g., Baron-Cohen, 1994, 2005; Becchio et al., 2008; Chapter 6), it is pertinent to ask to what extent difficulty with orienting to eye gaze in autistic populations is reflected as difficulty with processing gaze. Two prominent lines of thinking propose differing accounts of how autistic populations respond to eye contact, and, therefore, make differing predictions with respect to gaze processing. One, a gaze aversion model, posits that making eye contact leads to over-stimulation of the arousal system in the brain, comprising subcortical regions such as the amygdala and hippocampus (Charney, 2003; Pribram & McGuinness, 1975). This hyper-arousal is thought to lead individuals with ASD to actively avoid engaging with direct gaze (e.g., Dalton et al., 2005; Hadjikhani et al., 2017) and, potentially, prefer averted gaze over direct (Madipakkam, Rothkirch, Dziobek, & Sterzer, 2017). The other, a gaze insensitivity model, proposes that those with ASD show atypical gaze engagement because gaze is less likely to activate the social brain (Senju & Johnson,
Studies that support this latter model show, for example, that newborns at high risk for ASD orient to direct and averted gaze in the same manner as low risk newborns (Di Giorgio et al., 2016), that toddlers with an ASD diagnosis show similar first saccade latencies as age-matched controls when cued to look at eyes, but longer post-cueing latencies (Moriuchi, et al., 2017), and, generally, that individuals with ASD are able to orient to gaze cues but that difficulty may lie in attributing meaning to those cues (e.g., Senju et al., 2004; Swettenham, et al., 2003; Senju, Kikuchi et al., 2008).

Despite a vast body of work investigating gaze processing in ASD, it remains unclear to what extent individuals with higher autistic traits are able to orient to eyes as a function of gaze. The SITCE, potentially, offers one route to answering this, given that the effect appears to be a function of observers’ tendency to incorporate sophisticated socio-cognitive coding of gaze within a visual search paradigm. Interestingly, recent evidence suggests that direct gaze priors may be intact in those with high-functioning ASD (Pell et al., 2016), although direct gaze may still not be voluntarily chosen over averted when given a choice of stimuli to socially engage with (Dubey et al., 2015). Research on visual search with non-social stimuli in autistic populations, points to a ‘superior search’ pattern from infancy (Gliga et al., 2015), into childhood (Plaisted et al., 1998; O’Riordan et al., 2001), and adulthood (Almeida, Dickinson, Maybery, Badcock, & Badcock, 2010; Brock, Xu, & Brooks, 2011; O’Riordan, 2004). This search advantage is often a product of faster and more efficient target absent trials (O’Riordan et al., 2001; Keehn & Joseph, 2016) and is thought to reflect enhanced perception in autistic populations (Joseph, Keehn, Connolly, Wolfe, & Horowitz, 2009; Remington, Swettenham, Campbell, & Coleman, 2009).

Far fewer studies, however, have looked at visual search with social stimuli. There is some evidence to suggest that autistic groups demonstrate a similar tendency to detect threatening faces from among an array of faces with other emotions (e.g., Ashwin et al., 2006; Krysko, & Rutherford, 2009), although this advantage appears not to hold under more complex conditions of greater number of distracters or inverted faces (Ashwin et al., 2006), or when face stimuli are photo-realistic (Farran et al., 2011). Those studies, however, did not compare direct versus averted gaze. Of the two studies that did, one found no SITCE for children with ASD when stimuli were laterally oriented faces (Senju, Hasegawa, & Tojo, 2005, Experiment 2), which the authors suggest is more indicative of feature-based feature processing rather than an impairment in detecting direct gaze. The other study found an SITCE for the autistic group when faces were forward-facing (Senju, Kikuchi et al., 2008).
both in upright and inverted conditions when targets were present, while the control group only showed the effect in the upright condition, which the authors suggest reflects a greater influence of bottom-up processing rather than top-down.

The aim of the present chapter was to investigate the SITCE across high and low autistic groups (as measured by the Autism Quotient Questionnaire (AQ); Baron-Cohen et al., 2001). Previous work examining visual search in high AQ individuals (e.g., Almeida et al., 2010, 2013; Bayliss & Kritikos, 2010; Brock et al., 2011; Kaldy, Giserman, Carter, & Blaser, 2016) suggests that those with higher autistic traits show similar attentional-perceptual profiles as individuals with a diagnosis of ASD, and, more generally, that autistic traits extend as a continuum into the typical population, and are associated with neurological differences in response to eye gaze (Nummenmaa et al., 2012). Experiment 7.1 investigated the SITCE with forward-facing stimuli (using the same stimuli as in Experiment 2.1). Observers were instructed to find the odd-one-out gaze and only one gaze type was presented within one block. The gaze aversion view would predict no SITCE for the high AQ group. However, autistic observers are able to look at direct gaze when instructed to do so (Moriuchi et al., 2017) and have shown the SITCE with forward-facing stimuli (Senju, Kikuchi et al., 2008). Bearing in mind that an investigation of the SITCE with middle AQ observers had led to a reversed effect (Experiment 2.1), this reversed effect was again expected for both low and high AQ observers in this first experiment, i.e., no differences between both sets of observers. Experiment 7.2 investigated the SITCE using the optimised laterally averted stimuli. Given that the only other previous study using laterally averted stimuli had not found an effect, the present design also incorporated top-down pictorial cues — one block with 100% valid cues and the other with nonpredictive cues (i.e., Experiment 4.1 design). Both gaze aversion and gaze insensitivity views suggest that autistic observers might benefit from the presence of top-down cues, but do not make clear predictions for how cues might interact with gaze type — whether the presence of valid top-down cues might facilitate visual search for gaze in high AQ observers in the same manner as for low AQ observers, i.e., by applying a selective direct gaze prior, or whether top-down templates might equally facilitate both gaze types, thus rendering the effect null.
2. Experiment 7.1: Investigating the influence on autistic traits on the SITCE using forward-facing stimuli

2.1 Methods

The aim of this experiment was to investigate whether higher autistic traits, as measured by the AQ questionnaire (Baron-Cohen et al., 2001), might lead to differences in task performance on the SITCE, compared to lower scores for these traits. Previous work has found that when stimuli are forward-facing, both autistic and neurotypical observers demonstrate the SITCE (Senju, Kikuchi et al., 2008). A gaze aversion hypothesis would predict no SITCE for the higher scoring group, despite viewing forward-facing stimuli, while a gaze insensitivity hypothesis might predict the opposite. Bearing in mind that the present forward-facing stimuli had led to a reverse SITCE (Experiment 2.1), here, it was predicted that both Low and High AQ observers would demonstrate this reverse effect, i.e., we would not expect to see the Target Gaze x Set Size term interact with the AQ term.

2.1.1 Power Analysis and Sample Size

Observers were recruited as part of a larger experiment (described previously in Experiment 2.1). A power analysis suggested that 35 observers would provide sufficient power to detect medium- to large-sized effects for a within-between subjects RM ANOVA (Cohen’s $f = 0.33$, two groups, eight measures, power = 0.8). From the larger sample, 19 observers were assigned to the Low AQ group ($m = 4, f = 15$; ages 18-35; AQ scores 4–15) and 16 observers to the High AQ group ($m = 7, f = 9$; ages 18-35; AQ scores 32–49).

2.1.2 Apparatus, Stimuli, and Procedure

The stimuli, apparatus, and procedure were as described in Experiment 2.1 — i.e., within each block, half of all trials had a Direct Gaze target and half Averted, half of all trials had a target present while in half targets were absent, and half of all trials were presented at Set Size 7 and half at Set Size 13 (Figure 1 shows a schematised example of trial procedure). In addition, all observers completed the Standard Progressive Matrices (SPM; Raven, 1958) after the experimental task.
2.1.3 Results and Discussion

2.1.3.1 Behavioural Analysis

*Figure 2.* Mean Response Times (accuracy rates in parentheses) for Averted and Direct Gaze targets, separately at Set Sizes 3 and 7 separately for Low AQ observers (Left panel) and High AQ observers (Right panel) for Experiment 7.1. Error bars indicate +/- 1 SEM paired diffs.

*Figure 1.* Schematised sequence of displays in a typical trial from Experiment 7.1 (Set Size 7, Direct Gaze Target, T = target location).
For each observer (N= 35), RT data for accurate responses (M= 96.61, SD= 2.10) were trimmed, in the standard manner, to exclude any RTs ±3 standard deviations. Figure 2 plots the inter-observer mean RTs for each Target Gaze at each Set Size, separately for Low and High AQ conditions. The plots did not suggest a difference between AQ conditions — both sets of observers appeared to demonstrate the pattern of shallower search slopes for Averted Gaze targets compared to Direct Gaze that was seen in Experiment 2.1. A four-way within-between RM ANOVA, with within-subject factors of Target Gaze (Averted Gaze, Direct Gaze), Target Presence (Present, Absent), and Set Size (7, 13 items) and between-subjects factor of AQ (Low, High) confirmed these initial impressions. There was a main effect of Target Gaze \( [F(1, 33) = 11.447, p = .002, \eta_p^2 = .258] \) in the opposite direction to the SITCE, i.e., RTs to Averted Gaze targets were faster than to Direct, but in line with earlier results using these same stimuli. Main effects for Target Presence \( [F(1, 33) = 275.799, p < .001, \eta_p^2 = .893] \) and Set Size \( [F(1, 33) = 187.524, p < .001, \eta_p^2 = .850] \) were observed, in the expected directions. The standard Target Presence x Set Size \( [F(1, 33) = 119.444, p < .001, \eta_p^2 = .784] \) was observed as well as the (reversed) Target Gaze x Set Size \( [F(1, 33) = 187.524, p < .001, \eta_p^2 = .850] \) interaction. As expected, the main effect of AQ was not significant \( [F(1, 33) = 1.479, p = .233, \eta_p^2 = .043] \) and did not interact with the key Target Gaze by Set Size interaction \( [F(1, 33) = .072, p = .791, \eta_p^2 = .002] \). In fact, other than a marginal interaction with Target Presence \( [F(1, 33) = 3.987, p = .054, \eta_p^2 = .108] \), for which there was no predication, AQ did not interact with any terms \( (F \text{ values} < 2.242, p \text{ values} > .144) \). No other interactions were significant \( (F \text{ values} < 2.088, p \text{ values} > .158) \).

A corresponding analysis of accuracy revealed main effects for Target Gaze \( [F(1, 33) = 7.005, p = .012, \eta_p^2 = .175] \), Target Presence \( [F(1, 33) = 3.987, p = .054, \eta_p^2 = .108] \), and Set Size \( [F(1, 33) = 36.638, p < .001, \eta_p^2 = .108] \), but not for AQ \( [F(1, 33) = .846, p = .364, \eta_p^2 = .025] \). The Target Gaze x Set Size \( [F(1, 33) = 10.829, p = .002, \eta_p^2 = .247] \) and Target Gaze x Target Presence \( [F(1, 33) = 6.359, p = .017, \eta_p^2 = .162] \) interactions were significant. No other interactions were significant \( (F \text{ values} < 2.609, p \text{ values} > .116) \).

3.1.3.2 SPM Analysis

A one-way ANOVA on standardised SPM scores revealed a weak effect \( [F(1, 34) = 4.381, p = .044, \eta_p^2 = .117] \), such that High AQ observers had higher scores than Low AQ. The aim of the SPM had been to act as a control to ensure that any potential differences in task performance were not as a result of differences in cognitive ability. However, since this
effect was weak (and favoured High AQ observers) SITCE task performance was not attributed to this.

In line with predictions, Experiment 7.1 found that differences in AQ scores did not lead to differences in task performance. Experiment 7.1, however, used forward-facing stimuli, which had suffered from low-level confounds. It is highly likely that both Low and High AQ observers were simply responding to the perceptual differences between stimuli. Chapter 3 had established a SITCE in the expected direction using laterally averted stimuli, which better controlled for sclera-pupil ratios between averted and direct gazes. Thus, the aim of Experiment 7.2 was to use these optimised stimuli to investigate potential differences in performance between High and Low AQ observers. A previous study has found that ASD participants are unable to demonstrate a SITCE when stimuli are laterally averted (Senju, Hasegawa, & Tojo, 2005, Experiment 2), a finding those authors suggest is a preference for feature-based visual processing rather than an inability to process gaze altogether. If this were to be the case, then High AQ observers might benefit from top-down templates for target gaze. Chapter 4 had established that there were two distinct processes that govern the SITCE — Process 1, a direct gaze bias that guided attention and scaled with set size, and Process 2, a selective application of that bias to top-down templates which did not scale with set size. If Low and High AQ observers are able to process gaze in a similar manner, we would not expect differences in either Process 1 or 2 between observers. However, if gaze processing were to differ between Low and High AQ observers, and, importantly, if High AQ observers were to respond to top-down templates in a non-direct-gaze-biased manner, we would expect both Process 1 and 2 to interact with the AQ term. Importantly, then, the aim of Experiment 7.2 was to investigate whether AQ differences led to differences in Process 1 and Process 2 of the SITCE.
3. Experiment 7.2: Investigating the influence of autistic traits on the SITCE using predictive pictorial cues

3.1 Methods

Experiment 7.2 was designed to investigate whether differences in AQ led to differences in Process 1 (Target Gaze x Set Size interaction) and Process 2 (Cue Predictiveness x Set Size interaction) of the SITCE that had been found previously in Chapter 4. If there was no difference in gaze processing between High and Low AQ observers, we would expect to observe both interaction terms. However, if there were differences in gaze processing, we would expect an interaction of either or both of these terms with the AQ term.

3.2 Power Analysis and Sample Size

Observers were recruited as part of a larger experiment described previously in Experiment 4.1. An average effect size of $\eta^2_p = .332$ (averaged from Chapter 4 experiments) for the Target Gaze x Set Size interaction suggested that 32 observers would suffice to power the interaction. However, the present investigation was interested in higher-order effects, thus, here, 20 observers were assigned to the Low AQ group ($m = 8, f = 12; \text{ages} 18-35; \text{AQ scores} 5-16$) and 20 to the High AQ group ($m = 6, f = 14; \text{ages} 18-35; \text{AQ scores} 29-49$). Observers were recruited and compensated as for Experiment 4.1.

3.3 Apparatus, Stimuli, and Procedure

The stimuli, apparatus, and procedure were as described in Experiment 4.1 — i.e., pictorial cues presented before the search display signalled, in a predictive or nonpredictive manner, the identity of the upcoming target; predictive and nonpredictive blocks were counterbalanced and within each block half of all trials had a target present and half absent, half of all targets were Direct Gaze and half Averted, half of all trials were presented at Set Size 3 and half at Set Size 7 (Figure 3 shows a schematic sequence of trial displays). In addition, all observers completed the Standard Progressive Matrices (SPM; Raven, 1958) after the experimental task.
3.4 Results and Discussion

3.4.1 Behavioural Analysis

*Figure 3.* Schematised sequence of displays in a typical trial from Experiment 7.2 (Set Size 7, Direct Gaze Target, Predictive Cue, T = target location).

*Figure 4.* Mean Response Times (accuracy rates in parentheses) for Averted and Direct Gaze targets at Set Sizes 3 and 7 separately for Predictive and Nonpredictive Cue conditions for (Top panel) Low AQ observers and (Bottom panel) High AQ observers for Experiment 7.2. Error bars indicate +/-1 SEM paireddiffs.
For each observer (N= 40), RT data for accurate responses (M= 95.86, SD= 3.41) were trimmed in the standard manner within each Cue Predictiveness condition. One observer had to be removed as their RTs exceeded limits even post trim. Figure 4 plots the inter-observer mean RTs for each Target Gaze at each Set Size separately for Low AQ and for High AQ at each Cue Predictiveness condition. Visual inspection of the plots suggested that across both groups there was a tendency toward shallower search slopes for Direct Gaze than Averted with Nonpredictive Cues and a general advantage for Direct Gaze targets irrespective of Set Size with Predictive Cues.

A five-way ANOVA, with the between-subjects factor of AQ (Low, High) and within-subjects factors of Cue Predictiveness (Predictive, Nonpredictive), Target Gaze (Averted Gaze, Direct Gaze), Target Presence (Present, Absent), and Set Size (3, 7 items) clarified these effects. There were main effects of Target Gaze [F (1, 37) = 39.238, p < .001, \( \eta_p^2 = .515 \)], Target Presence [F (1, 37) = 59.350, p < .001, \( \eta_p^2 = .616 \)], and Set Size [F (1, 37) = 306.011, p < .001, \( \eta_p^2 = .892 \)] in the expected directions. The standard Target Presence x Set Size interaction was also found [F (1, 37) = 62.508, p < .001, \( \eta_p^2 = .628 \)]. There was no main effect of AQ [F (1, 37) = 1.173, p = .286, \( \eta_p^2 = .031 \)]. In terms of interactions of interest, the Target Gaze x Set Size [F (1, 37) = 17.353, p < .001, \( \eta_p^2 = .319 \)] was significant, but did not interact with AQ [F (1, 37) = 1.458, p = .235, \( \eta_p^2 = .038 \)]. The Cue Predictiveness x Target Gaze [F (1, 37) = 6.255, p = .017, \( \eta_p^2 = .145 \)] interaction was significant but, again, did not interact with AQ [F (1, 37) = .019, p = .892, \( \eta_p^2 = .001 \)]. No other interactions were found other than a marginal Target Gaze x Target Presence x Set Size x AQ interaction [F (1, 37) = 3.337, p = .076, \( \eta_p^2 = .083 \)].

To clarify any possible effects of differences in AQ, this interaction was investigated further. Two three-way ANOVAs [2 (Target Gaze Direction) x 2 (Target Presence) x 2 (Set Size)] were conducted for each AQ condition. This analysis found that while both sets of observers showed a significant Target Presence x Set Size interaction (Low AQ [F (1, 19) = 29.254, p < .001, \( \eta_p^2 = .606 \)], High AQ [F (1, 18) = .774, p = .385, \( \eta_p^2 = .020 \)]), the pattern for Target Gaze x Set Size (Low AQ [F (1, 19) = 4.177, p = .055, \( \eta_p^2 = .180 \)], High AQ [F (1, 18) = 20.461, p < .001, \( \eta_p^2 = .532 \)]) and Target Gaze x Target Presence (Low AQ [F (1, 19) = .668, p = .424, \( \eta_p^2 = .034 \)], High AQ [F (1, 18) = 4.562, p = .047, \( \eta_p^2 = .202 \)]) varied. However, with respect to main terms of interest, as in Experiment 7.1, it seemed that
differences in AQ did not influence the SITCE. Instead, Process 1 and Process 2 appeared to be stable effects, that were dissociable, as demonstrated by lack of the three-way interaction \[ F(1, 37) = .774, p = .385, \eta^2_p = .020 \], as had been found in Chapter 4.

A corresponding analysis of accuracy revealed main effects for Target Gaze \[ F(1, 37) = 15.460, p < .001, \eta^2_p = .295 \], Target Presence \[ F(1, 37) = 39.537, p < .001, \eta^2_p = .517 \], and Set Size \[ F(1, 37) = 20.004, p < .001, \eta^2_p = .351 \] in the same direction as for RTs. Again, the main effect of AQ was not significant and did not interact with any main effects or interactions (F values < 1.268, p values > .267). The Target Presence x Set Size \[ F(1, 37) = 18.287, p < .001, \eta^2_p = .331 \], Target Gaze x Set Size \[ F(1, 37) = 11.778, p = .001, \eta^2_p = .241 \], and Target Gaze x Target Presence \[ F(1, 37) = 15.537, p < .001, \eta^2_p = .296 \] interactions were significant. Both three-way interactions, without the AQ term, were also significant, but were qualified by the significant four-way interaction \[ F(1, 37) = 5.409, p = .026, \eta^2_p = .128 \]. Two three-way ANOVAs [2 (Target Gaze Direction) x 2 (Target Presence) x 2 (Set Size)], conducted for each Cue condition, found a three-way interaction for the Predictive Cue condition \[ F(1, 38) = 8.837, p = .005, \eta^2_p = .189 \] but not Nonpredictive \[ F(1, 38) = 5.409, p = .011, \eta^2_p = .428 \], the former reflecting a significant Target Gaze x Set Size interaction only for Target Present trials \[ F(1, 38) = 14.361, p = .001, \eta^2_p = .274 \]. It is important to note that these effects reflect error differences in very small numbers of trials and do not threaten the main RT analysis.

3.4.2 SPM Analysis

A one-way ANOVA on standardised SPM scores revealed no differences between Low and High AQ observers \[ F(1, 37) = 2.388, p = .131, \eta^2_p = .061 \], suggesting that both sets of observers were equally matched in intellectual reasoning abilities.

Experiment 7.2 had found a SITCE with laterally averted stimuli for both Low and High AQ observers. These findings are in contrast to previous work which has suggested that having higher autistic traits may lead to greater feature-based processing, thus disrupting direct gaze processing (Senju, Hasegawa, & Tojo, 2005; Senju, Kikuchi et al., 2008). However, here, both Low and High AQ observers showed evidence for Process 1 and Process 2, suggesting that High AQ observers demonstrated a similar tendency to apply a direct gaze prior, with or without explicit top-down cues to guide attention; a finding in line with recent work which finds that a direct gaze prior may be intact in observers with high-functioning ASD (Pell et al., 2016). These results suggest that within a laboratory setting, at least, having higher autistic traits does not lead to atypical gaze processing.
4. Discussion

The present experiments investigated whether there were differences in attentional prioritisation of gaze in visual search as a result of differences in AQ traits. A large body of work suggests superior search patterns with non-social stimuli in autistic populations (e.g., Plaisted et al., 1998; O’Riordan, 2004), as also some support for a similar (to neurotypical) tendency to detect threatening faces from among other faces (e.g., Ashwin et al., 2006; Krysko, & Rutherford, 2009), although evidence is mixed (Farran et al., 2011). However, only two previous studies have investigated the SITCE in autistic populations — one finding no effect when children with ASD searched through laterally averted faces (Senju, Hasegawa, & Tojo 2005), another finding the effect with forward-facing stimuli (Senju, Kikuchi et al., 2008). A gaze aversion view suggests that those with ASD actively seek to avoid engaging with direct gaze due to an over-stimulation of brain areas that control emotion and arousal (e.g., Dalton et al., 2005; Hadjikhani et al., 2017) — predicting no SITCE, whether with forward-facing stimuli or laterally averted. A gaze insensitivity view, on the other hand, suggests that individuals with ASD engage less with gaze in general as it is less likely to activate the social centres of the brain (Senju & Johnson, 2009a). Such a view would not necessarily predict differences in response to one gaze type over the other, although individuals may be cued to pay more attention to direct gaze (e.g., Moriuchi et al., 2017).

Experiment 7.1 found a reversed SITCE for both Low and High AQ groups, using forward-facing stimuli – both sets of observers showed faster and more efficient RTs to Averted Gaze targets than Direct – consistent with results from Middle AQ observers in Experiment 2.1. These results, however, could support any of the hypotheses discussed, as it is highly likely that observers were responding to low-level stimulus confounds (unequal sclera-iris ratio for direct and averted gaze stimuli) rather than processing the stimuli as gaze. It is interesting to note, however, that High AQ observers showed a similar pattern of responses as Low AQ, i.e., the AQ term did not interact with the Target Gaze x Set Size interaction, showing no evidence for a superior search pattern here. Experiment 7.2 presented observers with laterally averted stimuli, preceded by a predictive or nonpredictive top-down cue, and found the SITCE for both Low and High AQ observers. Importantly, in a similar pattern as Low AQ observers, High AQ observers not only showed faster and more efficient responses in favour of direct gaze targets (Process 1), but also selectively applied gaze cues to respond significantly faster to direct gaze targets (Process 2). These results suggest that, within the scope of this task, individuals with higher autistic traits showed a similar tendency to preferentially select direct gaze targets over averted, both with and without top-down cues.
guiding attention. Findings from Experiment 7.2 are in contrast to a gaze aversion hypothesis and previous work on the SITCE in individuals with ASD (Senju, Hasegawa, & Tojo 2005). However, they are in line with more recent evidence for the presence of direct gaze priors in high-functioning ASD (Pell et al., 2016), offering further evidence that these priors may be intact in those with high autistic traits, although this would still be consistent with notions of gaze insensitivity and the recognition that in the present experiments High AQ observers may have been responding to gaze stimuli on the basis of their perceptual rather than socio-cognitive salience.

In daily-life social interactions, adolescents and adults with ASD self-report facing difficulties, e.g., “Eye contact is [an] inherently uncomfortable thing for me”, “I can’t concentrate while making eye contact…it’s like I need to shut off the visual input in order to completely process the aural input” (Trevisan, Roberts, Lin, & Birmingham, 2017). It may well be the case that within an experimental context, given task instructions to look at eyes, that individuals with High AQ are able to focus on the eye region and apply direct gaze priors but are unable to do so in more dynamic social contexts which contain more variables. Studies find that when autistic observers believe that the faces being viewed are live, they tend to show reduced looking behaviour and engagement with the stimuli (von dem Hagen & Bright, 2017) and that joint-attention cues in real time are compromised (Tanabe et al., 2012). It may also be the case that apparently typical behavioural findings mask difficulties with sensitivity to visual/social contexts and interactive partners (Gangi et al., 2018), and are as the result of more variable developmental pathways (e.g., Elsabbagh, Gliga et al., 2013; Pell et al., 2016). Given that the current High AQ sample consisted of university students who showed similar levels of intellectual functioning as the control group, it would be important for future work to determine whether this pattern of results holds true for lower-functioning individuals with ASD.
Chapter 8. Discussion

The ability to distinguish between direct and averted gaze types is of crucial adaptive value to humans, given the differing social signals each represents — one signalling attention toward you and the other away from you. The present thesis developed around wanting to better understand the underlying mechanisms in gaze perception, particularly whether the perception of direct gaze was somehow prioritised in attentional processing given its reported importance in both anecdotal and empirical evidence. The story that emerged, within the scope of this thesis, was far from simple, however. The forthcoming sections review the main findings and attempt to place them within the context of broader questions concerning gaze perception.

1.1 Evidence for a Direct Gaze Prior

Direct gaze, arguably a high priority socio-cognitive stimulus, could be expected to be attentionally prioritised by the visual system even in the presence of other gazes — the starting point for this thesis. Although evidence from neuroimaging and behavioural studies offers some support to this notion of a visual advantage accorded to direct gaze, it does not necessarily speak to an attentional prioritisation of direct gaze from among competing gaze influences. The SITCE offered one route to operationalising this proposition — a search asymmetry where direct gazing eyes are often detected more rapidly in arrays of averted gazing eyes, than vice versa. While the majority of previous studies investigating the SITCE had found a direct gaze advantage, methodological inconsistencies made it unclear which of those findings had been as a result of stimulus/task confounds and which as a result of preferential gaze processing. Thus, the first step for this thesis was to optimise task parameters and re-examine this effect.

Establishing the SITCE using our own lab equipment and stimuli proved harder than expected, however. Using similar stimulus dimensions as previous studies (e.g., Cooper et al., 2013; Senju, Hasegawa, & Tojo, 2005) Experiment 2.1 presented observers with forward-facing stimuli with both types of target gaze intermixed within the same block of trials, but found a reversed effect such that averted gaze targets were detected faster and more efficiently than direct. However, this was surmised to likely have been as a result of low-level confounds to which forward-facing stimuli are susceptible, exacerbated by the unequal sclera-iris ratios between the gaze stimuli. In the next attempt, Experiments 2.2a and 2.2b, in that same chapter, presented laterally averted faces with more equally matched sclera-iris ratios between gaze types. These experiments had, additionally, aimed to investigate whether differences in top-down expectations about upcoming targets might influence the SITCE. To
this end, Experiment 2.2a presented both gazes in an intermixed manner within the same block (thus not allowing for any prediction of upcoming target gaze), while Experiment 2.2b presented only one type of target gaze within each block of trials (better allowing for such a prediction). Although Experiment 2.2b did find some evidence for the SITCE, in the expected direction this time, in the form of a main effect of target gaze type, neither experiment was able to demonstrate both effects that had been a priori deemed as evidence for the SITCE — a main effect of gaze and an interaction with set size. Thus, any conclusions that could be drawn from these were limited. Chapter 2 had, as a result, not been entirely successful in establishing an SITCE — it appeared likely that the stimuli were still too small, not allowing them to be fully represented as gaze. Chapter 2 had also been unsuccessful in answering whether predictability of target gaze played a role in the SITCE — the blocked design conflated target repetition with target predictability, and neither experiment emphasised target search based on gaze identity.

Thus, the aim in Chapter 3 remained optimising task parameters and, accordingly, larger versions of the same laterally averted stimuli were now employed to better facilitate their representation as eye gaze. Experiment 3.1 presented averted and direct targets in separate blocks with faces arranged around a circle (as in the format favoured by the majority of previous studies), finding both a main effect of gaze direction and an interaction with the set size term. Experiment 3.2 additionally presented, as a control for any confounds, a reversed contrast polarity condition where, it was assumed, observers would be less able to code the stimuli as gaze, finding an absence of any gaze effects. Finally, then, these two experiments, had been able to establish an SITCE, using novel stimuli, that could not as easily be attributed to stimulus confounds (e.g., Conty et al., 2006) or potential issues with using multiple gazes as distracters (e.g., Senju, Hasegawa, & Tojo, 2005; Senju, Kikuchi et al., 2008). It was interesting to note, however, that this effect appeared evident in a narrower range of circumstances than previously assumed (e.g., more likely to find the effect with larger laterally averted stimuli), possibly because a true effect is sensitive to how realistically observers are able to represent the stimuli as eye gaze.

Having confidence that the SITCE could be observed using these novel stimuli, Chapter 4 examined, more concretely, whether this effect was influenced by top-down expectations of upcoming targets. While Experiments 2.2a and 2.2b, had made an attempt to address this, neither of those experiments had systematically manipulated knowledge of upcoming target gaze. In Chapter 4, target predictability was explicitly varied by presenting a pre-cue (either pictorial or semantic) before the main search display which reliably or
unreliably signalled the gaze direction of the upcoming target. The effect of top-down target templates could be expected to influence either/both set-size-dependent and set-size-independent effects, leading to differing predictions (as discussed in the introduction to the chapter — General Enhancement, SITCE Reduction, Flexible SITCE Increase, or Inflexible SITCE Increase). Experiment 4.1 presented, in separate blocks, either 100% or 50% valid pictorial cues, finding dissociable evidence for both effects. The first, a set-size-dependent direct gaze advantage when cues were nonpredictive, such that direct gaze was detected faster and more efficiently regardless of which gaze type was expected, potentially the result of noisy, parallel processing guiding attention to direct gaze (‘Process 1’). The second, a set-size-independent effect when cues were entirely valid, in the form of selectively faster responses to direct gaze targets, likely reflecting response criteria that determine target presence versus absence (‘Process 2’). Experiment 4.2 confirmed that the cue-dependent direct gaze advantage was an inflexible one, acting in an all-or-none manner — when only 80% valid or 20% valid cues were presented (again, in separate blocks), rather than variable predictability influencing the magnitude of the effect, both conditions were treated as equally unreliable and, as in the 50% valid case, a set-size dependent direct gaze advantage emerged. Experiment 4.3, and its replication Experiment 4.4, presented semantic cues in the same format as Experiment 4.1 and found the same pattern of results, suggesting that this effect was unlikely to be one of cue priming, providing further support for the existence of two dissociable components of the SITCE. Thus, across four experiments, there appeared to be reasonably strong evidence in support of a fixed direct gaze bias which, in tandem with top-down templates, acted to influence gaze processing in an obligatory manner.

1.2 Does Direct Gaze Attract Attention Exogenously?

Having fair confidence that Chapter 4 results supported the notion of a direct gaze prior (e.g., Mareschal et al., 2013, 2014), a logical follow-up question was whether this biased expectation for direct gaze would translate into direct gaze attracting exogenous attention (measured by proportion of initial saccades made) when placed in visual competition with averted gaze. Current consensus, which favours a Direct Gaze Salience view, certainly suggested so, while a PC view (e.g., Kanai et al., 2015; Rao & Ballard, 1999) would make the opposite claim since, in those models, exogenous attention should be biased away from direct gaze, which conforms to internal predictions, and toward averted gaze instead, which does not (e.g., Summerfield & Egner, 2009). That is, even in models that do not make this explicit hypothesis, attention should be cued to prediction error via ascending error signals (generated by deviance from a prior) that dominate processing.
Chapter 5 put these competing hypotheses to test. Experiment 5.1 presented what was essentially a gaze odd-one-out paradigm, with one crucial manipulation — observers were tasked with detecting the lighter mouth present on a face with non-unique gaze, while the odd-one-out gaze served as an active nontarget to cue exogenous attention towards itself. When there were four faces in the search display, results revealed an averted gaze advantage (in line with a PC view) while no such advantage emerged when there were only two faces. Although these findings appeared to support the PC view, its basic formulation would also have predicted an averted gaze bias when there were only two faces present in the display. Experiment 5.2, designed to answer whether, if at all, it was odd-one-out-ness or, perhaps, the number of items in a search display that was responsible for this observed bias at Set Size 4 — such that both gazes were equally balanced and the only unique element was the lighter mouth — found no such averted gaze advantage. It was clear, thus far, that any manner of an averted gaze bias could only be explained by PC models, which also make assumptions about predictability of stimulus patterns influencing target representations. Across the first two experiments, however, unique gaze had been task-irrelevant, also making it unclear whether or not the observed bias was as a result of attempted suppression effects (the ‘attentional white bear’ phenomenon). Experiments 5.3 and 5.4 made an attempt to examine, in Set Size 4 displays, since any effect was only likely to be here, whether such predictability might shed light on this apparent effect — contrasting task-relevant unique gaze (such that the position of the unique gaze cued target location) with task-irrelevant (such that unique gaze could not cue target location). Across both experiments, the pattern of results with respect to informative unique gaze was clear — an averted gaze bias when gaze uniqueness was highlighted. The results with respect to uninformative unique gaze were less so, however — there now appeared to be no such bias, despite the similarity between this condition and that in Experiment 5.1. Finally, Experiment 5.5 examined target predictability more explicitly, now directly concerning gaze direction, by presenting either predictive or nonpredictive semantic cues (in independent blocks) prior to the search display. Unexpectedly, no direct gaze bias emerged despite predictive cues providing reliable information about target gaze direction; contrary to current views and findings from Chapter 4. Results did reveal, however, that the proportion of initial saccades made to targets overall, regardless of gaze type, was significantly greater in the predictive compared to nonpredictive condition — suggesting that precise predictability had no role to play in influencing initial attention.

Despite no evidence for a direct gaze bias with respect to initial attentional allocation, the overall findings did, still, make a strong case for opposing attentional mechanisms
operating in the experiments described — the missing link being RT effects in those conditions where there had been clear reason to suppose a direct gaze advantage, i.e., Informative conditions in Experiments 5.3 and 5.4, and the Predictive condition in Experiment 5.5. When a clear averted gaze bias was found in initial saccades, i.e., informative conditions, no direct gaze RT advantage was found, but when no such gaze bias was found in initial saccades, i.e., predictive condition in Experiment 5.5 (but also nonpredictive condition in Experiment 5.5 and Set Size 4 trials in Experiment 5.2), an RT advantage favouring direct gaze was now found. It thus appeared that when attentional processes were guided by prediction error, such that unique averted gaze cued exogenous attention, this masked any possibility of a direct gaze RT advantage. On the other hand, when prior expectations guided attentional processes toward direct gaze targets, this was associated with a corresponding RT advantage, consistent with gaze-related top-down template effects that had been found in Chapter 4 (i.e., ‘Process 2’).

Neither Direct Gaze Salience nor PC models, in their basic forms, had been able to satisfactorily account for the pattern of findings across five experiments. An averted gaze bias, as predicted by PC accounts, was only revealed when an odd-one-out gaze was present in the display (i.e., Set Size 4 only) and its uniqueness was highlighted — i.e., there was no evidence for an averted gaze bias when displays did not contain unique gaze (Set Size 2 displays and Experiment 5.2, Set Size 4) or when observers were prompted to think of a particular gaze rather than search for uniqueness (Experiment 5.5). When endogenous attention was directed to one gaze type, whether direct or averted (through pre-cues), no gaze bias was observed; contrary to current views and findings from Chapter 4. As discussed in greater detail previously (Chapter 5, Discussion), a modified PC framework offered the most intuitive explanation for the key finding here — the critical role of gaze uniqueness in eliciting an averted gaze bias, that was otherwise absent. In essence, as proposed by nuanced PC frameworks (e.g., Bastos et al., 2012; Friston, 2010; Kanai et al., 2015), the generation of prediction error is dependent on the extent to which priors are released from their top-down limits, implying that predictions must be dynamic processes that evolve as the search display is processed. How might these top-down limits be released or strengthened? Based on present results, it is proposed that the key lies in the mode of attentional processing that is activated (by task instructions) — a prediction error mode activated when task instructions ask observers to attend to within-display prediction error (the averted gaze bias found in Experiment 5.1 and informative conditions of Experiments 5.3 and 5.4) or a strengthening of top-down representations when task instructions call for within-gaze comparison (Experiment
5.2 (no gaze bias but faster RTs to direct gaze targets observed), uninformative conditions of Experiments 5.3 and 5.4, and Experiment 5). When this averted gaze bias was further examined in rapid saccades for how it changed as a function of onset latency, rather than showing an early direct gaze bias in rapid saccades followed by an averted gaze one at longer latencies (as predicted by Press et al., 2019), this analysis found a clear averted gaze bias at the shortest latencies. In conclusion, the present results suggest that the information sought by top-down attention, rather than gaze direction, determined the manner in which gaze stimuli were coded and preferentially processed.

1.3 ‘Top-down’ versus ‘Bottom-up’ influences on gaze perception

At the heart of this thesis lies the intriguing question of whether it is primarily lower-level or higher-level influences that drive preferential attentional selection of direct gaze from among other gazes, mirroring the larger debate on this in the field of social perception. Earlier conceptualisations have typically assumed a one-way ‘feed-forward’ flow of information from bottom-up perception to higher levels of cognition (e.g., Blakemore & Decety, 2001; Nummenmaa & Calder, 2009) while more recent frameworks have argued for bi-directional information processing to account for the influence of prior knowledge and expectations on perception e.g., Kanai, Komura, Shipp, & Friston, 2015; Summerfield & Egner, 2009; Teufel, Fletcher, & Davis, 2010). Still more recent conceptualisations view predictions as a core component of successful information processing by an ‘agent’ (in the present case, the visual system) both in the form of top-down expectations and as bottom-up constraints (Teufel & Fletcher, 2020). How might findings from Chapters 4 and 5 be framed in terms of possible top-down and/or bottom-up effects on gaze processing?

In terms of effects that were reliably influenced by top-down manipulation, Chapter 4 had found evidence for a direct gaze prior (reflected in RT effects) that seemed to influence the SITCE both regardless of and in conjunction with predictive top-down templates — the former reflected as shallower search slopes to direct gaze targets and the latter as faster responses to direct gaze overall. A similar speeding of RTs to direct gaze targets was observed in Experiment 5.5 in both predictive and nonpredictive cue conditions, suggesting, as before, that framing of the task as search for gaze direction served to engage the biased gaze expectations of the visual system. In terms of effects when target gaze engaged endogenous attention but not exogenous, one of two outcomes was observed (with respect to initial saccades) — either a clear averted gaze bias when gaze was both the odd-one-out and was task-relevant (informative conditions of Experiments 5.3 and 5.4) or no gaze bias if there was no odd-one-out gaze (Experiment 5.1, Set Size 2 display and Experiment 5.2, Set Size 2...
and 4 displays) or search for unique gaze was not on the basis of its uniqueness (Experiment 5.5). In all conditions where an averted gaze bias in initial saccades emerged, any potential for a direct gaze RT advantage was obscured. This averted gaze bias was not entirely free of higher-level influences, however, in that it did require that the task be set up to emphasise within-display prediction error, i.e., target gaze had to be both the odd-one-out and task-relevant for a reliable effect. Within the scope of the experiments conducted (in Chapter 5), the condition where unique gaze was both task-irrelevant and the odd-one-out offered the best window into potential bottom-up effects in the sense of any effects there being less influenced by top-down instruction or conscious expectation. These findings were variable, however — where Experiment 5.1 found an averted gaze bias, similar conditions in Experiments 5.3 and 5.4 (uninformative) found no evidence for this, and a Bayesian analysis suggested that data were insensitive in the latter case (as discussed in greater detail in that chapter, this discrepancy could have either been as result of intermixed Set Size 2 trials or a Type 1 error in Experiment 1). While the current pattern of findings goes some way towards revealing the underlying influences driving attentional prioritisation of gaze, it remains a goal to explore in greater detail the complex interactions between attentional effects driven by bottom-up prediction error versus expectation effects driven by top-down predictions (discussed further in section 1.6.1).

1.4 Gaze processing in visual search: beyond perceptual templates

The finding that direct gaze is attentionally prioritised in visual search, even though it does not attract exogenous attention, can be explained by either of two views — the first, that any biased guidance may reflect simple perceptual templates, either as a result of intrinsic physical salience based on the stronger luminance-contrast signal for direct gaze or an association with its socio-cognitive consequences, which do not require specific coding of gaze-object relations or the second, that any prioritisation for gaze must incorporate sophisticated coding of eye gaze as looking at an object of salience, be that the observer or any other object. The former possibility, a perceptual template (either bottom-up or top-down), need only specify direct gaze’s visual features (a combination of sclera-iris/luminance contrast features), while the latter must incorporate notions of social salience of the gazed-at object. The Chapter 5 findings that processing prediction error leads to an averted gaze bias, though unexpected, do not take away from either the main findings of the SITCE or these contrasting possibilities which might explain the effect. Traditional investigations of gaze prioritisation have tended to compare direct versus averted gaze, which are distinguishable both on the basis of lower-level physical properties as well as higher-level socio-cognitive
associations. Despite previous research (including investigations in this thesis) attempting to minimise these differences, by virtue of an inherent distinction between both gazes, any differential processing, whether it favours direct or averted gaze, may reflect either social processing or some manner of specialist templates tuned to the physical features of either gaze type.

Chapter 6 attempted to disentangle which of the two mechanisms operates in multiple-face arrays by examining search for eyes gazing at and gazing away from another salient object (rather than the observer, which had been the premise in earlier chapters) — an approach that uniquely allows for a distinction between stimuli on the basis of mental state attribution, but not on the basis of their physical characteristics. Experiment 6.1 found faster and more efficient search for eyes gazing at a salient object than eyes gazing away from the object; an effect that was abolished when a prior pictorial cue indicated upcoming target identity. Experiment 6.2 replicated these conditions, and enhanced them by making gaze task-relevant as opposed to being the odd-one-out, finding the same pattern of results. Given that in the case of both congruent and incongruent gaze, target gazes looked away from the observer, the finding that averted gazing eyes looking at a salient object are detected faster and more efficiently from among other averted gazes looking away from the object rather than vice versa, suggests that it is the social meaning attributed to the spatial relationship between gaze and object that guides search.

A critical assumption made in the SITCE, but one that has yet to be explicitly tested, is that direct gaze prioritisation is as a result of observers intuitively understanding themselves to be the salient object being gazed at or gazed away from. Within the constraints of present SITCE task design however, namely that averted and direct gazes always differ both physically and in terms of gaze-object relations, an insight into underlying mechanisms guiding gaze prioritisation has been lacking. Chapter 6 generalised this idea and applied it to the search for gaze toward or away from other salient objects, that were not the observer. Findings from this investigation go some way toward answering why previous investigations of visual search for gaze (including findings in this thesis) have shown a preference for direct gaze rather than averted — rather than a simple perceptual template guiding attentional prioritisation, this process appears to be a function of the saliency of gaze-object relations. Eye gaze is a key building block of socio-cognitive development (e.g., Charman et al., 2000; Tomasello et al., 2005), and the finding that attentional prioritisation of gaze incorporates sophisticated socio-cognitive processes adds to an already vast body of literature which places gaze perception and communication at the heart of complex mentalising behaviours.
1.5 Individual differences in visual search for gaze

A large body of literature points to altered attentional processing in individuals on the ASD spectrum, for example difficulties with face/gaze perception (e.g., Dalton et al., 2005; Freeth et al., 2010; Senju et al., 2004) and ‘superior’ visual search patterns (e.g., Gliga et al., 2015; Plaisted et al., 1998; O’Riordan, 2004). Supporting the notion of autistic traits as a continuum, similarly altered neurological patterns of response to eye gaze have been found in the neurotypical population with higher autistic traits (Nummenmaa et al., 2012). Of particular relevance to the focus of this thesis is the suggestion that difficulty engaging with direct gaze adversely impacts cognitive and behavioural outcomes (e.g., Baron-Cohen, 2005; Senju & Johnson, 2009a). Despite evidence for gaze processing difficulties in ASD, the extent to which individuals with higher autistic traits are able to orient to eyes as a function of gaze remains an open question. The SITCE, as a task that appears to rely on the propensity of observers to explicitly process eyes as gaze, offered a potential method to answer to this key question. A gaze aversion account attributes avoidance of direct gaze in autistic populations to over-stimulation of brain centres involved in emotion and arousal (e.g., Dalton et al., 2005; Hadjikhani et al., 2017) and would thus hypothesise no SITCE as direct gaze would not be attentionally prioritised in this view. A gaze insensitivity account, on the other hand, proposes that individuals with autistic traits engage less with gaze in general as it is less likely to activate brain areas involved in social perception and cognition (Senju & Johnson, 2009a), thereby not necessarily predicting differences in SITCE performance, as the potential to be able to orient to direct gaze exists (e.g., Moriuchi et al., 2017; Senju, Kikuchi et al., 2008). Results from the two previous studies that investigated the STCE were mixed – one finding an effect with forward-facing faces (Senju, Kikuchi et al., 2008) and the other no effect with laterally averted faces (Senju, Hasegawa, & Tojo 2005) – thus motivating the need for further investigation.

Chapter 7 examined whether individuals with higher autistic traits (as measured by the AQ; Baron-Cohen et al., 2000) might show differences in task performance on the SITCE compared to individuals scoring lower on autistic traits, potentially revealing underlying differences in gaze processing mechanisms. Experiment 7.1 presented forward-facing stimuli, finding a reversed SITCE such that averted gaze targets were detected faster and more efficiently than direct in both sets of observers, in line with results in Experiment 2.1. As with those earlier results, any effects with the forward-facing stimuli were likely due to stimulus confounds (unequal sclera-iris ratios for direct and averted gaze stimuli) and thus could not have supported either gaze account. Experiment 7.2 presented observers with laterally
averted faces and, in a bid to understand whether high AQ observers might benefit from top-down instruction (and also whether this might reveal differences in the two dissociable effects detected in Chapter 4), predictive and nonpredictive cues were presented prior to search displays, in independent blocks. Interestingly, this manipulation again revealed no differences in task performance, i.e., neither Process 1 (faster and more efficient RTs to direct gaze targets) nor Process 2 (selective application of top-down cues favouring direct gaze) differed between high and low AQ observers. Thus, at least within the scope of the present experiments, it appears that high AQ observers have a tendency to apply a direct gaze prior in a similar manner to low AQ observers. These results are consistent with recent evidence for the presence of intact direct gaze priors in the high-functioning autistic population (Pell et al., 2016), however, they do not negate the possibility of such priors being less likely to guide attention in more real-world situations which are more dynamic and demand greater social engagement (e.g., von dem Hagen & Bright, 2017; Tanabe et al., 2012). Thus, it may well be the case that the present results reflect very particular experimental contexts within which individuals with higher autistic traits look at eye regions and demonstrate a propensity to apply direct gaze priors.

1.6 Implications and Future Questions

The present thesis made an attempt to answer how and why direct gaze, a foundational social stimulus, is prioritised in visual attention. The picture that has emerged is far from straightforward, however — the processing and prioritising of direct gaze seems to be determined by a complex interplay of factors that include prior expectations about direct gaze, weighted judgements of direct gaze against other gaze types in the visual environment, coding of gaze-object relations, and, overarching this, task goals that drive stimulus selection. In identifying these potentially key components of direct gaze perception, the present set of findings have implications for better understanding of gaze perception both for neurotypical populations, as well as those with socio-cognitive difficulties, such as ASD — shedding light on typical pathways and offering a window into how these components might be compromised in atypical attention. The present set of findings, given their complex nature, raised further questions. To highlight my future aspirations for this project, I briefly discuss these here:

1.6.1 An integrated model of gaze effects

In trying to reconcile findings from Chapter 4 (attentional prioritisation of direct gaze targets) and Chapter 5 (averted gaze bias driven by prediction error, at least at smaller set sizes), the need for an integrated model that could account for both effects was clear. Such a
framework would require in-depth analysis and computational modelling of the relationship(s) between initial saccades to target gaze and RTs to target gaze; beyond the scope of the present thesis but part of a developing collaboration with other lab members. On the basis of the intuition that earlier saccades to a target predict faster RTs, any single factor (for e.g., fixed attentional ‘grab’ of four items at once or a non-linear effect of prediction error magnitude) could adequately account for this. Potentially, the most promising conceptual framework would be one that could specify not only speeding of target recognition on the basis of prediction, but also a tendency to attend to sources of prediction error.

1.6.2 Maladaptive potential of averted gaze bias

The averted gaze bias found in Chapter 5, although within a particular experimental context, leads to the speculation that this might open perception to the possibility of maladaptive responses. Potentially, if there were to be individual differences in the extent to which task goals/expectations are able to modulate processing of prediction error, for example on the autistic spectrum, this might set up maladaptive pathways that divert attention away from direct gaze and towards averted gaze instead. In this case too, an integrated model of typical gaze effects would be a necessary starting point to understanding individual differences in gaze effects.

1.6.3 The key role of gaze-object relations

Chapter 6 had found that attentional prioritisation of gaze, within the context of visual search, incorporates sophisticated representations of gaze-object relations. That task design, however, had not directly compared direct and averted gazes. Without an equivalently salient gaze-object relationship for averted gaze, present SITCE task designs, both those employed in the current thesis and in previous studies, are biased to direct gaze. This leads to the question of whether gaze-object relations may be manipulated such that the one for averted gaze is rendered at least as salient, if not more, than the one for direct – a possible manipulation might be two observers attempting the search task together, such that the averted gaze target for one is the direct gaze target for the other – and what this might reveal about the fundamentality of visual context to gaze perception.

1.6.4 Generalisability of direct gaze prior in higher autistic traits

Chapter 7 had found evidence that observers with higher autistic traits demonstrate a similar tendency to apply a direct gaze prior, at least within specific task contexts. If these task parameters could be generalised to more ecologically valid contexts, this may offer the potential for intervention/behavioural training strategies.
The findings from the present thesis add to an already vast body of literature on direct gaze processing, and reiterate its central role in social perception. An overview of the results suggests that the route to attentional prioritisation of gaze is governed by a complex interplay of processes and is less straightforward than previously presumed. Having identified potentially key components of direct gaze processing in the present thesis, follow-up studies have the potential to reveal a more accurate model of gaze perception with a view to better understanding of neurotypical, and by extension atypical, social perception.
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