Attention Neglects a Stare-in-the-Crowd: Unanticipated Consequences of Prediction-Error Coding

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Abstract

Direct gaze – someone looking at you – is an important and subjectively-salient stimulus. Its processing is thought to be enhanced by the brain's internalised predictions – *priors* – that effectively specify it as the most likely gaze direction. Current consensus holds that, befitting its presumed importance, direct gaze attracts attention more powerfully than other gazes. Conversely, some Predictive Coding (PC) models, in which exogenous attention is drawn to stimuli that *violate predictions*, may be construed as making the opposite claim — i.e, exogenous attention should be biased away from direct gaze (which conforms to internal predictions), toward averted gaze (which does not). Here, searching displays with salient, 'odd-one-out' gazes, we observed attentional bias (in rapid, initial saccades) toward *averted* gaze, as would be expected by PC models. However, this pattern obtained only when conditions highlighted gaze-uniqueness. We speculate that, in our experiments, task requirements determined how prediction influenced perception.

145 words

Keywords: gaze perception, direct gaze prior, exogenous attention, averted gaze bias, predictive coding

Introduction

Another's eye gaze is the most direct external signal of their attention, and perception of it, fundamental to social cognition. Underscoring this pivotal role in apprehending others' attention and intentions, eye gaze stimuli activate large-scale neural networks often referred to collectively as the 'social brain', which prioritise stimuli for attention (e.g., Carlin & Calder, 2013; McCrackin & Itier, 2019; Teufel, Fletcher & Davis, 2009; Wiese, Wykowska & Müller, 2014). However, while all gaze cues are important, 'direct' gaze, when another person looks toward *you*, is often assumed to be of particular importance, and potentially of the highest priority for visual attention (e.g., Hamilton, 2016). Consistent with this assumption, previous work has suggested that it is harder to disengage attention from a direct gaze stimulus than an averted gaze one (Senju & Hasegawa, 2005). Further, direct gaze faces are more rapidly detected among arrays of averted gaze faces than vice versa, the 'stare-in-the-crowd' effect (SITCE; e.g., Ramamoorthy, Plaisted-Grant, & Davis, 2019; Senju, Hasegawa, & Tojo, 2005; Senju, Kikuchi, Hasegawa, Tojo, & Osanai, 2008), and even when gaze is task-irrelevant (Bockler, van der Wel, & Welsh, 2014; Doi & Shinohara, 2013). These findings have supported a broad consensus that direct gaze exerts a stronger 'pull' on attention than does averted gaze, perhaps reflecting its higher priority relative to other gaze types (e.g., Lyyra, Astikainen, & Hietanen, 2018; Mares, Smith, Johnson, & Senju, 2016; Yokoyama, Ishibashi, Hongah, & Kita, 2011). To the best of our knowledge, however, this assumption has not been tested directly. A key consideration of such a task design would be to place direct and averted gazes in visual competition with each other to index the relative ability of one gaze type to capture attention over the other; a paradigm that already exists in the visual search for gaze literature, the SITCE. This effect, based on the premise that, in the case of neutral faces, observers tend to make assumptions about gazer-object relationships – i.e., that observers themselves are the salient object being gazed at or away from – thus presumes direct gaze to be of greater attentional importance than averted.

The Attentional Pull of direct versus averted gaze: Previous work

Many previous visual search studies have examined the *relative* ability of one gaze type to attract attention over the other. Typically, this work has found a clear advantage for finding *direct gaze targets* over averted ones — a 'stare-in-the-crowd' effect (SITCE; e.g., von Grünau & Anston, 1995; Conty, Tijus, Hugueville, Coelho, & George, 2006; Senju et al., 2005; Doi & Shinohara, 2013; Ramamoorthy et al., 2019, though see Cooper, Law, & Langton, 2013). However, it remains unclear whether the greater efficiency of search observed for direct gaze genuinely reflects a greater tendency for those stimuli to attract attention. For example, some studies only report an overall speeding of responses to direct gaze (e.g., Conty et al., 2006; Doi & Ueda, 2007; Framorando, George, Kerzel, & Burra, 2016), rather than an effect of gaze direction on *search slopes*, a measure of how rapidly the observer can search through the display stimuli to find the target. Further, even when such a search slope effect is observed, it may be that this reflects the ease with which observers' attention can select each nontarget and subsequently disengage from it as they search for the target. When searching for a direct gaze target, these nontargets would typically have averted gaze and when searching for an averted gaze target, nontargets would be direct gaze. If, as previous work has suggested, it may be more difficult to disengage attention from direct gaze than averted gaze faces (e.g., Senju & Hasegawa, 2005; Ueda, Takahashi, & Watanabe, 2014) this might account for the SITCE, without recourse to assuming a greater initial attentional pull by those stimuli.

Other, related, work has examined stimulus-based cueing of attention to direct versus averted gaze when presented as an irrelevant stimulus feature in change blindness paradigms. These, similarly to standard search paradigms, have comprised multiple-face arrays and have concluded that direct gaze (or more specifically, changes from averted to direct gaze) particularly captures attention (Lyyra et al., 2018; Yokoyama, et al., 2011). It may be argued, however, that the cartooned, direct facing stimuli employed in those studies (in which a direct gaze always involved a dark circle, representing the iris and pupil, in the middle of an outline eye shape) comprised luminance confounds that gave rise to an apparent direct gaze bias. This criticism applies particularly to stimuli in which the face stimulus directly faces the observer. It may also be levelled at naturalistic stimuli in which the sclera and pupil largely disappears for averted gaze, but not direct gaze (Böckler, van der Wel, & Welsh, 2014; Boyer & Wang, 2018), but is greatly mitigated by the stimuli devised by Senju and colleagues (Senju et al., 2005). Those stimuli employ an image of a face which is averted roughly 45 degrees to the left of the observer. Crucially, then, direct gaze is achieved by the pupil moving to one side and averted gaze by the pupil moving to the other, *by approximately the same amount.* This is distinct from the manipulation employed by other studies (e.g., Conty et al., 2006; Mares et al., 2016) in which the amount of sclera is not equated in the two conditions. One further report (Crehan & Althoff, 2015) did manipulate stimuli in this manner, finding increased number and duration of saccades toward direct gaze stimuli. However, they only included conditions in which a single direct gaze was presented among multiple averted gazes; they did not present a single averted gaze among direct. Accordingly, while that study demonstrated direct gaze attention in a more naturalistic setting than previous work, it conflated gaze direction (direct versus averted) with gaze uniqueness. Thus, whether it is unique direct gaze or unique averted that captures exogenous attention remains an open question.

Models to explain exogenous attention capture: Bayesian versus Predictive Coding

Bayesian models offer one possible framework to describe the computational mechanisms underpinning these effects. Indeed, Mareschal, Calder, and Clifford (2013) found that observers were biased to interpret ambiguous gaze as *direct*, irrespective of head orientation (Mareschal, Otsuka, & Clifford, 2014), concluding that the brain incorporates a Bayesian 'prior' biased toward direct gaze. This prior, an internalised distribution of probabilities in which some versions of stimuli or events are more likely than others, effectively treats direct gaze as the most likely direction. This primary action of prediction in perception, then, might account for the existence of enhanced processing of direct gaze.

However, some Predictive Coding (PC) frameworks can be construed to make the opposite prediction, particularly with respect to allocation of *exogenous* attention (the clearest, Itti and Baldi, 2009). PC frameworks typically conceive of the brain as a predictive coding processor in which higher layers of hierarchical networks apply predictions to representations in lower layers. These predictions may speed processing of items that conform to likely interpretations on the basis of the prior. However, differences between predictions and input in lower layers are also assumed to generate 'prediction error' signals (where the prediction is imperfect) that are passed up from each layer to the next to fine-tune subsequent predictions (e.g., Kanai, Komura, Shipp, & Friston, 2015; Rao & Ballard, 1999). In principle, stimuli that give rise to little or no prediction error must carry little new information and *can be ignored*, whereas those deviating more from prior expectations will yield a larger prediction error that summons attention and engages learning mechanisms to update predictions (e.g., Summerfield & Egner, 2009). For some authors, this prediction holds because attention serves to optimise precision estimates (to weight prediction error model updating) and the prediction error signal strength is assumed to correlate (Feldman, & Friston 2010; Hohwy, 2012).

This principle, that stimuli eliciting somewhat greater prediction error (or greater 'surprise') should attract attention exogenously, has received support in cases of clear violations of conscious predictions (e.g., Itti & Baldi, 2009). However, it has not, to our knowledge, been applied to socio-perceptual priors, such as those specifying gaze, which are built up over a lifetime's interaction (or perhaps innately specified, e.g., Johnson, Senju & Tomalski, 2015). If such perceptual biases constitute 'predictions' in the right senses, PC models (those that assume attention bias toward prediction error) should make a clear, counterintuitive prediction about gaze bias. Specifically, given that direct gaze signals attention toward the observer (deviating little from prior expectations) as opposed to averted gaze which signals attention away from observers (deviating more from expectations), PC models could make the prediction that, other things being equal, attention should be drawn toward averted gaze on the basis of larger prediction error. That is, attention should be biased toward averted gaze.

Our review of literature suggests that, in general, attention prioritises (is most strongly drawn to) direct gaze over averted gaze. Such a conclusion is consistent with, and indeed predicted by Bayesian models incorporating a direct-gaze prior. It tends to run contrary to the predictions of PC models, which are more consistent with the opposite finding: prioritising of *averted* gaze. This opposition between the predictions of PC models (enhanced attention to, and processing of, items that differ from expectations) versus Bayesian models (enhanced processing of items that conform to expectations) is neatly articulated by Press, Kok, & Yon (2019); we return to discuss their view on this 'perceptual prediction paradox', later.

The Current Studies

The present set of experiments were designed to investigate the exogenous self-cueing ability of direct versus averted gaze, using our own stimuli (based upon those designed by Senju et al., 2005. We measured patterns of initial saccades in response to gaze stimuli to index initial overt attentional allocation and guidance (e.g., Eckstein, Guerra-Carrillo, Singley, & Bunge, 2017). By extension, as the observer's gaze was not constrained, they also likely provided an approximate measure of covert attention bias, though this assumption was not required for our purposes. Our previous work, using the same stimuli, had found a very robust direct gaze bias in response times that could not readily be ascribed to luminance contrast effects (Experiment 2, Ramamoorthy et al., 2019), in agreement with the large majority of previous literature. Thus, prior to Experiment 1, we expected unique direct gaze to preferentially cue exogenous attention over averted gaze, reflected as a greater proportion of initial saccades. Predictions for subsequent experiments were updated based on observed effects.

Experiment 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 visual search format, with one unique gaze face and one (or three) face(s) with the opposite gaze direction.

In each case, the target was defined as the lighter mouth present on a non-unique gaze face, while the unique gaze, designated the ‘active nontarget’, was expected to exogenously cue attention to itself. Experiment 2 investigated whether gaze uniqueness was a pre-requisite for exogenous self-cueing observed in Experiment 1, while Experiments 3 and 4 examined whether predictability in stimulus patterns influenced exogenous attention capture, comparing initial saccades to task-irrelevant gaze (in the same manner as Experiment 1) versus to task-relevant gaze (the target item always had unique gaze). Finally, Experiment 5 investigated the influence of top-down search templates on exogenous self-cueing when gaze was task-relevant — presenting predictive and non-predictive pre-cues before onset of the search display and asking observers to search for the unique gaze.

Our primary dependent variable of interest was the proportion of initial saccades directed to the relevant gaze of interest in each display. We chose initial saccades, rather than overall number/duration of saccades, as this intuitively maps onto notions of stimulus ‘attentional pull’ – its exogenous ability to summon attention to itself. Reaction time measures were only discussed for those conditions in which there were grounds to make a prediction regarding response times (RTs) of a direct or averted gaze advantage — conditions in which unique gaze was task-relevant (in the manner of the SITCE), i.e., task-relevant conditions in Experiments 3 and 4 and both conditions in Experiment 5. RTs for all conditions are presented in the appendix for a complete picture of results.

Experiment 1: Exogenous Self-Cueing by Direct versus Averted Task-Irrelevant Gaze

Methods

Experiment 1 investigated the exogenous self-cueing ability of direct 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 target and one 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 we could compare the proportion of *initial* saccades, following display onset, directed to the active nontarget

Observers and sample size

We 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, Erdfelder, Lang, & Buchner, 2007). We ran this experiment with 17 volunteers (*m* = 5, *f* = 12, ages 18-35), having booked one person extra due to a booking error). Observers were recruited from an online volunteer recruitment system and were paid £5 (equivalent to $6.43) for their time. The study was approved by the University of Cambridge Psychology Research Ethics Committee.

Stimuli and Apparatus

Stimuli were presented using E-Prime 2.0 software (Psychology Software Tools, Inc., 2013) on a 21.5-inch Dell LCD monitor (model number P2414HB) at a resolution of 1920 x 1080 and a simulated refresh rate of 60 Hz. Participants were seated approximately 70 cm from the screen and had their head in a chin rest, with their right eye tracked using an SR EyeLink 1000 (SR Research Ltd., 2005-2009) eye-tracker 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. Each face image subtended 6.3° x 6.3° of visual angle and was presented against a uniform black background.

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 shows an example of a display at 'set size 4' with four stimuli. To create these, a photograph of author NR looking towards the camera, and thereby observer, was taken and converted to greyscale to construct the direct gazing face. The eye region from a similar image of NR looking away was superimposed onto the direct gazing face to construct the averted gazing one. The lighter shade of mouth was constructed by adjusting the luminance of the mouth region in the original greyscale images.

Figure 1. Examples of search displays in Experiment 1. Left panel: Example of a Set Size 2 display with Averted Gaze Target and Direct Gaze Active Nontarget; Right panel: Example of a Set Size 4 display with Direct Gaze Target and Averted Gaze Active Nontarget. T = Target, ANT = Active Nontarget, NT = Nontarget

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 while 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 our analyses and discussion we adopted the term ‘*active’* for this nontarget (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.

Measures and Predictions

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 1, we expected to find a greater proportion of initial saccades made to the Direct Gaze Active Nontarget than Averted, in line with a Bayesian framework. We also calculated the proportion of initial saccades to a lighter mouth Target and other Nontargets. We expected any such effects to be weak, given the subtle difference in luminance between Target and Nontarget luminances. Average RTs (Appendix, Table 1) and proportions of initial saccades to the lighter mouth Target (Appendix, Table 2) were collected for completeness, but are not discussed further.

Results

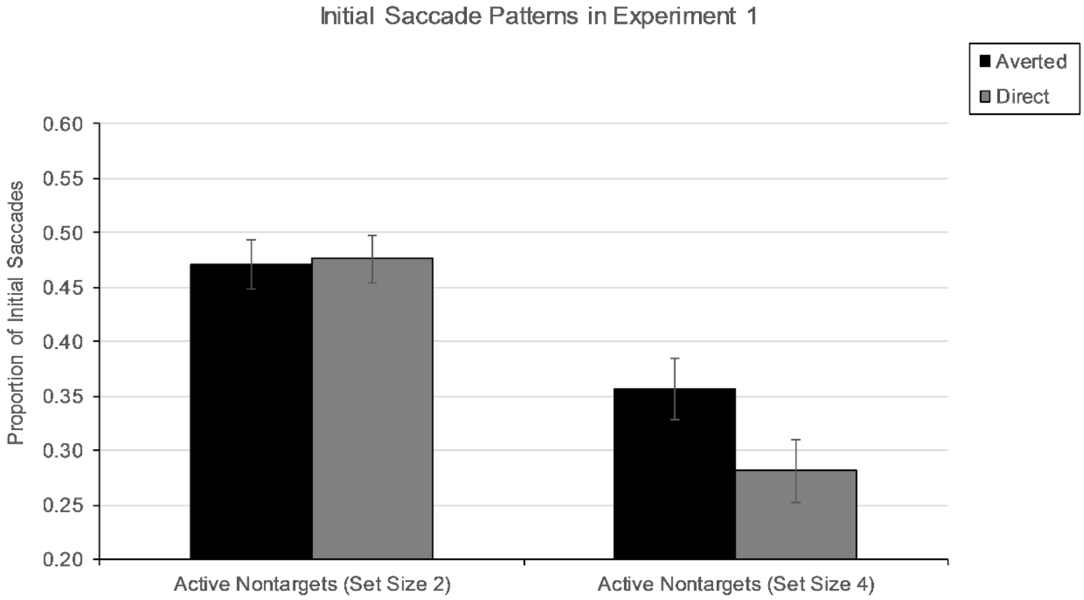

Figure 2. Proportion of initial saccades to Active Nontargets type – an index of cueing by task-irrelevant gaze – for each Set Size and Gaze in Experiment 1. Error bars indicate +/- 1 $SEM_{paireddiffs}$.

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. 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) we halved the values at Set Size 2 before running the ANOVA. A two-way repeated measures ANOVA with factors Gaze (Averted, Direct) and Set Size (two, four items) revealed main effects of Gaze [$F(1, 15) = 7.317$, $p = .016$, $\eta_p^2 = .328$], Set Size [$F(1, 15) = 20.216$, $p < .001$, $\eta_p^2 = .574$] and an interaction between the terms [$F(1, 15) = 5.244$, $p = .037$, $\eta_p^2 = .259$]. To investigate the source of this interaction, we ran follow-up t-tests. 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, d = -.058]. 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, d = .659].

Discussion

Gaze effects at Set Size 4 were *broadly speaking*, more consistent with predictions of PC models, contrary to our expectations. 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, we considered two key differences between them. 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 2 replicated the conditions of Experiment 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 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 1.

Experiment 2: Gaze Bias in the Absence of Unique Gaze

Methods

Experiment 2 was designed to confirm whether gaze uniqueness was required to see the averted gaze advantage observed in Experiment 1, Set Size 4. Across both set sizes, the only unique element was the lighter mouth on the target. We made no prediction regarding the presence of an averted gaze bias at Set Size 4, but expected not to detect one at Set Size 2, following the results of Experiment 1.

Observers

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 1 (Cohen’s d ≈ 0.8) our power analyses from Experiment 1 did not need updating.

Stimuli, Apparatus, and Procedure

All aspects of Stimuli, Apparatus and Procedure were as for Experiment 1, with the sole exception that each Set Size 4 now comprised two faces with direct gaze, two with averted.

Results

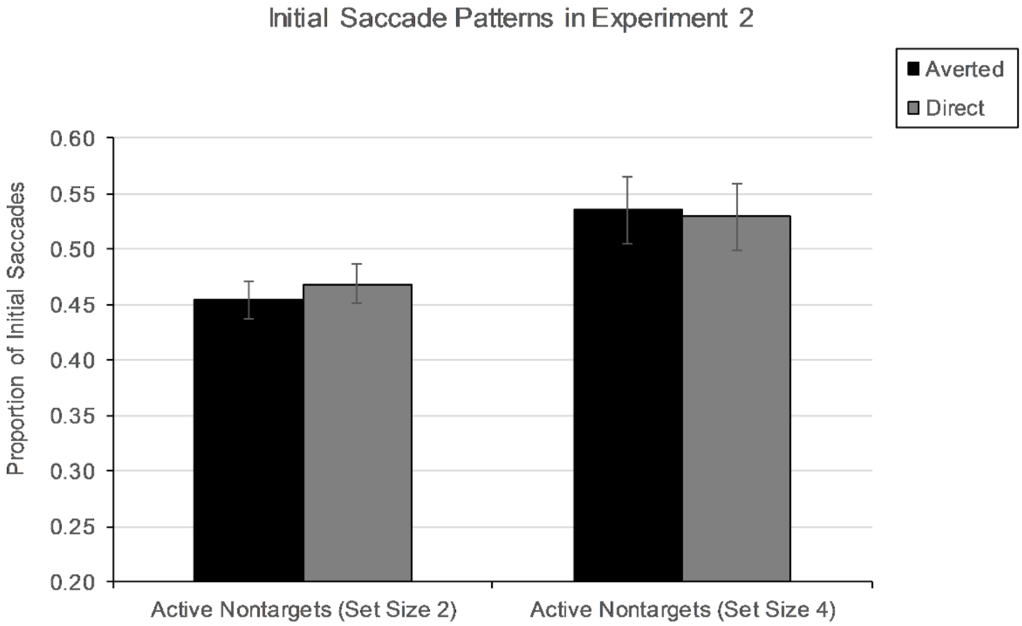

Figure 3. Proportion of initial saccades to Active Nontargets separately for each Set Size and each Gaze type in Experiment 2. Error bars indicate +/- 1 $SEM_{paireddiffs}$.

Bias toward Active Nontargets

Figure 3 plots the proportion of initial saccades in the same format as Figure 2. A two-way, repeated measures ANOVA with factors of Gaze (Averted, Direct) and Set Size (two, four items) 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 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, d = -.209]. 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, d = .052).

Discussion

In Experiment 2, finding no gaze bias at both Set Size 2 and 4 supported two useful, related assertions. First, with our stimuli, there was no general difference between direct and averted gaze in terms of the power of those stimuli to cue attention to themselves. *Neither the current consensus that direct gaze preferentially captures attention, nor PC models,* correctly predicted this. Moreover, the absence of any difference in this simple comparison precludes explanations of our findings in Experiment 1, Set Size 4 in terms of gross stimulus confounds — consistent with the view that the Set Size 4 effect seen there was a result of greater attention cueing by averted gaze *only when that gaze was an odd-one-out*.

One limitation when interpreting Experiments 1 and 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 1, Set Size 4 had reflected attempted suppression of gaze related information in those displays, or instead reflected more typical processing of them, Experiment 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 1, or (ii) when the unique gaze was highly task-relevant and *informative* – a 100% valid cue to the target's location.

Experiment 3: Informative versus Uninformative Unique Gaze

Methods

Experiment 3 was designed to investigate the attention cueing properties of unique gaze, direct or averted, in Informative (task-relevant) and Uninformative (task-irrelevant) 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 1 and 2). 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 1 and 2).

In the *Informative* Unique Gaze condition, we predicted that initial saccades would be more biased toward direct gaze targets than averted; this was on the basis of our previous visual search findings (Ramamoorthy et al., 2019). Conversely, we predicted that in the *Uninformative* Unique Gaze condition, attention as measured by initial saccades would be biased toward the averted gaze nontargets, as in Experiment 1. With respect to RTs, based on previous literature on the SITCE (e.g., Senju et al., 2005), 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 we did not have specific predictions for Uninformative condition RTs when unique gaze and unique mouth are on different faces.

Observers and sample size

Based on the sample size and power calculated in Experiments 1 and 2, 16 observers (*m* = 5, *f* = 11, ages 18-35) were recruited and compensated for their time, as before.

Stimuli, Apparatus, and Procedure

All aspects of the experiment were as described for Experiments 1 and 2, with the following exceptions. As we were investigating unique gaze effects, all trials only comprised set size 4 displays. 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. Three-quarters of the trials had unique (odd-one-out) gaze and unique mouth on different faces, while a quarter of all trials had unique gaze and unique mouth on the same face. The latter quarter of trials served as check of whether between-task manipulation had been effective but were excluded from our main analysis on account of too few trials.

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. Each condition began with a practice block (Informative, 8 trials; Uninformative, 8 trials), comprising feedback as in Experiments 1 and 2.

Results

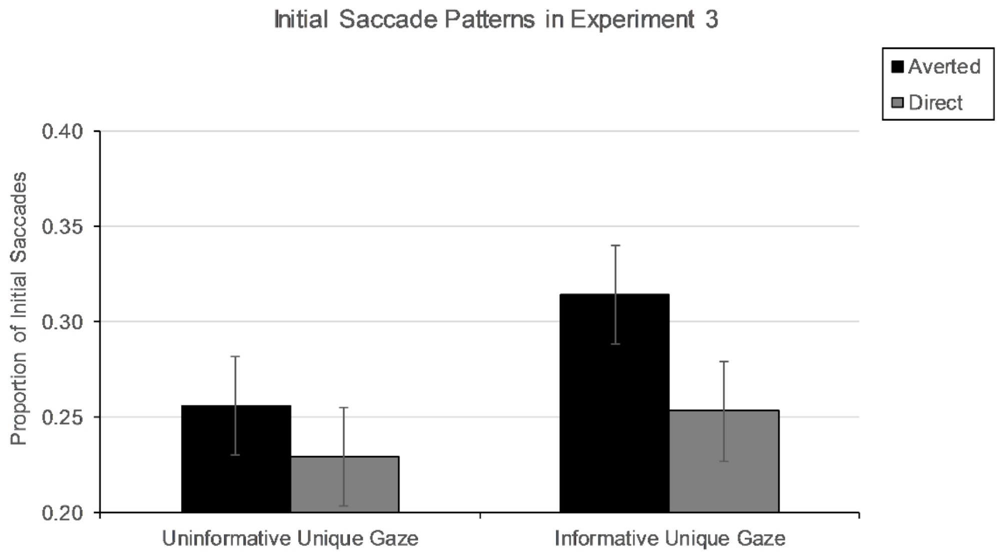

Figure 4. Proportion of initial saccades to Active Nontargets in the Uninformative condition (left pair of bars) and to Targets in the Informative condition (right pair of bars) separately for each Gaze type in Experiment 3. Error bars indicate +/- 1 $SEM_{paireddiffs}$.

Bias toward Unique Gaze

We calculated the proportion of initial saccades to the *unique gaze* in each condition – 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). 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, η_p^2 = .475], but not of Gaze Informativeness [F(1, 15) = 2.166, p = .162, η_p^2 = .126] and no evidence of an interaction between the terms [F(1, 15) = .540, p = .474, η_p^2 = .035].

These results provided no statistical basis to examine the effects of Unique Gaze separately in the two conditions. Nonetheless, we had reason *a priori* to do so (we expected opposite effects 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, d = .586] 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 = .312, d = .262]). This 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 an averted gaze bias was uncertain when unique gaze was uninformative — it had been evident in Experiment 1, but was not clearly evident here.

Manual responses

RT data were only considered for accurate responses (i.e., when the correct item was 'clicked'; *Mean Accuracy* = 97.7%, *SD* = .04). For each participant, data within each Gaze Informativeness condition and Gaze Type were trimmed to exclude any RTs that were ±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, $\eta_p^2 = .049$], Gaze Informativeness [$F(1, 15) = 2.808$, p = .115, $\eta_p^2 = .158$] or their interaction [$F(1, 15) = .881$, p = .363, $\eta_p^2 = .055$]. As with eye movements, we ran planned follow-up paired sample t-tests 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 [t(15) = 1.263, p = .226]. 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.

Discussion

We had found a clear averted gaze bias in the Informative Condition, consistent with PC model predictions rather than Bayesian, indicating that such a bias need not only be observed when gaze is task-irrelevant. There was less clear evidence that the Uninformative and Informative conditions differed however, despite the bias observed in the Informative Condition when the two conditions were analysed independently. RT findings had also not shown any difference between the two. 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 4 replicated the conditions of Experiment 3, except that in the Informative 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. Note, however, 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.

Experiment 4: Unique Gaze as the task-relevant dimension

Methods

In the Informative condition of Experiment 4, observers were explicitly told to look for the odd-one-out gaze while ignoring the mouths of the faces. In the Uninformative 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 1. We expected to see a larger difference between the Informative and Uninformative Unique Gaze Conditions, compared with Experiment 3.

Observers and sample size

Our Gaze Informativeness manipulation in Experiment 3 had a weaker-than-expected effect. Although we expected the effect here to be stronger, we also slightly increased the sample size to twenty observers (*m* = 8, f = 12, ages 18-35), to increase our 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.

Stimuli, Apparatus, and Procedure

Stimuli, apparatus, and procedure were as for Experiment 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.

Results

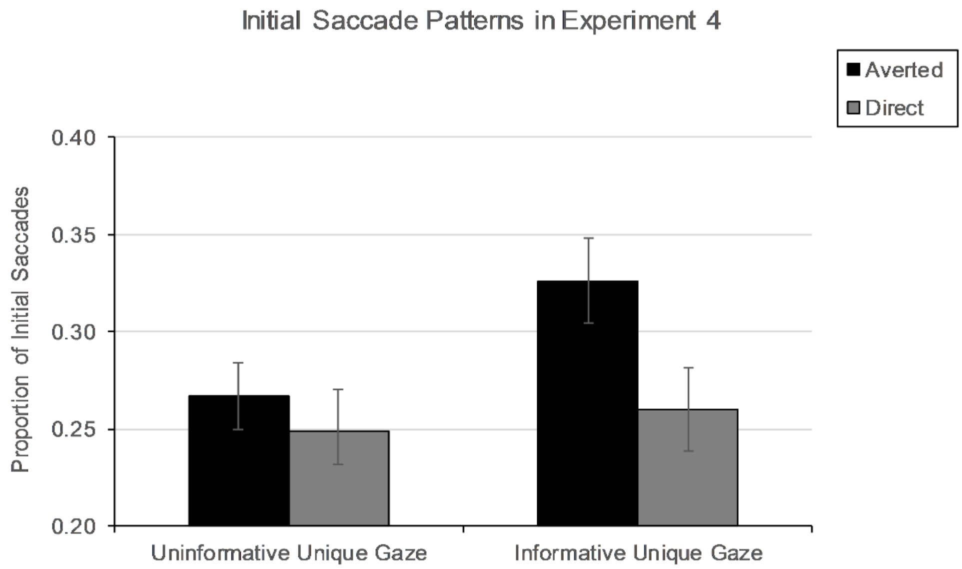

Figure 5. Proportion of initial saccades to Active Nontargets in the Uninformative condition (left pair of bars) and to Targets in the Informative condition (right pair of bars) separately for each Gaze type in Experiment 4. Error bars indicate +/- 1 $SEM_{paireddiffs}$.

Bias toward Unique Gaze

Figure 5 plots the proportion of initial saccades to Unique Gaze Faces in Experiment 4 in the same format as Figure 4. 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, η_p^2 = .195], a clear effect of Gaze [F(1, 18) = 11.689, p = .003, η_p^2 = .394], and no interaction between the two terms [F(1, 18) = 2.665, p = .120, η_p^2 = .129].

Paired t-tests revealed no differences in proportion of initial saccades to Averted Active Nontargets (*M* = .27, *SD* = .08) versus to Direct ones (*M* = .25, *SD* = .07) in the Uninformative Gaze condition [t(18) = 1.022, p = .320, d = .234], but a difference favouring Averted Targets (*M* = .32, *SD* = .10) over Direct Targets (*M* = .26, *SD* = .06), in the Informative Gaze condition [t(18) = 3.104, p = .006, d = .712]. These findings closely paralleled those of Experiment 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.

Manual responses

RT data for accurate responses (*Mean Accuracy* = 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, η_p^2 = .217], but no main effect of Gaze [*F*(1, 18) = .019, p = .892, η_p^2 = .001] or an interaction [*F*(1, 18) = .042, p = .839, η_p^2 = .002]. Thus, as in Experiment 3, RT patterns did not yield evidence that direct gaze was detected faster from among averted gaze nontargets, or vice versa.

Combined Analysis of Gaze in Experiments 3 and 4

To maximise power to detect an effect of Gaze Predictiveness and any potential influence on the size/presence of an averted gaze bias, we conducted a three-way repeated measures ANOVA, 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 3 versus 4), nor any interaction involving that term Experiment (Max *F* = 0.454, ns.), suggesting that the two experiments might be combined. As expected, this found a main effect of Informativeness [*F*(1, 33) = 5.870, p = .021, η_p^2 = .151] and of Gaze [*F*(1, 33) = 24.696, p < .001, η_p^2 = .428]. However, even with power maximised across these two studies, no clear evidence of their interaction [*F*(1, 33) = 2.410, p = .130, η_p^2 = .068] emerged. That is, we were unable to detect a clear influence of predictability on the (overall, very clear) tendency for unique averted gaze to attract attention (initial saccades) more than unique direct gaze.

Discussion

Experiment 4 exhibited the same pattern of eye movements and RT results as Experiment 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 1, Set Size 4, but not with Experiment 2, Set Size 4 (or either of the Set Size 2 conditions in Experiments 1 and

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 3 and 4 had been weaker (as main effects) than we 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, we designed Experiment 5 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 — gaze was now entirely task-relevant, and 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 while no such information was available in the Nonpredictive Condition.

Experiment 5: The role of top-down templates in Unique Gaze cueing

Methods

Experiment 5 replicated the conditions of the Informative Unique Gaze condition in Experiment 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. 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). We expected to find a greater proportion of initial saccades and RTs to direct gaze than averted gaze targets in the predictive condition, as Ramamoorthy et al. (2019) had found this as an RT effect using the same face stimuli (though at Set Sizes 3 and 7). Note that now, in the Predictive Cue condition at least, attention toward one gaze direction was *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.

Observers and sample size

Based on sample size and power estimates for Experiment 4, we again recruited 20 observers (*m* = 3, *f* = 17, ages 18-35), recruited and compensated for their time as in previous experiments.

Stimuli, Apparatus, and Procedure

Stimuli, apparatus, and procedure were as for the Informative Gaze condition in Experiment 4, with the addition of word cues at fixation, the duration of which was 1500 ms. Both fixation duration and cues were based on previous work from our lab (Ramamoorthy et al., 2019). 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. The run order of Predictive and Nonpredictive conditions was counterbalanced across participants.

Results

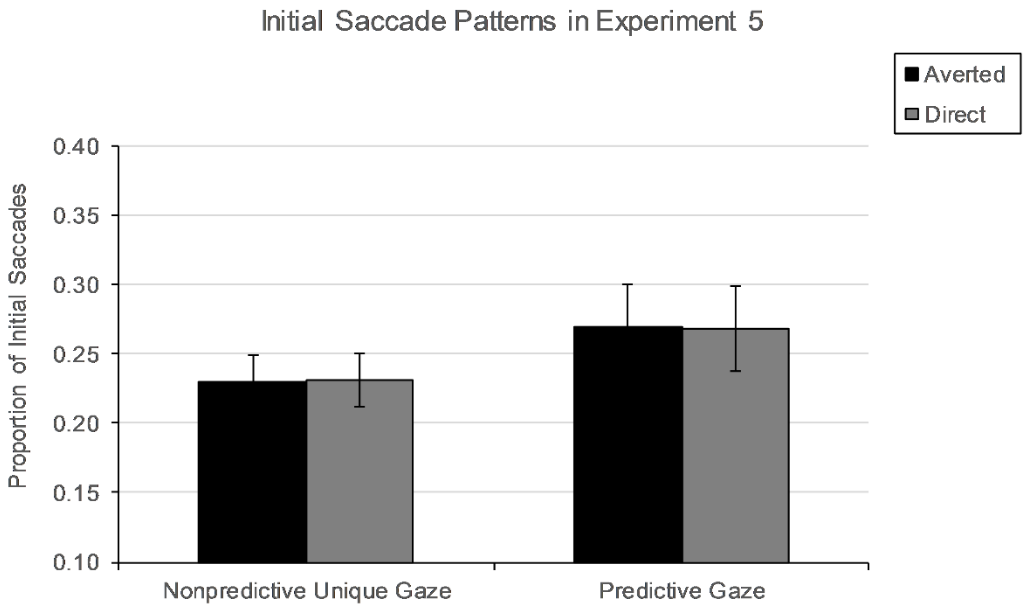

Figure 6. Proportion of initial saccades to Targets in the Nonpredictive condition (left pair of bars) and Predictive condition (right pair of bars) separately for each Gaze type in Experiment 5.

Bias toward Unique Gaze

Figure 6 plots the proportion of initial saccades to targets of each gaze type (Averted, Direct), separately for Predictive and Nonpredictive conditions. 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, $\eta_p^2 = .245$] — 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 [$F(1, 19) < .01$, n.s.] nor an interaction between the terms [$F(1, 19) = .007$, n.s.].

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, revealed significant main effects of Cue Predictiveness [$F(1, 19) = 23.665$, p < .001, $\eta_p^2 = .555$] and Gaze [$F(1, 19) = 12.586$, p = .002, $\eta_p^2 = .398$], but not the interaction between both terms [$F(1, 19) = 1.195$, p = .288, $\eta_p^2 = .059$]. 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, d = .412]) 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, d = 1.00]). As we predicted, RTs in the Predictive Cue Condition were faster for *Direct* Gaze than Averted Gaze Targets.

Discussion

Providing 100% valid top-down cues was associated with no effect of Gaze Type on initial saccades, suggesting the possibility that a 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 in the Nonpredictive condition, suggesting that observers had treated the two conditions differently, there too we found the same pattern of lack of gaze prioritisation. This latter finding was contrary to our predictions from Experiments 3 and 4, and likely involved the presence of an uninformative cue prior to each search display. We speculated that seeing an uninformative cue (in the context 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 3 and 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 3 and 4. Second, RTs showed a different pattern to those in Experiments 3 and 4.

Experiment 5 *had* now found 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 Ramamoorthy et al.'s (2019) suggestion that top-down cues on the basis of instructions always favour RTs to direct gaze targets relative to averted, (but do not influence attentional guidance). This same top-down influence in the Nonpredictive Cue condition, and a complete absence of such effects in Experiments 3 and 4 (Informative Gaze Conditions), 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. We concluded that both types of cue (predictive and unpredictive) had elicited top-down influences. This is plausible given that predictive cues (either indicating direct or averted gaze) had previously yielded RT effects exclusively for *direct gaze* targets (Ramamoorthy et al., 2019), and now it appeared that establishing an explicit expectation of *any particular gaze* had sped responses only to direct gaze.

Supplementary Bayesian Analysis

We had used standard Null Hypothesis Significance Testing (NHST) to analyse unique gaze effects across five experiments, revealing an *overall* bias to averted gaze. This appeared not to reflect a greater attentional pull of averted gaze over direct, as we had found no evidence for this bias when there was no 'odd one out' gaze (Set Size 2 conditions and Experiment 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). 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, we supplemented out NHST statistics with Bayesian t-tests (JASP team, 2018, Wagenmakers et al., 2018, (Jeffreys, Zellner, and Siow (JSZ) prior centred on zero, Cauchy's width, 707).

1. Displays with no unique gaze.

In our 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 2) – we found no evidence for an averted gaze bias. Pooling Set Size 2 scores from Experiments 1 and 2 to maximise power to detect any bias, we compared the proportion of initial saccades to Averted versus Direct Gaze Active Nontargets, subjecting this to a one-sample Bayesian t-test as described above. This found moderate evidence in favour of the null hypothesis (Bayes Factor $[BF]_{10} = 0.238$), concluding that *no gaze bias* had arisen for those displays. Similarly, for Experiment 2, Set Size 4, evidence moderately supported the null hypothesis (BF_{10} = 0.260). Thus, in both types of display without a unique gaze we found significant evidence for *no gaze bias*.

2. When observers are prompted to search for a particular gaze.

We had also not found 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-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 revealed moderate evidence in favour of the null hypothesis (BF_{10} = 0.232). Again, this suggested that there had been *no averted-gaze bias*.

3. An uncertain case: *irrelevant* unique gaze

We observed an averted gaze bias for Unique, task-irrelevant gaze in Experiment 1. However, in similar conditions, of the Uninformative Gaze Conditions of Experiments 3 and 4, we found no such evidence. Pooling this data across Experiments 3 and 4, we found that the data was insensitive (BF_{10} = 0.488). Thus, here, we could not be as convinced that there had been an absence of an averted gaze bias. It is possible either that intermixture of Set Size 2 trials in Experiment 1 (with no unique gaze), but not in Experiments 3 and 4, highlighted gaze uniqueness in Set Size 4 trials in Experiment 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 3 and 4 (with informative unique gaze).

To summarise the outcomes of our supplementary Bayesian analyses, we found evidence of *no averted-gaze bias* if: (1) no gaze in a display was unique (an 'odd one out'), or (2) participants 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 is readily interpreted 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.

General Discussion

Previous studies investigating the effects of direct versus averted gaze have largely supported the assumption that direct gaze eyes cue our attention to them more powerfully than do averted gaze eyes. This hypothesis also underpins the standard account of the SITCE — the shallower response time slopes in visual search to detect direct gaze targets among averted gaze distractors than vice versa (e.g., Senju et al., 2005; Senju et al., 2008). However, our current findings seem directly to contradict that assumption and that account. Using the same gaze stimuli as in our previous work – which had found a clear SITCE and implicated a direct gaze prior (Ramamoorthy et al., 2019) – here, instead, we found evidence of a bias toward unique averted gaze stimuli when that uniqueness was highlighted. It remains unclear how this apparent contradiction can be resolved. At first glance, it appears that there are oppositional attentional mechanisms at play — one, a direct gaze prior which speeds processing of direct gazing eyes, the mechanism for which must be attributed to templates (e.g., Mareschal et al., 2013; Mareschal et al., 2014), perhaps innately specified (Johnson et al., 2015), and the other, an averted gaze bias which attracts exogenous attention and must be attributed to prediction error processes which bias attention toward unexpected stimuli (e.g., Kanai et al., 2015; Summerfield & Egner, 2009).

The present set of experiments put these competing hypotheses to test, finding that neither the Bayesian nor the PC accounts in their basic forms adequately predicted our findings here. Experiment 1 presented what was essentially a gaze odd-one-out paradigm, with one crucial manipulation — gaze was task-irrelevant, observers were asked to search for the lighter mouth, while the unique gaze served as the active nontarget to cue exogenous attention to itself. Results revealed an averted gaze advantage for initial saccades when there were four faces in the search display (in line with a PC view), while no such advantage emerged when there were only two faces. Experiment 2, designed to confirm whether, if at all, uniqueness was a pre-requisite for the averted advantage, found no gaze bias when both gazes were equally represented in the search display. These initial findings effectively precluded a key role for direct or averted gaze simply being more salient than the other (and reassured us that none of the findings at Set Size 4 could have reflected stimulus confounds, or a general attentional bias toward either gaze direction).

It was clear, thus far, that any averted gaze bias could only be explained by PC models, which may also make assumptions about predictability of stimulus patterns influencing target representations (e.g., Geng & Behrmann, 2005; van Moorselaar & Slagte, 2019; Wang & Theeuwes, 2018). Accordingly, Experiments 3 and 4 compared the exogenous self-cueing ability of gaze when it was task-relevant versus task-irrelevant in set size 4 displays, since any effect observed was only likely to be here. Across both experiments, the pattern of results with respect to unique task-relevant gaze was clear – an averted gaze advantage when uniqueness was highlighted – but less so when gaze was unique but task-irrelevant – there now appeared to be no such bias. Finally, in Experiment 5, when gaze was both unique and endogenously cued, neither an averted nor direct gaze bias emerged for initial saccades.

The argument for differing attentional expectations (direct gaze prior versus prediction error) becomes more substantive when examining those conditions in which there was a clear reason to suppose the existence of a direct gaze prior in terms of RT effects (based on previous studies including our own) — informative conditions in Experiments 3 and 4 and the predictive condition in Experiment 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 (but also nonpredictive condition in Experiment 5 and Set Size 4 trials in Experiment 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 our previous work (i.e., response criteria that determine target presence versus absence). We note that despite the difference between the displays of our previous study and the current work in terms of set size (the number of items in a display) – 3 or 7 items in the previous displays, 2 or 4 items in the present displays – our previous work had also not found reliable RT advantages for direct gaze targets in 3-item displays, only in 7-item ones.

How might these two types of attentional expectation be combined to explain the present findings? The most obvious solution is that they operate independently and additively. However, this cannot explain the absence of evidence for a gaze bias when averted and direct gazes are balanced in a display, whether that be at Set Size 2 or 4. One possibility, as has recently been suggested (Press, Kok, & Yon, 2020) is that expectations, under some conditions, seem to enhance perception of expected stimuli, while under others, to enhance perception of unexpected stimuli. Briefly, those authors speculate that initially, following stimulus onset, expectations enhance processing of expected stimuli (in the current case, direct gaze eyes). Subsequently, as prediction errors are calculated (which will be larger for averted gaze eyes), unexpected stimuli come to be prioritised for processing. To seek support for this suggestion, within the limited scope of our current project, we predicted, on the basis of their view, that we should see a direct gaze bias at shorter saccade latencies and potentially an averted gaze bias at longer latencies; we also hoped to contrast this timing view with a view that emerges from the current findings. We examined the rapid initial saccades toward our face stimuli (typical of those observed for repeated face stimuli and very limited spatial saccade targets (Crouzet, Kirchner, & Thorpe, 2010; di Oleggio Castello & Gobbini, 2015). However, results from this analysis (plotted in Figure 7) find striking evidence for an averted gaze bias at even the shortest latencies. This is not as might be predicted by a timing view (although this by no means falsifies that account), but is more consistent with a perspective we now propose.

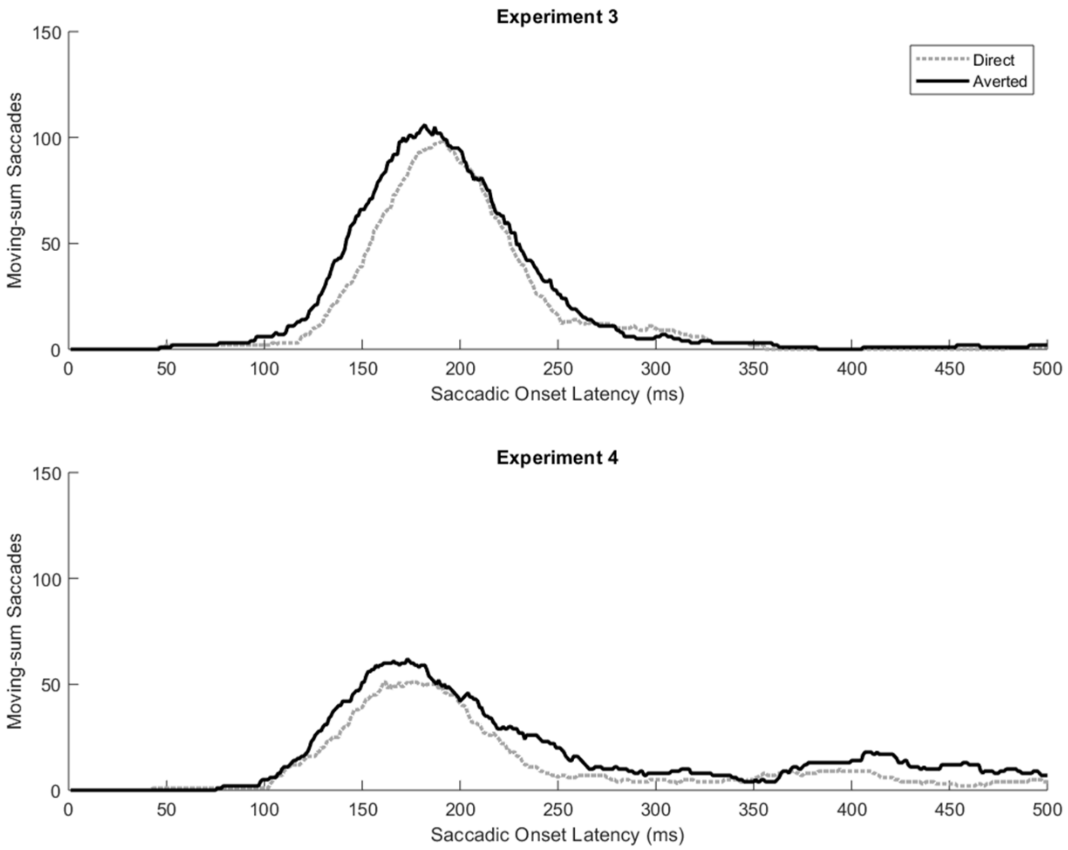

Figure 7. Density Plots for initial-saccade onset latencies in the Informative Gaze conditions of Experiments 3 and 4, separately for saccades directed to Averted Gaze and Direct Gaze Targets.

A modified PC framework offers the most parsimonious explanation for our findings. 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 1 and informative conditions of Experiments 3 and 4) or a strengthening of top-down representations when task instructions call for *within-gaze* comparison (no gaze bias, but faster RTs to direct gaze targets observed in Experiment 2, uninformative conditions of Experiments 3 and 4, and Experiment 5).

In conclusion, across five experiments, we found a clear bias toward averted gaze only 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 assumptions 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 principle that stimuli eliciting somewhat greater prediction error (or greater ‘surprise’) should attract attention exogenously, has received support in cases of clear violations of conscious predictions (e.g., Itti & Baldi, 2009). However, it has not, to our knowledge, been applied to social or protosocial processes, such as those specifying gazer-object relationships (e.g., Ramamoorthy, Jamieson, Imaan, Plaisted-Grant, & Davis, in press), which are built up over a lifetime’s interaction (or perhaps innately specified, e.g., Johnson, Senju, & Tomalski, 2015). Our results suggest that, in present case, the information sought by top-down attention, not stimulus timing, determined the manner in which predicted or unpredicted gaze stimuli were coded and preferentially processed by observers.

Appendix

Table 1				
	RTs to Odd-one-out Gaze			
	Averted		**Direct**	
	Mean	SD	Mean	SD
Experiment 1, Set Size 2	1479	275.4	1456	237.4
Experiment 1, Set Size 4	2288	613.8	2321	693.9
Experiment 2, Set Size 2	1299	296.2	1325	292.2
Experiment 2, Set Size 4	2206	712.5	2102	646.6
Experiment 3, Uninformative condition	1911	517.5	1910	465.9
Experiment 3, Informative condition	2167	695.3	2093	513.5
Experiment 4, Uninformative condition	1832	391.3	1834	284.8
Experiment 4, Informative condition	1991	373.3	2001	409.0
Experiment 5, Nonpredictive condition	1985	535.4	1893	431.9
Experiment 5, Predictive condition	1567	560.9	1419	431.0

Note: odd-one-out gaze is the Active Nontarget in the uninformative cases (Experiments 1,2, and Experiment 3 and 4 Uninformative) and the Target in the informative cases (Experiments 3,4, and 5)

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

Table 2		
	Target	
	Averted	Direct
Experiment 1, Set Size 2	0.45	0.46
Experiment 1, Set Size 4	0.25	0.24
Experiment 2, Set Size 2	0.50	0.50
Experiment 2, Set Size 4	0.22	0.24
Experiment 3, Uninformative condition	0.21	0.27
Experiment 4, Uninformative condition	0.24	0.27

Table 2. Proportion of initial saccades to Targets in Experiments 1, 2, 3, and 4

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