Fractionating the 'Stare in the Crowd' Effect:

Two distinct, obligatory biases in search for gaze

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Abstract

Direct gaze – someone gazing at *you* – is an important social cue that might be expected to capture visual attention, even in the presence of other faces. Consistent with this, direct gazing eyes are often detected more rapidly in arrays of averted gazing eyes, than vice versa; a search asymmetry termed the 'Stare in the Crowd Effect' (SITCE). Here, we examine top-down influences on the SITCE by manipulating observers' knowledge of the target's gaze prior to the search display. Our findings revealed two dissociable components of the SITCE. The first, which scaled with set size but was unaffected by prior knowledge, was attributed to noisy, parallel gaze processing that guides attention toward direct gaze ('Process 1'). The second, an overall response time advantage for direct versus averted gaze targets, *irrespective* of set size, was attributed to criteria for determining target presence versus absence ('Process 2'). Prior knowledge of the target's gaze direction increased the direct gaze advantage, rather than speeding up responses for both target types (typically expected for 100% valid cues). This unusual pattern suggests that top-down gaze-related influences may comprise an obligatory bias toward direct gaze.

Keywords: direct gaze, target template, visual search, gaze prior

Public Significance Statement

Among several identical faces, human adults can detect eyes gazing toward them (direct gaze) more quickly than eyes gazing away. This preferential processing of direct gaze is a key building block of human cognitive development. This study revealed that this preference is made up of two, separate effects – better guidance of our attention toward direct gaze eyes, irrespective of what we expect to see, and faster decisions about direct gaze task relevant items.

Gaze direction provides a salient, external cue to another's attention and communicative intent (e.g., Senju & Csibra, 2008; Senju, Johnson, & Csibra, 2008), its importance underscored by the high contrast between the human iris and sclera (Kobayashi & Kohshima, 1997). In particular, *direct* gaze – eyes gazing directly at you – is a potent social signal. Neonates look longer at direct gaze than averted gaze (Farroni, Csibra, Simion, & Johnson, 2002), and in adults, direct gaze enhances other processes related to a given face, such as gender categorisation (Macrae, Hood, Milne, Rowe, & Mason 2002) and memory for identity (Mason, Hood, & Macrae, 2004). Indeed, faces with uncertain gaze direction are more likely to be judged as direct gaze (Mareschal, Calder, & Clifford, 2013; Mareschal, Otsuka, & Clifford, 2014), indicating a bias toward judging uncertain gaze as direct.

Typically, this evidence for the social and cognitive importance of direct gaze relates to *individually-attended* faces. It cannot speak to the relative importance accorded direct gaze versus averted gaze. However, given its importance in human cognition, we would expect direct gaze stimuli to be prioritised for attention when multiple faces are presented and processed *simultaneously*, i.e., that parallel processing of eye stimuli will guide attention toward direct gaze stimuli in scenes comprising multiple faces. The key test of this prioritisation would require that direct and averted gaze stimuli be placed in direct competition for our attention.

In their influential study of visual search for gaze, von Grünau and Anston (1995) asked observers to search for direct gazing eyes from among varying numbers of eyes with averted gaze, or to search for averted gazing eyes from among eyes with direct and averted gaze. They found a search asymmetry favouring more rapid detection of the direct gaze targets than the averted ones, referred to as the 'stare in the crowd effect' (SITCE). This asymmetry superficially resembles those search asymmetries used successfully to identify simpler visual features that drive rapid and efficient search (such as for unique orientation e.g., Treisman & Gormican, 1988; Wolfe & Horowitz, 2004). It is therefore tempting to suppose, as many authors have done, that the SITCE reflects the attention-grabbing properties (or higher attentional priority) of direct gaze in parallel processing of those features (e.g., Conty, Tijus, Hugueville, Coelho, & George, 2006; Senju, Kikuchi, Hasegawa, Tojo, & Osanai, 2008; von Grünau & Anston, 1995). However, this view of the SITCE is not without its critics. Alternative views ascribe the SITCE to stimulus confounds (Cooper, Law, & Langton, 2013) or to enhanced target processing without attention-guidance (Framorando, George, Kerzel, & Burra 2017).

Is there an SITCE in visual search?

In von Grünau & Anston's (1995) original demonstrations, observers searched for targets that were simple cartoons of direct gazing eyes among left and right averted gaze distracters. Correspondingly, averted gaze targets, whether left or right, were detected from among direct gaze and opposite-direction averted gaze distracters. They found clear advantages for detecting direct over averted gaze – an SITCE – but that design suffered from two significant shortcomings. First, in front-facing faces, direct eye gaze stimuli differ markedly from averted gaze stimuli in terms of their physical properties; observers likely detected the target simply on the basis of those visual features without coding gaze direction. Second, the eye stimuli were cartoons, bearing only a broad (rather abstract) resemblance to genuine eye gaze stimuli.

To circumvent these issues, Senju, Hasegawa, and Tojo (2005) used photographs of *laterally oriented* faces, depicted with the face directed at 45 degrees relative to the observer and the eyes at 90 degrees to the observer (or directed towards the observer). This served to minimise differences between direct and averted eye stimuli, other than a left-right asymmetry (pupils on the left versus on the right) to which search processes are typically not sensitive. These stimuli have been the foundation for most subsequent search tasks (including those reported here). However, previous work has typically not assessed whether this manipulation works. For example, the direct gaze stimuli in Conty and colleagues' (2006) study had a larger area of sclera present compared to averted, which could well have supported the more rapid search for those stimuli than the averted gaze stimuli, without recourse to processing of gaze. To preclude such stimulus confounds in generating an apparent SITCE, a control condition is required in which gaze coding is disrupted while key factors remain unchanged. In gaze coding, this typically involves inverting the face stimulus (e.g., Senju et al., 2005; Senju, Kikuchi, et al., 2008, experiment 2) or, in the non-search literature, reversing the contrast polarity of faces (Ricciardelli, Baylis, & Driver, 2000; Ricciardelli, Betta, Pruner, & Turatto, 2009; Experiment 2 of our study).

While Senju and colleagues provided evidence that their reported SITCE was not due to low-level confounds, more subtle problems also restrict the interpretation of their studies; whether searching for direct or averted gaze targets, those displays included downward gaze distracters (Senju et al., 2005) or opposite-direction averted gaze distracters (Senju, Kikuchi, et al., 2008). That is, observers were searching either for direct gaze targets among two or more types of averted gaze distractors, or for averted gaze targets among direct gaze *and* (other types of) averted gaze distractors. The advantage those studies found for direct gaze targets may therefore have reflected a relatively easier detection of an odd-one-out from among visually similar distracters.

Other studies that have avoided these issues have reported superior performance (faster response times) to find direct gaze compared to averted gaze stimuli. However, these either did not manipulate 'set size' – the number of items in a given display (e.g., Framorando et al., 2017; Doi & Ueda, 2007; Doi, Ueda, & Shinohara, 2009) – or did not report gaze-direction influences on the effect of set size (Conty et al., 2006). Instead, they reported only faster response times in general for direct gaze, describing this as an SITCE.

This reveals a lack of agreement about which finding(s) would constitute an SITCE – a disagreement that is often not made explicit.

In visual search tasks, performance (as opposed to the underlying cognitive processes) might be affected by the manipulation of gaze direction in two broad respects: as a function of set size and independent of set size. First, the degree to which direct gaze speeds up a response may scale with the number of items in a display (the ‘set size’; e.g., von Grünau & Anston, 1995). For *inefficient* search, typically found for gaze, response times increase with the number of items in a display, yielding a positive search ‘slope’ expressed in RT increase per display item. If manipulation of gaze direction affects the search slope, this is consistent with it influencing a search process; either parallel processing of gaze direction guiding attention, such that direct gaze items are attended earlier during search, *or* with a self-terminating, serial search process, each item in a display being searched more quickly. Second, gaze direction may influence RTs *independently of set size* – that is, independently of the number of items in the display. In very efficient search, this can reflect efficient parallel processing of gaze direction, but in SITCE studies it more likely reflects a *non-search* process – perhaps relating to response criteria for deciding that a target is present or not. While models of visual search can all be tweaked to produce any observed effects, this broad distinction (which does not demand strict adherence to any particular search model), is widely accepted, and forms part of the conceptual basis for the current work. Either of these types of effects has been considered to constitute an SITCE in previous work – effects independently of set size (e.g., Framorando et al., 2017) or effects that scale with set size only (e.g., Cooper et al. 2013, Senju et al., 2005, experiment 1; Senju, Kikuchi, et al., 2008) or both (Senju et al., 2005). We note the importance of distinguishing the two types of patterns conceptually, and, to anticipate our findings here, also distinguishing them empirically in terms of the effects of predictive cues.

Top-Down Target Templates and the SITCE

With the possible exception of Framorando et al. (2017), our review of the literature revealed no studies that directly studied the role of top-down influences on the SITCE. That study, unfortunately, did not manipulate set size and suffered from confounds associated with the use of forward-facing faces. However, the Framorando study highlighted a potentially important role of task (and associated top-down variables) in the SITCE. Most of the previous literature investigating the SITCE has presented only direct gaze targets or only averted gaze targets within a given block of trials (e.g., Conty et al., 2006; Cooper et al., 2013; Senju et al., 2005; Senju, Kikuchi, et al., 2008; von Grünau & Anston, 1995). As only one type of target was present in each block, participants knew, prior to each display, the target for which they would need to search, just as would be the case for trials with informative cues. It is possible that the SITCE depends entirely on the ability of observers to make such a prediction. Conversely, the SITCE may operate in a stimulus-driven manner, irrespective of the observer's expectations. Either of these possibilities would be consistent with previous SITCE findings, and also with findings that human judgements about an individual face's gaze (as opposed to arrays of faces in search tasks) are biased toward direct gaze, consistent with a notional Bayesian 'prior' favouring direct gaze (Mareschal et al., 2013); such priors may either be flexible, altering as a function of observer's expectations, or fixed.

Here, we sought to elucidate the role of top-down, trial-by-trial predictions in the SITCE, versus more stimulus-driven and less flexible processes. Experiments 1 and 2 established the presence of an SITCE with our own stimuli and apparatus. Within a given block of trials, targets all had the same gaze (either direct or averted), so the observer knew the gaze of the target in advance of each display. In Experiments 3-5, we explicitly manipulated the predictability of target gaze. 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 reliably whether the subsequent target would have direct or averted gaze, so that the observer could form a top-down search template for that gaze direction. In the remaining blocks of trials, there was no predictive cue. By comparing performance in the predictive (informative) cue blocks versus nonpredictive (uninformative) cue blocks, we 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/non-targets 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.

Establishing a top-down target template would be expected to have either, or both, of two effects in our tasks: 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 response times* 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. However, the exact interpretation is not yet crucial to our conclusions here (see General Discussion). Irrespective of whether top-down target template effects on responses do, or do not, scale with set size, some basic views of top-down processing and the SITCE make different predictions as to what we should see:

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 (100% 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. SITCE Increase

Potentially, if top-down target templates were to operate like a fixed Bayesian Prior (i.e., a fixed bias toward processing direct gaze that is applied regardless of whether an observer attempts to establish a target template for direct or averted gaze), we might expect the presence of predictive cues (supporting top-down templates) to increase the magnitude of the SITCE.

Plan of current work

In Experiment 1 we sought to establish the presence of an SITCE using our own stimuli and software. Next, Experiment 2 replicated the conditions of the first experiment, adding control conditions to exclude explanations in terms of stimulus-confounds. Experiment 3 examined the influences of 100% valid pictorial cues as to what the target in each search display would be, and Experiment 4 did so for verbal cues. Experiment 5 was a replication of 4.

Experiment 1: The Stare in the Crowd Effect

In Experiment 1, we sought to establish an SITCE. The stimuli were (our own) black and white photographs depicting the same head and shoulders image with either direct gaze or averted gaze.

Power analysis and Sample Size

A power analysis suggested that for a within-subjects factors, repeated-measures ANOVA with 8 measurements, 16 observers would provide 80% power to detect a medium-sized effect (Cohen's f = 0.25). We ran this experiment with 17 observers having booked one extra person in case required (*m* = 5, *f* = 12, ages 18-35), who were recruited from an existing university student database as well as via an online observer recruitment system. Observers were paid £7.50 for participating. The study was approved by the University of Cambridge Psychology Research Ethics Committee.

Stimuli and Apparatus

The visual search task was presented with E-Prime 2.0 software on a 21.5-inch Dell monitor (P2414HB) at a resolution of 1920 x 1080. Observers were seated about 70 centimetres from the screen and made responses via a standard USB keyboard. Search displays were comprised of faces (with head and shoulders, e.g., Fig. 1) with either direct gazing eyes or averted gazing eyes. Following Senju and colleagues (2005), these images depicted faces laterally averted to the observer's right, and thus averted eye gaze was to the right from the observers' perspective. To construct these images, a photograph of Author NR gazing toward the camera (and hence, in the image, toward the observer) was first converted to greyscale. This direct gaze image was kept as the template onto which the eye region from a similar averted gaze image was then superimposed to form the averted gaze stimulus. We also presented ‘placeholder’ closed eye stimuli prior to the search display, in the same positions as each of the subsequently presented faces. These were made by superimposing the closed eye region from a similar image onto the direct gazing template image.

Each individual face fit within an area of roughly 279 pixels squared, subtending a visual angle of approximately 6° 3' x 6° 3'. Face stimuli were arranged on an imaginary circle (approximately 258 mm diameter) centred on the centre of the display. The faces in set size 7 were arranged in one configuration, while those in set size 3 had three different configurations, with faces roughly equally spaced to avoiding ‘bunching’ in any one part of the display.

Procedure

Each trial began with a brief (250 ms) presentation of ‘placeholder’ face stimuli – the same stimuli as would appear in the subsequent search display, but with the eyes closed (an example trial is shown in Figure 1). This gave the naturalistic impression of several faces opening their eyes. These placeholder stimuli were designed to minimise distracting effects of other facial features in our displays by presenting these prior to the eye stimuli themselves, allowing observers to focus their attention on the eyes in particular. When, in previous work, faces were presented with the eyes already open, observers may have been distracted by the simultaneous onsets of many facial features while they were attempting to locate and code the faces’ eyes – our manipulation should have minimised those effects. When the eye gaze of the faces was revealed (in the search display) observers searched the display to find a direct gazing target from among averted gazing non-targets, or an averted gazing target from among direct gazing non-targets. On half the trials, a target pair of eyes was present, and on the remaining trials, no target was present. Observers were instructed to detect whether a target was present, or not, as quickly and accurately as possible and to indicate their decision using one of two keys on a computer keyboard. The search display was terminated by the observer's response and no feedback was given regarding errors.

The search task was presented in 4 blocks of 60 trials each, with the first two blocks of 120 trials being one type of target eye gaze (either direct gaze or averted) and the next two blocks of 120 trials being the opposite target eye gaze. The first two blocks were followed by a 10 second break, and order of presentation was counterbalanced across observers. Each gaze direction search task began with a practice block (20 trials, with 4 trials of each unique combination) and observers received feedback on their responses ("Correct!" = correct response, "------" = incorrect response). The main experimental blocks followed, for which observers did not receive any feedback.

Within each block, half of all trials comprised a target while half did not, and half comprised seven images while half comprised three. Position of display elements was randomised, and order of presentation was varied unpredictably for target presence and displays of different set sizes.

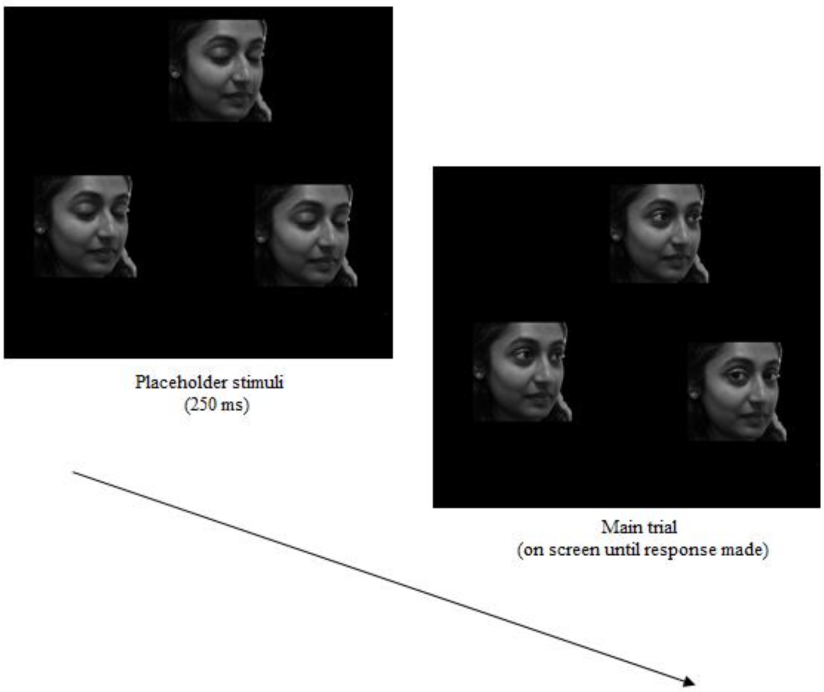


Figure 1. Schematic sequence of trial displays in Experiment 1

Results and Discussion

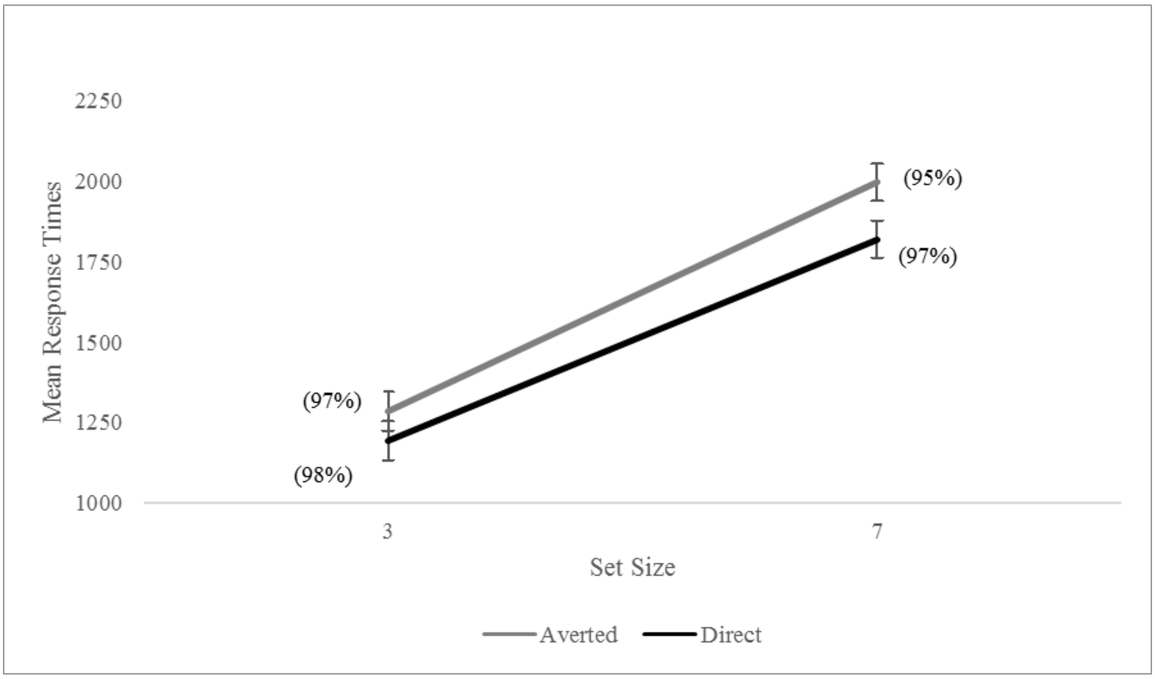


Figure 2. Mean Response Times (accuracy rates in parentheses) for Averted and Direct Target Gazes in Experiment 1, at Set Sizes 3 and 7 separately. Error bars indicate +/- 1 $SEM_{paireddiffs.}$

For each observer (*N*= 17), RT data for accurate responses (*M*= 96.69, *SD*= 2.45) were trimmed to exclude any RTs ±3 standard deviations (separately for each combination of Target Gaze, Target Presence and Set Size). Figure 2 plots the inter-observer mean RTs separately for trials in which the target was direct gaze versus averted gaze, and for each set size. Visual inspection of the plot 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, repeated measures ANOVA, with factors of Target Gaze (Direct Gaze or Averted Gaze), Target Presence (Present or Absent) and Set Size (3 or 7 items), yielded significant main effects of Target Gaze [F (1, 16) = 6.192, p = .024, η_p^2 = .279], Target Presence [F (1, 16) = 62.779, $p < .001$, η_p^2 = .797], and Set Size [F (1, 16) = 141.795, $p < .001$, η_p^2 = .899].

All effects were in the expected direction: 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.

A two-way interaction was observed between Target Presence and Set Size [F (1, 16) = 45.146, p < .*001*, η_p^2 = .738], reflecting greater search slopes for Target Absent trials as in previous SITCE studies (e.g., Conty et al., 2006; Senju et al., 2005). The Target Gaze by Target Presence interaction was not significant [F (1, 16) = .448, p = *.513*, η_p^2 = .027]. Contrary to our expectation, the two-way interaction between Target Gaze and Set Size was only marginal [F (1, 16) = 3.3.09, p = *.088*, η_p^2 = .171].

Corresponding analyses of accuracy yielded only a main effect of Target Presence [F (1, 16) = 22.078, p < .*001*, η_p^2 = .580] and a marginal effect of Set Size [F (1, 16) = 4.405, p = *.052*, η_p^2 = .216], following the RT patterns. No main effect of Target Gaze [F (1, 16) = 2.901, p = *.108*, η_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*, η_p^2 = .221]. Again, following the RT patterns the Target Presence by Set Size interaction was significant [F (1, 16) = 5.976, p = *.026*, η_p^2 = .272].

Experiment 1 thus established the presence of a ‘stare in the crowd effect’ (SITCE) using our own stimuli, for faces that were laterally-averted, 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 nontarget.

Experiment 2: SITCE with Reversed Contrast Polarity

Experiment 2 had two primary aims. First, to establish whether the overall RT advantage observed in Experiment 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. This second study therefore replicated the conditions of Experiment 1 twice, within the same observers: once with standard face stimuli and once with the images' contrast polarity reversed to disrupt gaze processing.

Sample Size

On the basis of our previous sample, we recruited 17 new observers (m = 6, f = 11, ages 18-35), from an existing university student database as well as via an online observer recruitment system. Each was paid £10.

Stimuli, Apparatus, and Procedure

The apparatus and the standard face stimuli were the same as in Experiment 1. To create the reverse contrast stimuli, we inverted the polarity of the standard stimuli, such that dark regions (e.g., iris) became light, and light regions (e.g., sclera) became dark. 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. As shown in Figure 3, our 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 we included this condition 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 1 except for the addition of a fixation cross prior to the placeholder stimuli (250 ms), as we felt that trials were perceptually better demarked from one another by the addition of a fixation cross rather than placeholder stimuli alone. 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.

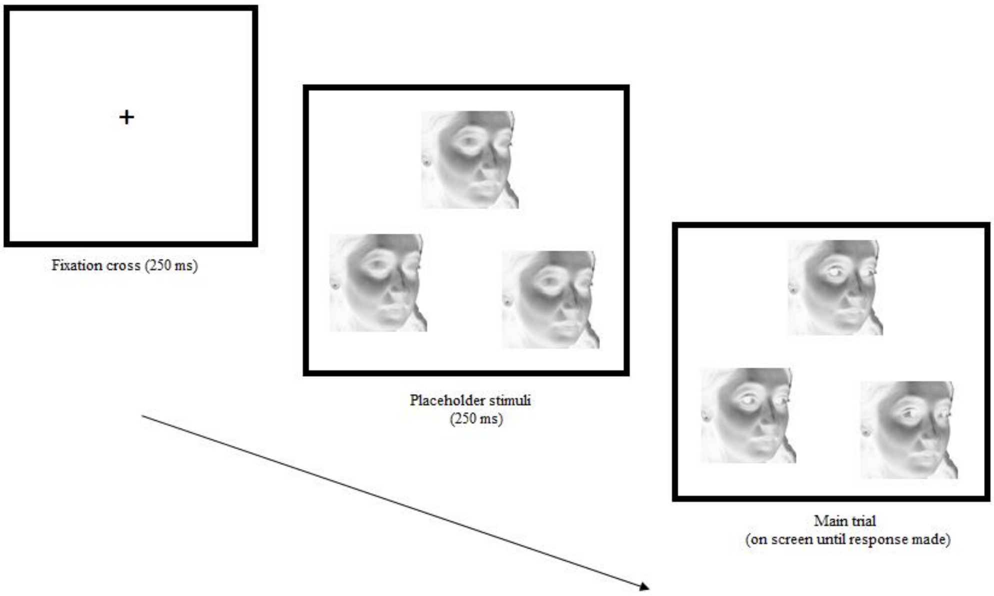


Figure 3. Schematic sequence of trial displays in Reversed Contrast Polarity condition of Experiment 2

Results

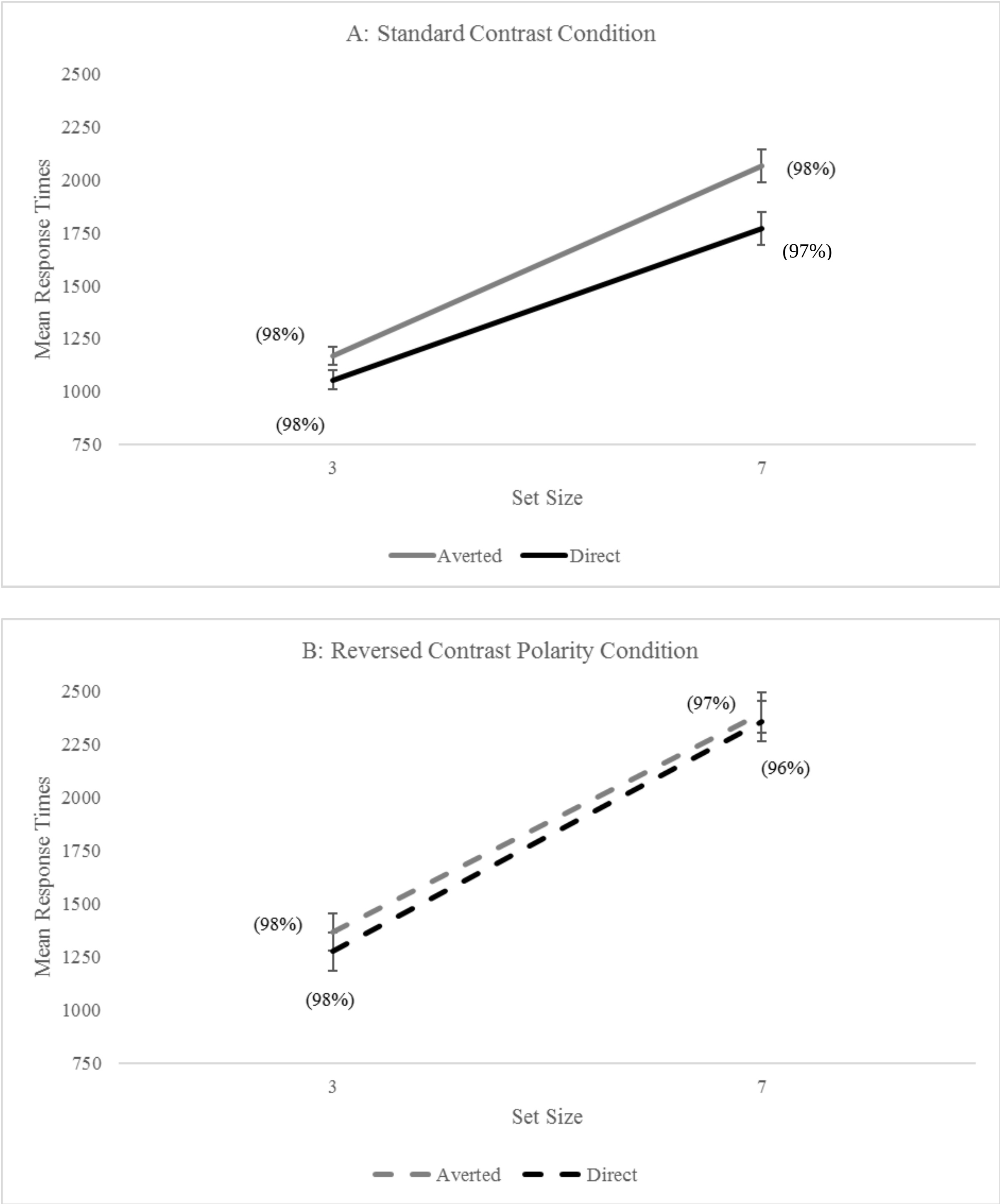


Figure 4. Mean Response Times (accuracy rates in parentheses) for Averted and Direct Target Gazes, separately at Set Sizes 3 and 7 for (A) Standard Contrast condition and (B) Reversed Contrast Polarity condition of Experiment 2. Error bars indicate +/- 1 $SEM_{paireddiffs}$.

Analysis was as for Experiment 1, but with the addition of a new factor, Contrast Polarity (Standard or Reverse). One observer had to be excluded because even post trim, their RTs fell outside 3 standard deviations of the group mean. Figure 4 plots mean response times in Experiment 2 for Standard Polarity conditions (Figure 4A) and Reversed Contrast Polarity conditions (Figure 4B). Visual inspection of the plots suggested the presence of an SITCE for the Standard Polarity but not Reversed Contrast Polarity condition, as we had predicted. These impressions were confirmed in a four-way repeated-measures ANOVA, with the within observer factors of Contrast Polarity (Standard or Reversed), Gaze direction (Direct or Averted Gaze), Target Presence (Present or Absent), and Set Size (3 or 7). This yielded main effects of Contrast Polarity [F (1, 15) = 21.504, $p < .001$, $\eta_p^2 = .589$], Target Gaze [F (1, 15) = 5.706, $p = .03$, $\eta_p^2 = .276$], 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 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 Size [F (1, 15) = 21.206, $p < .001$, $\eta_p^2 = .586$]. No other two or three-way interactions were observed (all F values ≤ 2.167, $p > .162$).

To reveal the source of the main three-way interaction, we ran two three-way ANOVAs for each Contrast Polarity. The Standard Contrast condition ANOVA yielded both a main effect of Target Gaze [F (1, 15) = 12.635, p = .*003*, η_p^2 = .458] and a Target Gaze by Set Size Interaction [F (1, 15) = 12.908, p = .*003*, η_p^2 = .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*, η_p^2 = .036], the interaction with Set Size [F (1, 15) = .915, p = .*354*, η_p^2 = .057].

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

Experiment 2 greatly strengthened our evidence for two types of effects involving search for gaze direction. In the Standard Contrast condition, we found strong evidence for a Target Gaze by Set Size interaction – the search slopes when searching for direct gaze targets were shallower (more efficient) than when searching for averted gaze targets (the main effect of Target Gaze cannot be interpreted as the higher-order interaction qualifies this effect). 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. We saw no such effects, reassuring us that the direct gaze biases (SITCEs) we were observing reflected coding of gaze direction in those stimuli (highly disrupted by contrast reversal).

Experiment 3: The Influence of Predictive Pictorial Cues on the SITCE

With the foundation in place for two observable effects when searching for eye gaze, we next investigated the influence of top-down target templates on performance. We used pictorial cues that informed the observer, prior to each search display, which target 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, the observer could not predict which type of target they would next be asked to search for. We could then present two types of blocks of trials: blocks in which trials contained non-predictive cues prior to the display, providing a baseline performance for each observer, and blocks in which 100% valid cues signalled, at the beginning of each trial, which type of target the observer 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.

To briefly recap the expected outcomes and other possible patterns in this new study, we expected to find an SITCE that scaled with set size (though this had only been marginal in Experiment 1, we had also observed it in Experiment 2, greatly increasing our confidence in the effect). Additionally, with regard to the influence of predictive cues, three different views of the SITCE (and of search for gaze in general) suggested three possible patterns in the new study. First, the default *General Enhancement* prediction, which assumes that top-down effects on gaze processing parallel those for other visual features, such that the SITCE would remain unaffected, but performance would overall be enhanced by predictive cues (either a main effect of Cue Predictiveness or an interaction with Set Size). Second, *SITCE Reduction*, which might be predicted if the SITCE resulted from a tendency to default to direct gaze using a top-down direct gaze template that could be counteracted by voluntarily forming a template for averted gaze. Third, *SITCE Increase,* if top-down templates for gaze effectively rigidly specify a preference for direct gaze, even though they are voluntarily applied.

Sample Size

An average effect size of η_p^2 = .317 for the key two-way interaction suggested that 16 participants would suffice to power that interaction. However, as that effect had been variable and we were now interested in a higher-order interaction, with four factors in the experiment, we increased the sample size to twenty observers (*m* = 9, *f* = 11, ages 18-35, sample size estimated using PANGEA software, jakewestfall.shinyapps.io/pangea). Observers were again recruited and paid (£10) as for the previous experiments.

Apparatus, Stimuli and Procedure

All aspects of methods were as for Experiment 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 5A 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 squared, subtending a visual angle of approximately 4° 5' x 4° 5'). In Predictive Cue blocks the cue predicted reliably which of two targets the observer would be asked 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). 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.

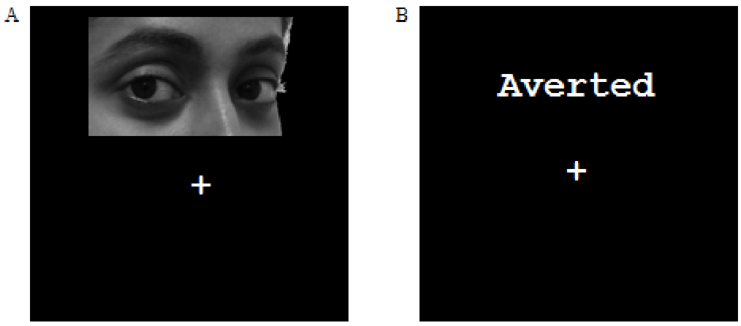
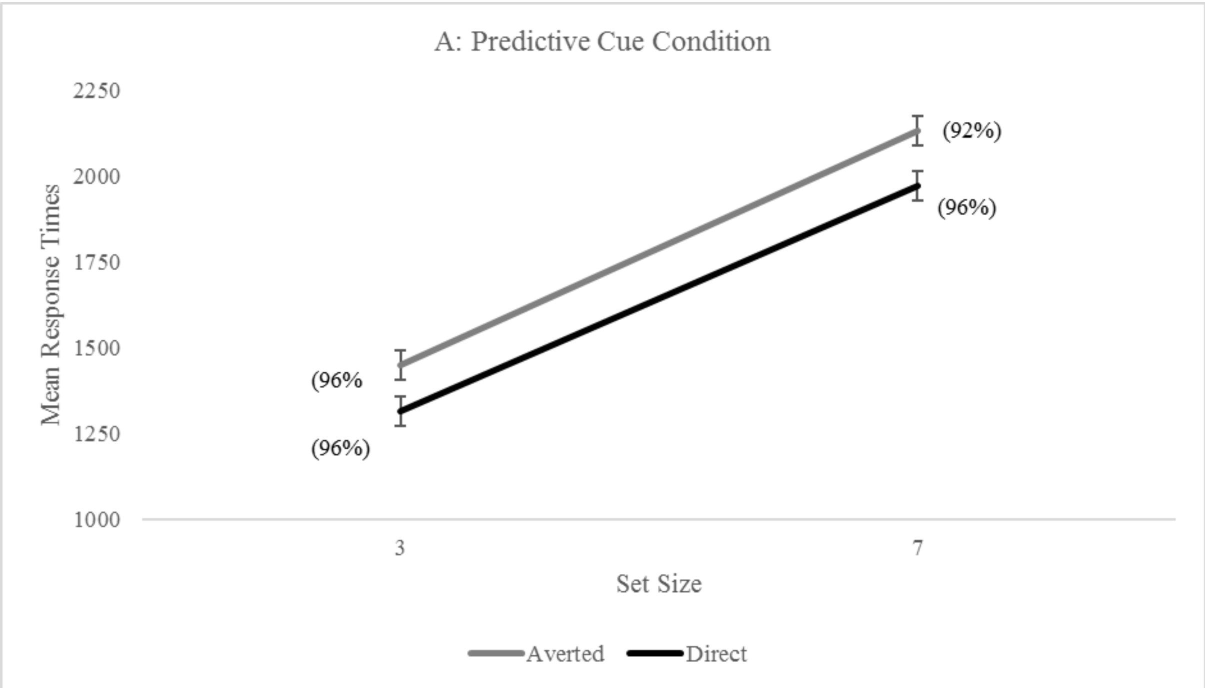


Figure 5. (A) Examples of Direct Gaze Cue from Experiment 3 and (B)Averted Gaze Cue from Experiments 4 and 5.

Results and Discussion



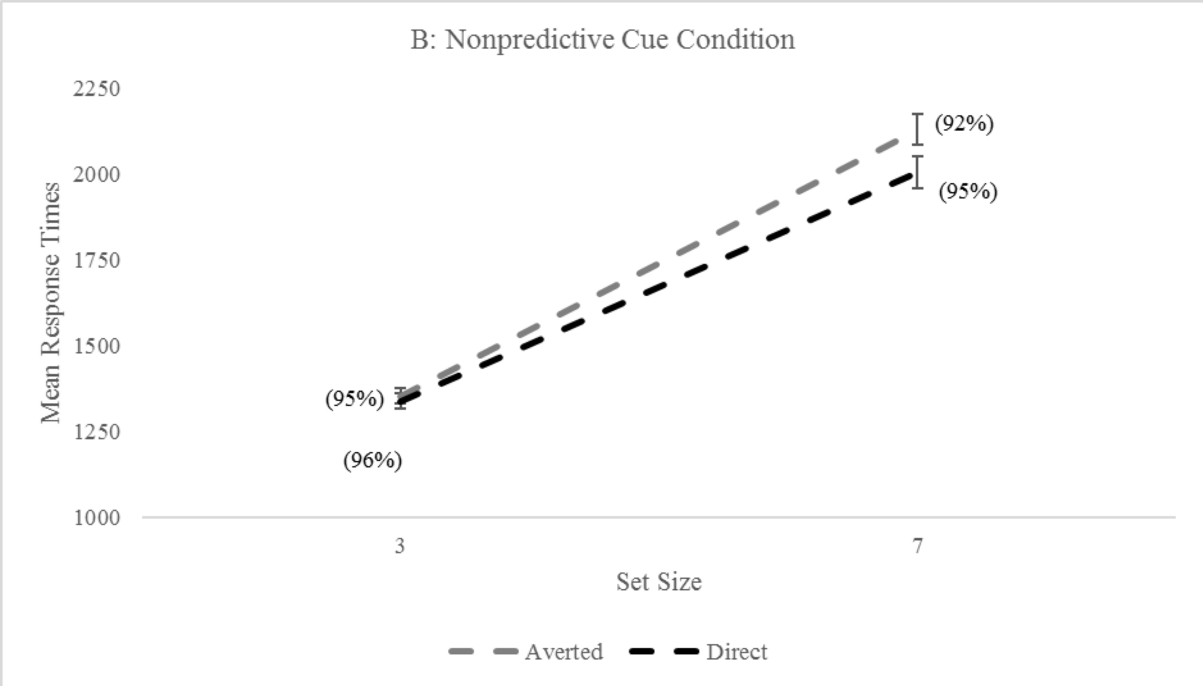


Figure 6. Mean Response Times (accuracy rates in parentheses) for Averted and Direct Target Gazes, at Set Sizes 3 and 7 separately for (A) Predictive Cue condition and (B) Nonpredictive Cue condition of Experiment 3. Error bars indicate +/- 1 $SEM_{paireddiffs}$.

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 6 plots mean RTs for each Set Size and Target Gaze, separately for Predictive Cues (Figure 6A) and Nonpredictive Cues (Figure 6B). Visual inspection of the plots suggested that there was again 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 repeated measures ANOVA, identical to that in Experiment 2, but with the factor Cue Predictiveness (Predictive or Nonpredictive) replacing Contrast Polarity, clarified which of these effects were reliable. There were main effects of Target Gaze [F (1, 19) = 17.445, p = *.001*, η_p^2 = .479], Target Presence [F (1, 19) =

16.903, $p = .015$, $\eta_p^2 = .471$], and Set Size [F (1, 19) = 116.505, $p < .001$, $\eta_p^2 = .860$] as expected, as also the expected Target Presence by Set Size interaction [F (1, 19) = 28.538, $p < .001$, $\eta_p^2 = .600$].

More importantly, we observed a two-way interaction between Cue Predictiveness and Target Gaze [F (1, 19) = 7.217, $p = .015$, $\eta_p^2 = .275$]– the advantage for direct gaze targets versus averted gaze targets was greater in the Predictive Cue condition than the Nonpredictive. The interaction between Target Gaze and Set Size was again marginal [F (1, 19) = 3.151, $p = .092$, $\eta_p^2 = .142$]. Though evidence for this effect was weak in the current study, the corresponding pattern in accuracy scores [F (1, 19) = 4.428, $p = .049$, $\eta_p^2 = .189$], and in two previous experiments, bolstered our confidence that it was a real effect – revealing that the difference between the two Target Gaze directions (slower and less accurate for Averted Gaze, faster and more accurate for Direct Gaze Targets) tended to be greater at Set Size 7 than Set Size 3. No other two-way or three-way interactions were significant (all F values $\leq$ 1.424, $p > .247$).

The interaction between Cue Predictiveness and Target Gaze effect was not reliably influenced by Set Size [F (1, 19) = 1.424, $p = .247$, $\eta_p^2 = .070$]. That is, contrary to our impressions from visual inspection of the plot, Cue Predictiveness did not reliably alter the two-way interaction between Target Gaze and Set Size. Note that, on the basis of this one null result, we could have no confidence that there was no effect, as opposed to a small, undetected effect to which the data were insensitive. However, any numerical trend in the data was toward Predictive Cues *reducing* the interaction. In contrast, Predictive cues had significantly *increased* the main effect of Target Gaze. We therefore had initial evidence that the SITCE component which scaled with Set Size (yielding the Target Gaze by Set Size interaction) versus the component that did not scale with Set Size (yielding the main effect of Target Gaze) were very differently affected by Cue Predictiveness.

In this experiment, our use of pictorial cues 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, we had anticipated this possibility prior to running the experiment and planned a supplementary analysis to rule it out. This would also serve to demonstrate that the effect was not due to masking by the cue. First, we selected from the Nonpredictive cue blocks, only those 50% of trials in which the cue did match the target. In terms of perceptual priming, these trials were physically identical to the Predictive cue blocks. With priming effects thus removed, we re-ran our analyses to check whether our key findings regarding Cue Predictiveness remained. Consistent with an effect of prediction / top-down templates, and no effect of perceptual priming, we found that the interaction between Cue Predictiveness and Target Gaze remained [F (1, 19) = 11.573, p = *.003*, η_p^2 = .379], that this was not influenced by Set Size [F (1, 19) = 1.022, p = *.325*, η_p^2 = .051], and that there was overall a marginal Target Gaze by Set Size interaction [F (1, 19) = 3.063, p = *.096*, η_p^2 = .139].

Applying the same analysis as for RTs to accuracy data revealed significant effects of Target Gaze [F (1, 19) = 9.391, p = *.006*, η_p^2 = .331], Target Presence [F (1, 19) = 22.315, p < *.001*, η_p^2 = .540], and Set Size [F (1, 19) = 9.470, p = *.006*, η_p^2 = .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*, η_p^2 = .189], and the Target Presence by Set Size interaction was significant [F (1, 19) = 6.111, p = *.023*, η_p^2 = .243]. In addition, the Target Gaze by Target Presence interaction was significant [F (1, 19) = 8.339, p = *.009*, η_p^2 = .305], though qualified by a three-way interaction with Set Size [F (1, 19) = 7.240, p = *.014*, η_p^2 =

.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*, η_p^2 = .272] as opposed to Target Absent [F (1, 19) = .065, p = *.802*, η_p^2 = .003]. No other interactions were significant (all F values ≤ 2.095, p > *.164*), in line with our 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 3 had therefore provided evidence of an SITCE, again, and of a rather selective effect of top-down target templates in this task. There was clearly no general performance enhancement, so we could exclude the first *General Enhancement Prediction*. That is, 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. 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. However, the outcome was less clear for the set-size-dependent element of SITCE, the shallower search slopes often found for direct gaze targets. To provide further evidence for each of these elements, we replicated the conditions of Experiment 3, but now used word cues "Direct" or "Averted" in place of the previous pictorial cues in Experiment 3. This should preclude any of the potential bottom-up, perceptual priming effects of pictorial cues on search.

Experiment 4: SITCE with Semantic Cues

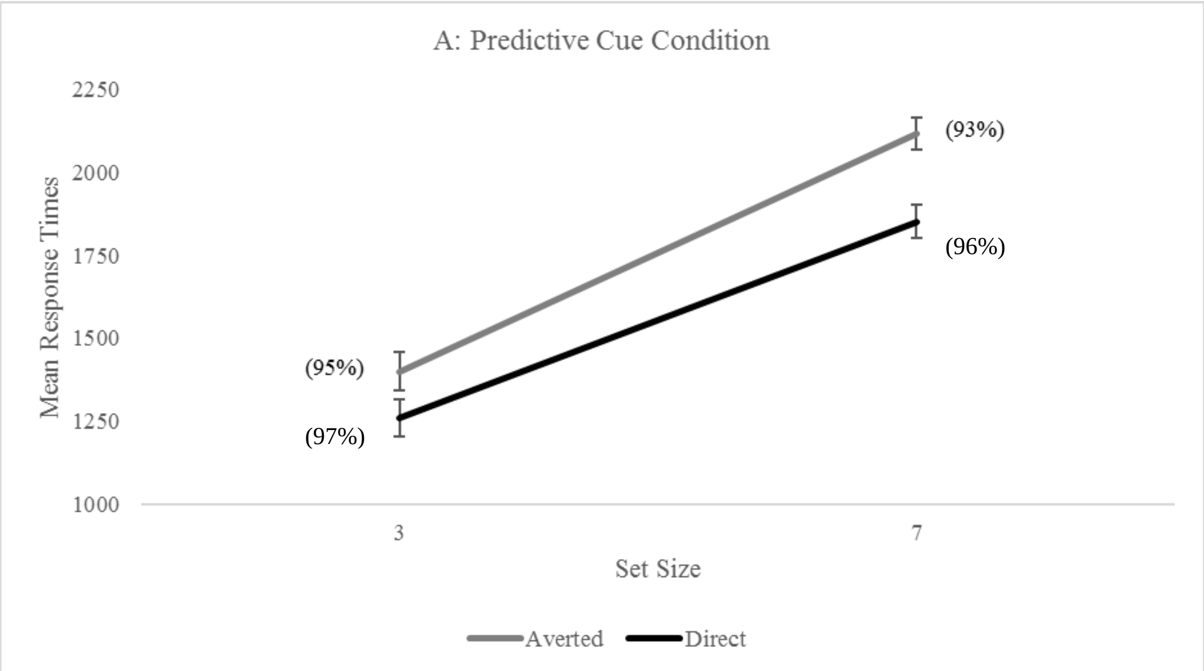
Sample Size

Sample-size was based on that employed for Experiment 3. Twenty observers (*m* = 6, *f* = 14, ages 18-35) were recruited from an existing database as well as via an online observer recruitment system, and paid for their time (£10) as before.

Apparatus, Stimuli, and Procedure

The apparatus, stimuli and procedure were as for Experiment 3, 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 (see Figure 5B for Averted Gaze example). 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.

Results and Discussion



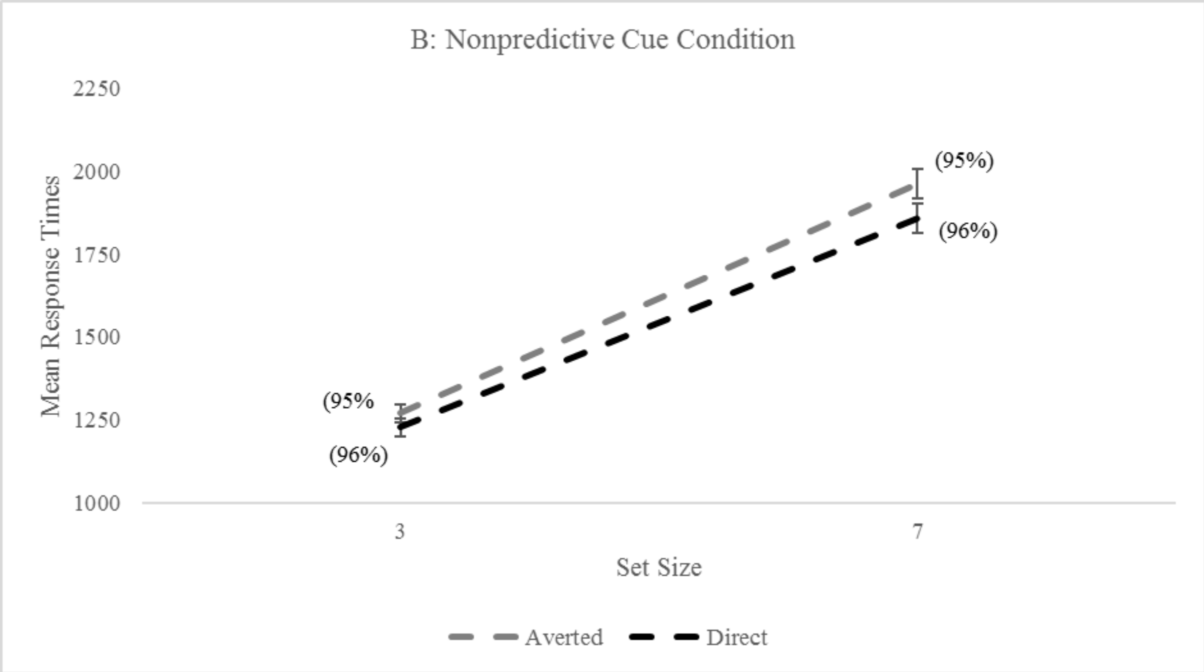


Figure 7. Mean Response Times (accuracy rates in parentheses) for Averted and Direct Target Gazes, separately at Set Sizes 3 and 7 for (A) Predictive Cue condition and (B) Nonpredictive Cue condition of Experiment 4. Error bars indicate +/- 1 $SEM_{paireddiffs}$.

For each observer (*N*= 20), RT data for accurate responses (*M*= 95.45, *SD*= 3.80) were trimmed as for Experiment 3 (and according to the same principle as in all the current experiments). Figure 7 plots, in the same format as Figure 6, mean RTs for conditions in Experiment 4. 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 non-targets themselves. Identical analyses to those for RTs in Experiment 3 yielded expected main effects of Target Gaze [F (1, 19) = 21.441, $p < .001$, η_p^2 = .530], Target Presence [F (1, 19) = 25.965, $p < .001$, η_p^2 = .577], Set Size [F (1, 19) = 327.562, $p < .001$, η_p^2 = .945], and the standard two-way interaction between Target Presence by Set Size [F (1, 19) = 268.252, $p < .001$, η_p^2 = .934]. In terms of interactions of interest, the two-way interaction between Target

Gaze and Set Size was significant [*F* (1, 19) = 8.401, $p = .009$, η_p^2 = .307], reassuring us 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, $p = .029$, η_p^2 = .228]. As in Experiment 3, 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, $p = .297$, η_p^2 = .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 we had concluded for Experiment 3.

In corresponding analysis of accuracy scores, main effects of Target Gaze [*F* (1, 19) = 9.425, $p = .006$, η_p^2 = .332], Target Presence [*F* (1, 19) = 21.064, $p < .001$, η_p^2 = .526] but not Set Size [*F* (1, 19) = 2.660, $p = .119$, η_p^2 = .123] were found. Two-way interactions between Target Gaze and Target Presence [*F* (1, 19) = 10.402, $p = .004$, η_p^2 = .354] and Target Presence and Set Size [*F* (1, 19) = 20.185, $p < .001$, η_p^2 = .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, $p = .007$, η_p^2 = .323] were found. 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 Nonpredictive Cue condition [*F* (1, 19) = .5.515, $p = .030$, η_p^2 = .225], but not the Predictive Cue condition [*F* (1, 19) = .289, $p = .597$, η_p^2 = .015], the former effect reflecting a marginal two-way (Target Gaze by Set Size) interaction [*F* (1, 19) = 3.103, $p = .094$, η_p^2 = .140] and significant for Target-Absent trials [*F* (1, 19) = 5.218, $p = .034$, η_p^2 = .215]. As these effects reflected error differences in very small numbers of trials and did not adversely impact our RT analyses, we did not analyse them further.

Overall, these results increased our confidence in our conclusions from Experiment 3 – that top-down search templates related to gaze direction (encouraged in conditions with predictive cues) had increased a component of the SITCE that was relatively independent of set size. 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.

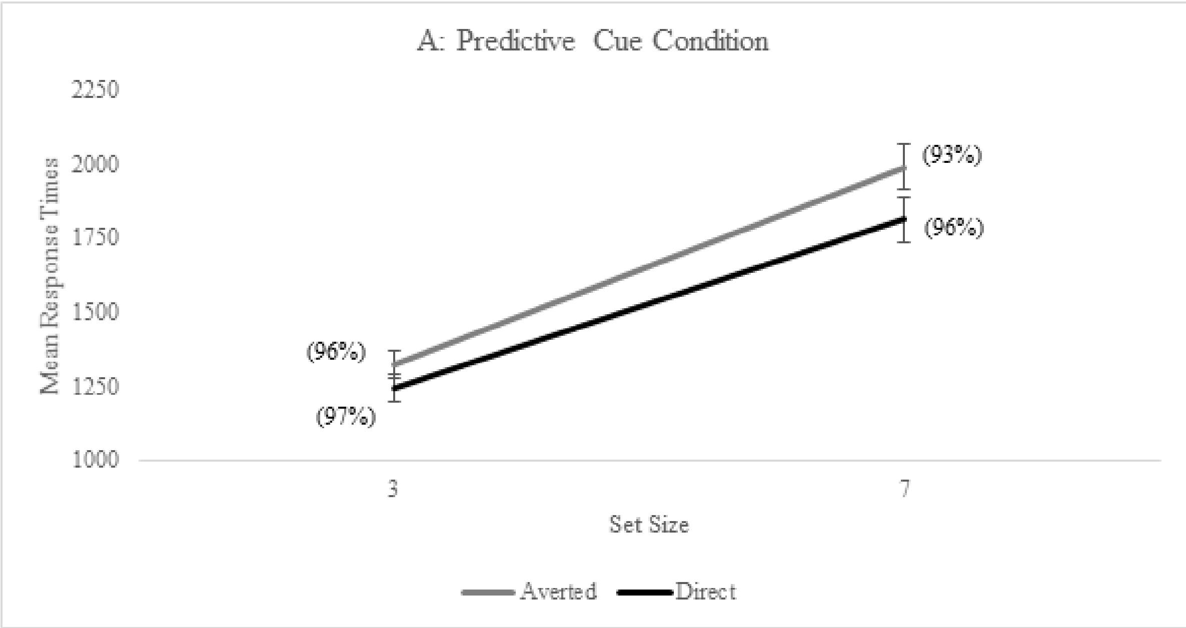
Experiment 5: Replication of Experiment 4

We replicated Experiment 4 to have more evidence for the interaction between Target Gaze and Set Size, a key aspect of the SITCE. Our pre-registration of this replication is available at https://aspredicted.org/dg8j9.pdf.

Sample Size, Apparatus, Stimuli, and Procedure

Effect sizes for the Target Gaze by Set Size interaction from Experiments 1 to 4 yielded η_p^2 = 0.27. Thus we decided to keep the sample size the same as Experiment 4. 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.

Results and Discussion



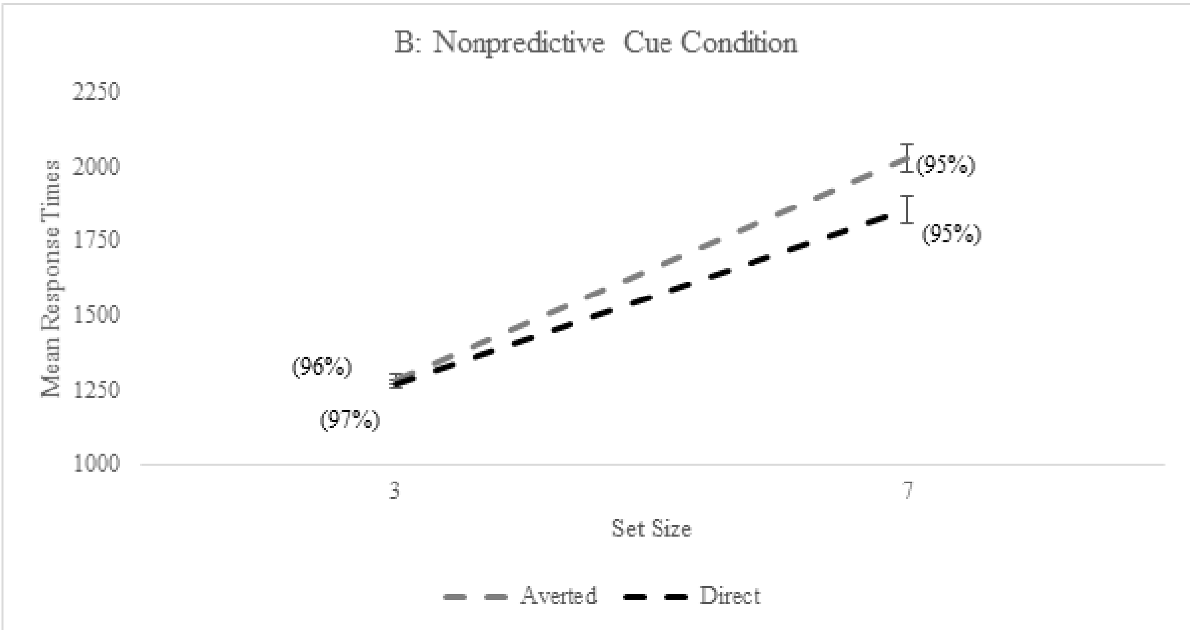


Figure 8. Mean Response Times (accuracy rates in parentheses) for Averted and Direct Target Gazes, separately at Set Sizes 3 and 7 for (A) Predictive Cue condition and (B) Nonpredictive Cue condition of Experiment 5. Error bars indicate +/- 1 $SEM_{paireddiffs}$.

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. Figure 8 plots mean RTs for conditions in Experiment 5, in the same format as Figure 7. Visual inspection of the plots suggested that results were largely parallel to those in Experiment 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 showed main effects for Target Gaze [F (1, 17) = 35.574, $p < .001$, η_p^2 = .677], Target Presence [F (1, 17) = 55.461, $p < .001$, η_p^2 = .765], and Set Size [F (1, 17) = 289.841, $p < .001$, η_p^2 = .945], and the standard visual search interaction of Target Presence by Set Size [F (1, 17) = 116.115, $p < .001$, η_p^2 = .945]. With respect to interactions of interest, the Target Gaze by Set Size interaction was replicated [F (1, 17) = 20.549, $p < .001$, η_p^2 = .547], and, crucially, this interaction was not influenced by Cue Predictiveness [F (1, 17) = .791, $p = .386$, η_p^2 = .044], as expected. The Cue Predictiveness by Target Gaze interaction did not reach significance [F (1, 17) = 2.774, $p = .114$, η_p^2 = .140]. However, as this effect was in the same direction as Experiments 3 and 4, 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, $p = .067$, η_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, $p = .025$, η_p^2 = .263], Target Presence [F (1, 17) = 11.604, $p = .003$, η_p^2 = .406], and Set Size [F (1, 17) = 9.290, $p < .007$, η_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, $p < .001$, η_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 our primary dependent variable, very small, and not found in Experiment 4, we do not analyse them further.

Combined Analyses

We had planned (as detailed in our pre-registration description) to combine results from Experiment 4 and 5 to further increase power. We ran a five-way within-between repeated measures ANOVA, 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, $p < .001$, $\eta_p^2 = .585$], Target Presence [F (1, 36) = 74.807, $p < .001$, $\eta_p^2 = .675$], and Set Size [F (1, 36) = 614.292, $p < .001$, $\eta_p^2 = .945$] in the expected directions. The key Target Gaze by Set Size interaction was also found [F (1, 36) = 25.636, $p < .001$, $\eta_p^2 = .416$], and, as before, was not influenced by the factor of Cue Predictiveness [F (1, 36) = .001, $p = .973$, $\eta_p^2 = .000$]. The standard Target Presence by Set Size interaction was also present [F (1, 36) = 345.656, $p < .001$, $\eta_p^2 = .906$]. In addition, the Cue Predictiveness by Target Gaze interaction was significant [F (1, 36) = 8.121, $p = .007$, $\eta_p^2 = .184$], reassuring us 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, $p = .048$, $\eta_p^2 = .105$], 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, $p = .065$, $\eta_p^2 = .092$], such that response times to predictive cues were slower in Experiment 4 than in Experiment 5. The between-observers factor of Experiment was not significant [F (1, 36) = .186, p = .669, η_p^2 = .005]. No other interaction terms were significant (all F values ≤ 1.895, p > .177).

Multiple-Experiment Analyses and Discussion

We used standard Null Hypothesis Significance Testing (NHST) statistics to analyse each of our five 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. We ascribed each 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. We 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.

For each of these terms, 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, we next conducted Bayesian analyses of this three-way interaction, the two two-way interactions and another term of importance for our interpretation (discussed below). To simplify the analyses, we reduced two-way (2x2) and three-way (2x2x2) within-observers interactions of interest to a single value per observer, according to which term was being analysed. For example, to analyse the Target Gaze x Set Size interaction, we calculated average RTs for each combination of Target Gaze and each Set Size (averaging across levels of Cue Predictiveness and Target Presence). To find the two-way interaction, we needed then only to compute the Direct Gaze advantage at each Set Size by subtracting the average RT (for each observer) for Direct Gaze targets from that for Averted Gaze targets. Finally, we subtracted the resulting Direct Gaze advantage at Set Size 3 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; all conclusions robust for prior widths of 0.5, 1 or 2). These analyses are reported and discussed below for each of the two-way interactions and the three-way interaction.

Overall Evidence for 'Process 1': Target Gaze x Set Size interaction

We first considered the two-way interaction revealing an SITCE component that scaled with Set Size – the two-way interaction between Target Gaze and Set Size that was significant in three experiments and marginally so in two experiments. Overall, there was very strong evidence for the presence of this effect when collapsing across experiments (BF_{10}= 448219). There are two broad classes of cognitive mechanisms to which we 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* Non-targets (one at a time, or several at a time) to find a Direct Gaze Target than through Direct Gaze Non-targets 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, we were able to effectively exclude this account on the basis of our 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). On 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 our five 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 evidence in favour of H_0 (BF_{10}=0.117) – providing evidence that the SITCE effect on search slopes was *the same* for Target Present and Target Absent trials. We could therefore exclude effects of gaze direction on purely serial search elements of search as an explanation for the effect of gaze direction on search slopes. Accordingly, we conclude 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 Non-targets than Averted Gaze Targets among Direct Non-targets. Note that this conclusion does not depend upon search being either strictly parallel or serial: our 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).

Overall Evidence for 'Process 2': Target Gaze x Cue Predictiveness interaction

We then turned our attention to the second SITCE component, which we propose is influenced by Cue Predictiveness, but not Set Size. As discussed in the Introduction, 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 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.

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

Finally, we sought to establish whether there was evidence against a three-way interaction between Target Gaze, Set Size and Cue Predictiveness. Such evidence would bolster our conclusions that the two processes above, each identified with a two-way interaction term, were dissociable. To compute the single scores for this analysis, we calculated the Target Gaze x Set Size interaction (as described above) separately for Predictive Cue and Nonpredictive Cue trials, for each observer in Experiments 3-5, then subtracted one set of scores from the other. When analysed using a one-sample Bayesian t-test, as for the previous analyses, we found moderate evidence in favour of the null hypothesis (BF_{10}=0.181), i.e., the evidence from Experiments 3-5 favoured the absence of a three-way interaction. We 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).

General Discussion

Here, we first established an SITCE that could not readily be ascribed to stimulus confounds or potential issues of using multiple non-target types (e.g., Senju et al., 2005; Senju et al., 2008). Experiment 1 investigated the SITCE using laterally averted faces (with direct and leftward averted gaze) arranged in a circle, and Experiment 2 replicated these conditions, and included within the same observers a reversed-contrast-polarity control 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).

Next, in Experiments 3 to 5, we investigated how 100% predictive cues, 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 straight-ahead faces and were thus subject to likely luminance confounds related to the eye region (see our discussion in the Introduction). 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 pictorial cues (Experiment 3) and semantic (Experiments 4 and 5), predictability of cues influenced a component of the SITCE that did not scale with set size. We concluded 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. We concluded that 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 our experiments.

From these findings, it would appear that the SITCE observed in Experiments 1 and 2 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 our 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. The watching eyes effects model (W.E.; Conty, George, & Hietanen, 2016) takes this idea further, proposing 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, our 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.

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