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# A fresh look at saccadic trajectories and task irrelevant stimuli: Social relevance matters

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ABSTRACT

A distractor placed nearby a saccade target will cause interference during saccade planning and execution, and as a result will cause the saccade's trajectory to curve in a systematic way. It has been demonstrated that making a distractor more task-relevant, for example by increasing its similarity to the target, will increase the interference it imposes on the saccade and generate more deviant saccadic trajectories. Is the extent of a distractor's interference within the oculomotor system limited to its relevance to a particular current task, or can a distractor's general real-world meaning influence saccade trajectories even when it is made irrelevant within a task? Here, it is tested whether a task-irrelevant distractor can influence saccade trajectory if it depicts a stimulus that is normally socially relevant. Participants made saccades to a target object while also presented with a task-irrelevant (upright or inverted) face, or scrambled non-face equivalent. Results reveal that a distracting face creates greater deviation in saccade trajectory than does a non-face distractor, most notably at longer saccadic reaction times. These results demonstrate the sensitivity of processing that distractors are afforded by the oculomotor system, and support the view that distractor relevance beyond the task itself can also influence saccade planning and execution.



## 1. Introduction

When a rapid eye movement, or saccade, is made towards a target, the path that the saccade takes is often slightly curved (Viviani, Berthoz, & Tracey, 1977; Yarbus, 1967). The magnitude and direction of this curvature can be influenced by the presence of nearby non-target objects. Relevant (Sheliga et al., 1995; Sheliga, Riggio, & Rizzolatti, 1994, 1995) or even task-irrelevant (Doyle & Walker, 2001; McSorley, Haggard, & Walker, 2004; Van der Stigchel & Theeuwes, 2005) non-target objects that are presented near a saccade's goal can change the curvature of a saccade in systematic ways. At its core, a saccade's trajectory can be interpreted as reflecting target selection and distractor inhibition within the oculomotor system. By examining what features of a target or a distractor influence a saccade's trajectory, one can infer what stimulus properties are prioritized or are considered salient by the oculomotor system during target selection and saccade planning.

In general, a distractor whose features attract attention will influence the trajectory of a saccade aimed to a nearby target (e.g. Nummenmaa, Hyönä, & Calvo, 2009; Theeuwes & Van der Stigchel, 2009; Van der Stigchel, Mulckhuyse, & Theeuwes, 2009). To explain this behavioral effect, it is often assumed that in the oculomotor system, likely at the level of the midbrain superior colliculus (SC), a priority map represents attended objects based on their low-level saliency and their goal-related relevance (Fecteau & Munoz, 2006; Godijn & Theeuwes, 2002; McSorley, Haggard, & Walker, 2004). Each attended location or object is represented by a population of neurons that encode a movement vector to the target. The greater the object's combined salience (for example, strong stimulus intensity; Bell et al., 2006) and relevance (e.g. its similarity to a target object, Ludwig & Gilchrist, 2003; or proximity to the goal, McSorley, Cruickshank, & Inman, 2009), the stronger its initial activation will be upon the priority map. Populations representing separate but nearby objects will overlap within the map, shifting the overall activity distribution to generate a weighted vector average based on the strength of their respective activation. The result is a saccade whose trajectory represents a combination of that which would be generated in response to the presentation of either the distractor or the target in isolation. Saccade accuracy can be improved through active enhancement of the target's

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representation, and possibly through inhibition of the non-target representation (thought to be accomplished either by top-down inhibition, Al-Aidroos & Pratt, 2008; Van der Stigchel, 2010; Walker, McSorley, & Haggard, 2006, inhibitory projections from the substantia nigra, White, Theeuwes, & Munoz, 2012, or through lateral interactions within the SC itself, Wang, Kruijne, & Theeuwes, 2012). According to some inhibitory accounts, it is thought that as time passes, inhibition to the distractor shifts the overall activity within the priority map such that peak activity is further away from the distractor's true location, which results in a saccade that initially deviates away from the target and the distractor's locations (Van der Stigchel, Meeter, & Theeuwes, 2006).

To date, the study of saccadic trajectories has primarily relied upon within-task manipulations of simplistic target and distractor stimuli in order to manipulate the relative priority of the distractor to the participant. For example, a distractor can be made more relevant by either directly requiring participants to attend to it in order to determine the saccade goal (e.g. Sheliga, Riggio, & Rizzolatti, 1995), or by making it more similar to the target (e.g. by sharing its color, Ludwig & Gilchrist, 2003, or shape, Mulckhuyse, Van der Stigchel, & Theeuwes, 2009). Studies of this kind have established that saccade trajectories are more strongly affected by the distractor when it is arbitrarily made relevant for an experimental task. If, however, the overarching goal of this line of research is to establish how the oculomotor system behaves in everyday life, then one (of many) important avenues to explore is whether trajectory modulations can be observed in response to distractors whose relevance is defined more broadly than just within the task itself. The present studies examine whether a distractor that is inherently meaningful, not just within the task-at-hand but in everyday life, can elicit stronger trajectory deviations when compared to a distractor which lacks that general relevance but shares the same low-level visual properties. To test this, images of faces and unrecognizable scrambled faces were used as distractor stimuli. Both stimuli were task irrelevant, but while the former is socially relevant outside the paradigm itself, the latter is not.

Social stimuli were chosen as a test of whether the oculomotor system is sensitive to task-irrelevant distractor relevance primarily because of the strong evidence that faces are treated as relevant social stimuli in other paradigms. Even from early infancy, people pay special attention to faces over non-face stimuli (Farroni et al., 2005; Johnson et al., 1991; Mondloch et al., 1999). Faces, especially when presented upright, have been shown to attract (Devue, Belopolsky, & Theeuwes, 2012; Langton et al., 2008; Theeuwes & Van der Stigchel, 2006) and hold attention (Bindemann et al., 2005), and are detected over non-face stimuli, even under difficult viewing conditions (Devue et al., 2009; Mack et al., 2002). This attentional bias to attend to faces may be in part due to their strong activation of specialized face areas such as the fusiform gyrus (or fusiform face area, FFA; Kanwisher, McDermott, & Chun, 1997; McCarthy et al., 1997; Rhodes et al., 2004). Even in more unconstrained viewing conditions, faces are looked at more often than would be expected based on their low-level saliency (Birmingham, Bischof, & Kingstone, 2009), and demonstrate their social relevance by acting to guide attention to other relevant features in a scene (Castelhano, Weith, & Henderson, 2007). Note, however, that this evidence of strong prioritization of faces does not necessarily predict that within the oculomotor system, representations of task-irrelevant social stimuli are enhanced upon the priority map (e.g. would cause greater interference within a saccadic trajectory paradigm). The advantages for face vs. non-face stimuli may stem from privileged processing at other levels, for example at the FFA or superior temporal sulcus, and this information may or may not be easily accessible during saccade planning and execution. Thus, that faces are treated as a special, socially relevant stimulus in other tasks makes them an ideal test case for determining whether oculomotor planning is also affected by relevance that is not defined by the task itself.

A handful of trajectory-based studies have diverted from using simplistic target and distractor stimuli (e.g. basic geometric shapes, lines), though only a small number have used images of faces, the majority of which employed the face as a central attentional cue rather than as a distractor (Hermens & Walker, 2010; Nummenmaa & Hietanen, 2006; West et al., 2011). Thus, as in many other non-trajectory tasks, the face is the focus of attention, and therefore these studies cannot be used to speak to whether task-irrelevant social stimuli influence oculomotor planning. However, in one of the few studies where faces were used as peripheral distractor stimuli, only faces which displayed threatening emotional expressions elicited stronger saccadic trajectories when compared to non-face stimuli (Schmidt, Belopolsky, & Theeuwes, 2012). In other words, emotional (especially threat-based) salience, *not* social faces more generally, affected saccade trajectories, possibly due to a direct fast connection between the amygdala and superior colliculus (LeDoux, 1996). Given the literature reviewed above demonstrating that faces are generally prioritized by the attentional system at other levels of processing, Schmidt et al.'s implicit conclusion – that the social relevance of faces bears no influence within the oculomotor system – is worth further exploration. If true, then these results imply that both the oculomotor system's ability to process the social relevance of a given distractor, and its sensitivity to influences of social relevance found elsewhere in the brain, are highly constrained.

However, to propose that the oculomotor system is insensitive to social stimuli based on the null results of Schmidt, Belopolsky, and Theeuwes (2012) could be premature. Despite their finding that a neutral distracting face did not influence saccade metrics, there are several reasons why general face (and by extension, social) information may still be prioritized by the oculomotor system. First, the authors report average trajectory deviations, yet it is known that deviations change across saccadic reaction times (SRTs), with greater deviation away from the target and distractor at longer SRTs (McSorley, Haggard, & Walker, 2006). As such, it may be that a face-based effect was averaged out when trials were collapsed across all response times. Alternatively, Schmidt and colleagues may have failed to find an effect of the neutral face distractor on trajectory because the time period they examined was suitable for detecting fast subcortically generated effects, but was too short to observe cortically mediated social relevance effects. Further, the relevance of a face stimulus may be manifested not as an initial boost in the distractor's representation, but as a perseverance of the signal overtime, consistent with findings demonstrating that faces hold attention to their location (Bindemann et al., 2005). This information could be difficult to observe if longer time periods were not examined separately.

In the present paper, findings are presented from two studies that together demonstrate a significant influence of a social stimulus – a distracting face – on saccadic trajectory. These results run contrary to what could be concluded from existing trajectory literature and suggest instead that the social relevance of a face is influential in oculomotor planning and execution. In Study 1, upright faces, which are known to engage many processes unique to face processing, were tested for their ability to cause greater saccade deviation when compared to inverted face distractors. In Study 2, the results of Study 1 are compared to findings using scrambled versions of the face stimuli used in Study 1 in order to determine whether faces, regardless of their orientation, might be prioritized within the oculomotor system over meaningless color- and luminance-matched objects. Both studies expand on previous work in two ways. First, they provide a detailed analysis of saccadic trajectory effects at various SRTs, exploring whether previous face-based effects may have been averaged out and missed. Further, by employing a fixation onset event (Ross & Ross, 1980), average participant SRT was delayed so that any resulting differences in trajectory after longer distractor processing times could be examined.

## 2. Study 1: upright and inverted faces

### 2.1. Methods

#### 2.1.1. Participants

Participants were 18 volunteers (age range = 17–25 years) from the University of British Columbia. All participants gave informed written consent and participated in exchange for course credit or $10. Thirteen participants were female, 16 were right handed and all reported normal or corrected-to-normal vision. Work was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki).

#### 2.1.2. Apparatus

Eye movements were monitored using a desktop-mounted EyeLink 1000 eye-tracker (SR Research, Ontario, Canada) recording at a sample rate of 1000 Hz. Saccade start and end points were defined using velocity and acceleration thresholds of 30°/s and 8000°/s$^2$, respectively. A standard 9-point calibration and validation procedure was completed at the start of each block, and within blocks when necessary. Calibration and validation were repeated until an average measurement error under 1.0° was obtained. Stimuli were presented on a 17-inch SRT monitor with 1024 × 768 pixel resolution and a 60 Hz refresh rate. Viewing distance was held constant at 60 cm with the use of a chin and forehead rest.

Stimuli were presented against a black background. The target object was a white cross (1.08 × 1.08°), presented 8.84° above or below central fixation. The distractor (3.95 × 5.38°) was chosen equally and randomly from four color faces (two male, two female; taken from the Face Database of Minear & Park, 2004), and was presented with equal probability to the left or right of the target, at 45 angular degrees from the target. The eyes of each face were aligned to the center of the image, and the faces were elliptically cropped without removing any facial features. All images were equally likely to be shown upright and inverted, as well as mirror reversed. The fixation region was defined by a centrally presented dark gray annulus (radius of 2.15°). A small white dot (0.70°) at the center of the annulus served as the central onset stimulus, used to delay participant RTs (explained further in Procedure, below).

#### 2.1.3. Procedure

Fig. 1 shows a breakdown of the experimental procedure. Targets could appear above or below fixation with equal probability. For one third of the trials, no distractor appeared and this served as a means for collecting baseline trajectory measures from which distractor-present trials could be compared. For the remainder of the trials, a distractor onset simultaneously with the target. Distractor faces appeared with equal probability 45 angular degrees to the left or the right of the target, the same distance (8.84°) from the centre of the screen as the target. Trials began with the appearance of a central gray annulus, which participants were instructed to fixate within for a randomly determined duration between 500 and 1000 ms. If fixation was not detected after 1500 ms, or if fixation was not maintained within the central annulus for the duration of the fixation period, a red X appeared in the center of the screen for 400 ms and the trial then began afresh. If there were three successive false starts, then the initial eye tracking calibration and validation procedure was repeated, following which the trials resumed.

The timing between the onsets of the target (and distractor) and central dot were varied using a fixation onset paradigm. This paradigm served to increase the range of participant SRTs in order to facilitate a time-based analysis and, critically, to increase SRT in order to allow for an in depth examination of trajectory patterns at later time periods. Although a fixation offset paradigm – whereby a stimulus at fixation is removed prior to target onset – is a more commonly used procedure for manipulating response latency, its effect serves to decrease rather than to increase SRTs (Saslow, 1967). As such, it was ineffective to use a fixation offset procedure to meet our goals. On the other hand, the onset of a stimulus at fixation produces the opposite effect of increasing SRTs (Ross & Ross, 1980, see also Cabel et al., 2000). SRT increases as the delay between target onset and fixation point onset increases (to a point, of course: the onset of a stimulus at fixation would have no effect on SRT if it were to occur after the target program has been executed; Ross & Ross, 1980). As there was no fixation point at the start of the trial, asking participants to fixate within the central gray annulus ensured that participants were fixating at the location where the central onset would appear.

In half of the trials, the target (and distractor) appeared first, followed by the onset of the central dot. In the remaining half of the trials, the display sequence of the target (and distractor) and the central dot was reversed, such that the dot appeared at fixation first, which was then followed by the onset of the target (and distractor). The interval between the appearance of the central dot and the target (and distractor) was randomly determined for each trial in 50 ms steps from 0 to 200 ms. Thus, the SOA between target (and distractor) and central dot onset ranged between −200 ms and 200 ms in 50 ms intervals, with negative values denoting trials in which the target (and distractor) appeared prior to the central dot, and positive values denoting trials in which the central dot appeared prior to the target (and distractor). A SOA of 0 represents simultaneous onset of the target (and distractor) and the central dot. Thus, while the onset of a stimulus prior to the target might serve as a warning stimulus in some tasks, the effect of the central dot as a warning stimulus in this study would be especially limited, as its appearance relative to the target (and distractor) varied between −200 and 200 ms, i.e. was equally likely to occur before or after the target (and distractor). Participants were instructed to look to the target as quickly and as accurately as possible using one eye movement. Trials were separated by 800 ms. Participants completed 10 practice trials, followed by 12 blocks of 48 trials, for a total of 576 experimental trials.

### 2.2. Results

#### 2.2.1. Data handling

Saccadic curvature was calculated using the quadratic fit method (Ludwig & Gilchrist, 2002). Each saccade was rescaled to travel a common absolute distance, and the best fitting quadratic polynomial was determined. The amplitude of the saccade's curvature was measured using the quadratic coefficient, which is reported here in degrees of visual angle. The average trajectory during distractor-absent trials was subtracted from the trajectories collected from the distractor-present trials, thereby compensating for idiosyncratic deviations in baseline trajectories across participants and generating a measure of the effect of the distractor on curvature. This was done separately for upward and downward saccades, as trajectories are known to vary depending on saccade direction (Viviani, Berthoz, & Tracey, 1977). Trajectories deviating away from the distractor were assigned negative values, while trajectories deviating towards the distractor were assigned positive values.

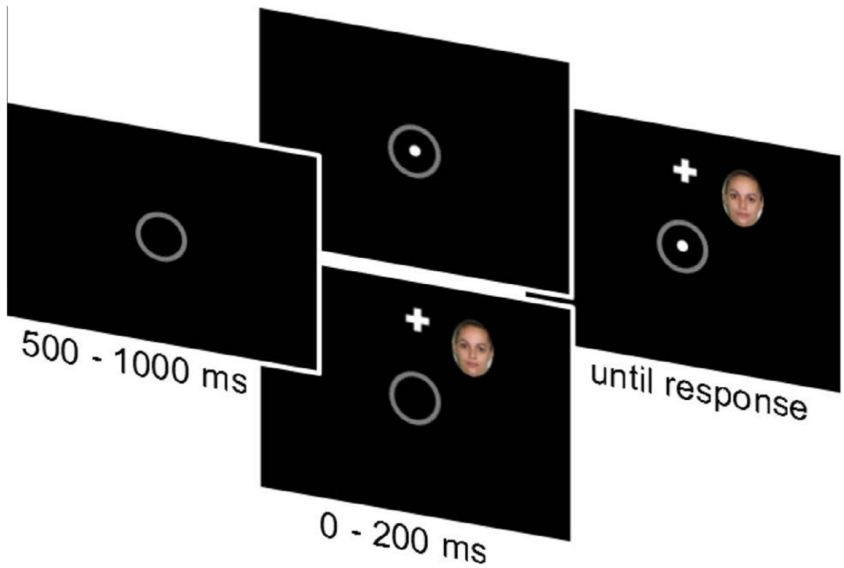


**Fig. 1.** Procedure for both Studies 1 and 2. Participants fixated within the central gray annulus (start area). In half of the trials, a central dot appeared inside the gray annulus (to delay SRTs), followed 0–200 ms later by the appearance of the target (and distractor; middle, top panel). In the other half of the trials, the target (and distractor) onset 0–200 ms prior to the central dot appearing (middle, bottom panel). In two-thirds of all trials, a distractor onset simultaneously with the target. The target was a white cross; the distractor was an upright, or inverted face (Study 1), or a scrambled, non-face stimulus (Study 2). Participants were instructed to make a single saccade from fixation to the target as soon as the target appeared and to be as accurate as possible.

### 2.3. Trial exclusion

Trials were excluded if SRTs were below 100 ms or above 500 ms (2.91% of all trials), if participants' first saccade went to the distractor (0.53%), did not land at the distractor or within a 4.30° diameter of the target (12.28%) or if an individual's SRT or trajectory curvature was 2.5 standard deviations over or under their mean value for that condition (2.99%).

### 2.4. Trajectory time course

#### 2.4.1. Saccadic reaction time

For all analyses reported, if Mauchley's test of sphericity was significant (conservatively set at $p \leqslant .25$), degrees of freedom and $p$-values were adjusted using Greenhouse–Geisser (if $\varepsilon \leqslant .70$) or Huynh–Feldt (if GG $\varepsilon > .70$) adjustments (Girden, 1992). Each participant's distractor-present data was sorted based on SRT and quintile such that bin 1 represented the fastest 20% of their trials, and bin 5 represented the slowest 20% of their trials. Effects size measures were determined following the guidelines of Lakens (2013).

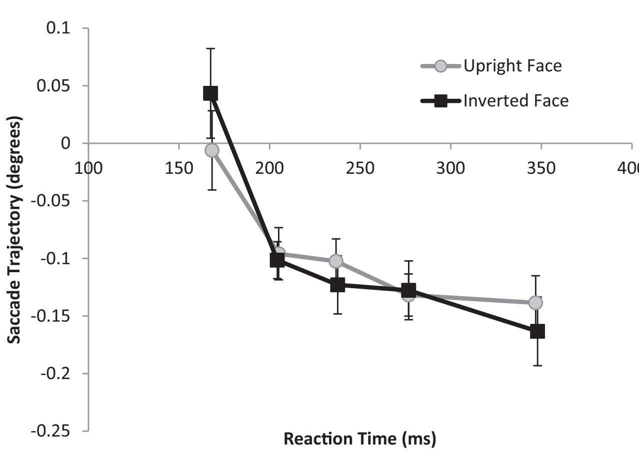


**Fig. 2.** Saccadic trajectory deviations relative to no-distractor trials for trials in which the distractor was an upright or inverted face. While saccades increasingly deviated away from the distractor location as reaction time increased, there was no effect of distractor type.

A repeated measures ANOVA was performed with distractor type (upright, inverted) and SRT bin (1–5) as within-subject factors. It revealed only a main effect of SRT bin, $F(1.19, 20.14) = 166.95$, $p < .001$, $\eta_p^2 = .91$. Importantly, there was no differential influence of SRT on the different types of distractors, suggesting that any distractor effects of saccadic curvature are not related to SRT differences.

#### 2.4.2. Saccadic trajectories

The mean trajectory for each SRT bin was determined for each participant for upright and inverted distractor conditions (Fig. 2). A repeated measures ANOVA was conducted with distractor type (upright, inverted face), and trajectory bin (1–5) as within-subject factors. There was a significant main effect of trajectory bin, $F(2.10, 35.74) = 7.97$, $p = .001$, $\eta_p^2 = .32$, revealing greater deviation away from the distractor location (relative to baseline) as SRT increased.[1] Interestingly, there was no significant effect of distractor type, $F(1, 17) = .004$, $p = .95$, $\eta_p^2 < .001$, nor was there a significant interaction between distractor type and trajectory bin, $F(3.50, 59.55) = 2.11$, $p = .11$, $\eta_p^2 = .10$. Thus, although the distractor influenced saccadic trajectory relative to when there was no distractor, there was no significant differentiation for upright vs. inverted faces.

### 2.5. Fixation onset effect

Using a repeated-measures ANOVA, the influence of the fixation onset paradigm on SRTs using distractor type (upright, inverted, or distractor absent) and SOA (−200, −150, −100, −50, 0, 50, 100,

[1] To examine if the use of four exemplar faces resulted in participant's habituating to the distractor faces, we analyzed saccadic trajectory from the first as compared to the second half of the study. There were no significant differences between study halves, $ps > .40$, indicating that participants did not perform differently with distractor experience.

150, 200 ms) as factors was evaluated. There was a main effect of SOA, $F(1.54,26.26) = 39.21$, $p < .001$, $\eta_p^2 = .70$, such that SRTs increased with SOA (fastest when fixation onset occurred prior to target/distractor onset; slowest when fixation onset occurred after target/distractor onset; i.e. there was a fixation onset effect, Ross & Ross, 1980). A main effect of distractor type was also noted, $F(1.29,21.86) = 4.79$, $p = .032$, $\eta_p^2 = .22$, which represented a non-significant difference for the effect of fixation point onset on SRT to be larger for the no distractor condition, ($M = 252.72$, SD = 40.98) compared to the distractor-present condition (upright: $M = 246.42$, SD = 40.83; inverted: $M = 246.70$, SD = 38.93), all $ps > .10$. The magnitude of the fixation onset effect was unaffected by distractor orientation. This pattern of results is consistent with previous findings that the remote distractor effect (Walker et al., 1997) is strongest when a fixation point offsets, and is actually absent when the fixation point remains on screen (Honda, 2005). The interaction was not significant ($p > .05$, $\eta_p^2 = .05$).

#### 2.5.1. Error analysis

Saccades rarely landed at the distractor location, and there was no significant difference in the percentage of erroneous saccades landing at the upright vs. the inverted face, $p > .05$, *Hedges*' $g_{av} = .11$. In addition to making erroneous saccades to the distractor, participants could have also made erroneous looks to a location that contained neither a distractor nor the target (i.e. to blank screen-space). The percentage of 'saccade to nothing' errors was calculated and submitted to a repeated-measures ANOVA with distractor type (absent, upright, inverted) as a within-subject factor. Results showed a significant effect of distractor type, $F(2,34) = 9.27$, $p = .001$, $\eta_p^2 = .35$, which was due to more errors made when a distractor was present than when there was no distractor (upright vs. absent: $t(17) = 3.21$, $p = .005$, *Hedges*' $g_{av} = .36$; inverted vs. absent: $t(17) = 4.01$, $p = .001$, *Hedges*' $g_{av} = .33$ ; upright vs. inverted $p > .05$, *Hedges*' $g_{av} = .03$). Error performance supports a lack of differentiation between upright and inverted face distractors.

### 2.6. Discussion

The results from Study 1 show a characteristic deviation away from the task-irrelevant distractor that is typical in time course analyses of saccade trajectory (e.g. McSorley, Haggard, & Walker, 2006). This shows that the distractor's presence has a significant influence on saccade execution. Interestingly however, the present study revealed no evidence that upright faces were treated differently than inverted faces. This stands in contrast to results using other paradigms in which upright faces are processed differently than inverted face, typically with upright faces showing a distinct advantage in recognition-based tasks (Valentine, 1988). Face orientation effects are often interpreted as evidence that upright faces receive specialized or additional processing via face-sensitive brain regions like the FFA (Yovel & Kanwisher, 2005). Importantly, however, face inversion effects are not consistently demonstrated in face detection tasks where additional face processing is unnecessary (Bindemann & Burton, 2008; Kanwisher, Tong, & Nakayama, 1998). Critically, the present study did not require participants to engage in a face recognition task; the distracting faces were purely task irrelevant. Thus, as the face stimuli were task-irrelevant, in-depth face processing may not have occurred.

Although people do not have as much everyday experience with inverted vs. upright faces, there is little doubt that inverted faces are still social stimuli. Nevertheless, Study 1's results do not demand the rejection of the hypothesis that socially-defined relevance is represented within the oculomotor system. The possibility remains that social stimuli are prioritized more than non-social distractor stimuli, and that the more in-depth processing necessary to differentiate between upright and inverted faces is not automatically engaged when the faces are presented as task-irrelevant distractors. In Study 2, upright and inverted distractor faces were replaced with scrambled versions of the same stimuli used in Study 1. We chose to perform an additional experiment rather than including a third, scrambled face condition in a modified version of Study 1, because doing so would have substantially increased trial number and we were already approaching a time point where participants would be fatigued, i.e. we were concerned that participant fatigue would compromise the data. By comparing the results from each study, it will be possible to determine whether distracting faces received any prioritization over non-socially relevant stimuli that are nevertheless matched on other low-level visual features (e.g. size, contrast, and luminance).

## 3. Study 2: scrambled faces

### 3.1. Methods

#### 3.1.1. Participants

Participants were 18 volunteers (age range = 18–27 years) from the University of British Columbia that has not participated in Study 1. All participants gave informed written consent and participated in exchange for course credit or $10. Thirteen participants were female, 16 were right handed and all reported normal or corrected-to-normal vision.

#### 3.1.2. Apparatus and procedure

Apparatus and procedure were identical to Study 1 with the exception that instead of using images of upright or inverted faces as distractors, participants were shown scrambled versions of the same faces. Scrambled images were created using a two-dimensional Fast Fourier Transform and subsequent phase randomization and reconstruction using the same spatial frequencies, luminance, and contrast as the original image (see West et al., 2011). Thus, for one third of trials, only the target appeared, while on the remaining two-thirds of the trials the target was accompanied by a nearby scrambled face.

#### 3.1.3. Results

The focus of the following analyses was to compare results from Study 2 (scrambled face) with those from Study 1 (face), though analyses of the results from Study 2 alone are also reported where appropriate. As Study 1 revealed no significant difference between upright and inverted distractor faces, distractor type from Study 1 was collapsed and analyses were performed to compare differences in face vs. scrambled face distractors. Performing the trajectory analyses below with only upright faces or only inverted faces from Study 1 did not produce a meaningful change to the reported results.

### 3.2. Trajectory time course

#### 3.2.1. Saccadic reaction time

As with Study 1, a repeated-measures ANOVA with SRT bin (1–5) showed an expected main effect, $F(1.24,21.11) = 173.67$, $p < .001$, $\eta_p^2 = .91$, where RTs differed based on the binning procedure. Results were compared from Study 1 and 2, by performing a mixed-factor ANOVA with distractor type (face, scrambled face) as a between-subject factor, and SRT bin (1–5) as a within-subject factor. This revealed only a main effect of SRT bin, $F(1.22,41.44) = 339.61$, $p < .001$, $\eta_p^2 = .91$. Importantly, there was no differential influence of SRT on the different types of distractors, suggesting that any effects of saccadic curvature are not related to SRT differences.

*3.2.2. Saccadic trajectories*

The mean trajectory for each SRT bin was determined for each participant. A repeated-measures ANOVA with trajectory bin (1–5) was performed on Study 2's data, demonstrating a main effect of trajectory bin, $F(2.43,41.23) = 6.96$, $p = .001$, $\eta_p^2 = .29$. Fig. 3 shows saccadic curvature across all SRT bins for Study 1 and 2. Trajectories from both experiments were compared in a mixed factor ANOVA with distractor type (face, scrambled face) as the between-subject factor, and trajectory bin (1–5) as the within-subject factor. There was a significant main effect of distractor type, $F(1,34) = 4.62$, $p = .039$, $\eta_p^2 = .12$, with greater deviation away from face than scrambled face distractors. There was also a significant main effect of trajectory bin, $F(2.19,74.38) = 13.27$, $p < .001$, $\eta_p^2 = .28$, with greater deviation at longer SRTs. Finally, there was a significant interaction between these factors, $F(2.19,74.38) = 3.25$, $p = .04$, $\eta_p^2 = .09$. After Bonferroni correction for multiple comparisons, follow-up independent *t*-tests at each trajectory bin revealed a significant difference at the longest SRT bin, $t(29.06) = 3.67$, $p = .005$, *Hedges*' $g_s = 1.20$. Thus, when participants were exposed to the distracting face and non-face stimuli for an extended time period, there was significantly greater saccadic trajectory deviation away from the face vs. the non-face distractor (Fig. 3).

As one additional interest of the present study was in determining whether faces retained attention more so than scrambled stimuli, the trajectory values from the slowest two SRT bins for both faces and scrambled faces were compared. If faces require sustained inhibition in order to be successfully avoided, then these two time periods should not differ. However, as inhibition is likely not sustained indefinitely (McSorley, Haggard, & Walker, 2009), evidence of saccade trajectories returning to baseline might be expected at the longest SRTs. If attention is maintained at the distractor location, however, such as in the salient face condition, it would be reasonable to expect that inhibition should also be maintained in order to facilitate target selection. Thus, it was anticipated that the slowest SRT bin for the saccades made in the presence of a scrambled face may show evidence of returning to baseline, whereas this would not be the case when the distractor was a face. That is, the slowest time bin should actually deviate away less than the second slowest time bin. Indeed, a paired samples t-test of the two slowest SRT bins confirms this prediction, faces: $t(17) = 1.65$, $p > .05$, *Hedges*' $g_{av} = .35$; scrambled faces: $t(17) = 2.51$, $p = .022$, *Hedges*' $g_{av} = .41$.

*3.3. Fixation onset effect*

For Study 2 alone, mean SRTs across SOAs (−200, −150, −100, −50, 0, 50, 100, 150, 200 ms) and distractor presence (absent, present) were submitted to a repeated-measures ANOVA. There was a main effect of SOA, $F(1.96,33.27) = 26.08$, $p < .001$, $\eta_p^2 = .61$, such that SRTS were slower when the fixation point onset after target (and distractor) had already appeared. There was also a main effect of distractor, $F(1,17) = 6.40$, $p = .022$, $\eta_p^2 = .27$, which was due to small but significantly slower responses when only a target was present vs. when a distractor was present. The interaction was not significant, $p > .05$, $\eta_p^2 = .02$. Once again the fixation onset paradigm had the anticipated and desired effect on SRTs.

To compare the effects of distracting face and scrambled face images, mean SRTs across SOAs were submitted to a mixed factor ANOVA with distractor type (face, scrambled face), distractor presence (absent, present) and SOA as factors. There was a main effect of SOA, $F(1.87,63.58) = 64.27$, $p < .001$, $\eta_p^2 = .65$, such that SRTs were slow when the fixation point onset after target (and distractor) onset. There was also a main effect of distractor presence, $F(1,34) = 11.66$, $p = .002$, $\eta_p^2 = .26$, such that distractor-present trials were significantly faster than distractor-absent trials (see Section 2.6). No other effects or interactions were significant (all *ps* > .05).

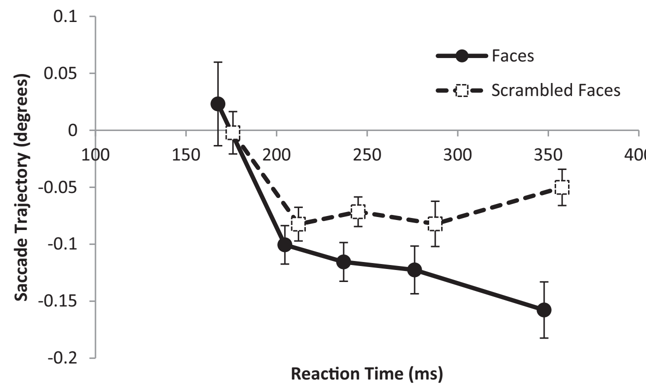


**Fig. 3.** Saccade trajectories (in degrees of visual angle) as a function of SRT for face and scrambled, non-face stimuli. Positive trajectory values indicate greater deviation towards the distractor than baseline; negative values indicate greater deviation away from the distractor than baseline. Upright and inverted faces were shown to not differ and have been collapsed together. Face distractors elicited greater deviation away at longer SRTS than did scrambled, non-face distractors.

*3.3.1. Error analysis*

No comparison could be made in erroneous saccades made to the target within Study 2 alone. Thus, the error rates across Study 1 and 2 were compared. Though it was very rare for saccades to land on the distractor, there was nevertheless a trend for participants to make more erroneous saccades to the distractor when it was a face ($M = 0.98\%$, SD = 1.20%) vs. when it was a scrambled face, ($M = 0.37\%$, SD = 0.53%), $t(23.28) = 1.99$, $p = .059$, *Hedges*' $g_s = .65$, which broadly supports the view that faces capture overt attention more so than do non-face distractors. Because error rates were so low, however, no conclusions will be made based on this finding alone.

In addition to making erroneous saccades to the distractor, participants could have also made erroneous looks to a location that contained neither a distractor nor target (i.e. to blank screen-space). The percentage of 'saccade to nothing' errors was calculated for trials with and without a distractor and submitted to a mixed-factor ANOVA with distractor presence (present, absent) as a within-subject factor and distractor type (face, scrambled face) as a between-subject factor. Results revealed that participants made significantly more erroneous saccades that did not land at any object when a distractor was presented alongside the target ($M = 16.83\%$, SD = 10.67%) vs. when it was not ($M = 13.92\%$, SD = 9.38%), $F(1,34) = 26.71$, $p < .001$, $\eta_p^2 = .44$. No other main effects or interactions were significant, (all, *ps* > .05). Thus, the presence of a distractor made participants less accurate overall in their saccades, but the identity (e.g. face or scrambled face) of the distractor did not impact error rates.

## 4. General discussion

The current experiments demonstrated that a distracting face has a greater impact on saccadic trajectory than a scrambled version of the same image, but only later in saccade planning (i.e. when SRTs were longest). This effect was not specific to upright faces; inverted faces were similar to upright faces, but different from scrambled, non-face distractors. Even though the distractor's identity (face vs. non-face) was irrelevant to the task, when SRT was long, face and non-face distractors produced measurably different effects on saccade execution. This suggests that the broad social relevance of a face may have impacted the strength of the distractor's representation within the oculomotor system's priority map.

While it has been shown that other features that impact the relevance of a distractor also create more interference, previous reports have primarily manipulated relevance as it is defined within the task. For example, when a distractor onsets in the same color as the saccade target, its relevance to the task at hand increases due to its similarity to the target (Ludwig & Gilchrist, 2003). As a result of these goal-driven signals, the distractor that shares the target's color produces greater trajectory modulations. Similarly, when a distractor shares the location of the target on other trials within the same study, it becomes more task-relevant compared to one which onsets at a location where a target never appears. As such, the distractor at the possible target location may be afforded an initial boost in activation within the priority map, which alters its impact on resultant saccadic trajectories (McSorley, Haggard, & Walker, 2009). What these previous studies do not speak to is whether distractors that vary in their relevance to the participant *beyond* the current task will also impact the strength of that distractor's interference during saccade planning. Here, it is shown that it does.

These findings are broadly supported by previous trajectories studies that have examined how threatening or taboo distractors impact saccade trajectory. For example, semantically salient (e.g. taboo) words have been shown to hold attention longer at their location, causing deviations away at long distractor-target SOAs (Weaver, Lauwereyns, & Theeuwes, 2011). Similarly, emotional scenes also cause greater deviation away when compared to neutral scenes (Nummenmaa, Hyönä, & Calvo, 2009). Threatening or emotional stimuli can be considered broadly relevant, as they might signify an immediate threat to the observer. Unlike these previous studies, which presumably relied on an emotional reaction to the distractor to elicit stronger oculomotor interference, the present results are the first to show that relatively emotionally neutral stimuli can cause greater deviation away from their location. Interestingly, it has been found across several studies that the effects of the emotional status of the stimulus is only represented in trajectory measures if given sufficiently long processing time, which was true to a lesser extent in the present results as well. The relative slowness of these effects on saccadic trajectory suggest that task-irrelevant distractor-specific details may not be immediately available but instead become integrated into the distractor's representation over time. This stands in contrast to findings of rapid face detection and/or processing, which occurs within as little as 100 ms (e.g. Braeutigam, Bailey, & Swithenby, 2001; Crouzet, Kirchner, & Thorpe, 2010), presumably due to the involvement of fast subcortical face-sensitive regions which include the superior colliculus (Johnson, 2005). Indeed, others have suggested subcortical activation to social stimuli is impaired in those with autism spectrum disorder, which could account for behavior differences in social orienting (Kleinhans et al., 2011). However, these studies did not always control social and emotional levels of the stimuli, making it difficult to parse out the role of fast subcortical face-specific routes independent of their emotional content. While it is possible that the SC displays face-sensitive properties, future investigations will need to distinguish between the social and emotional relevance of stimuli in order to more confidently conclude what is driving rapid vs. slower-building changes in stimulus processing. The current study demonstrates that at least for saccade planning and initiation, social stimulus relevance is incorporated relatively late, which suggests that fast subcortical face information is not the sole carrier of the prioritization information; instead, cortically-mediated relevance information may feed into the priority map at a later time.

Not only do the present results provide more consistency with social stimuli being afforded privileged or prioritized processing in other tasks, they can also be reconciled with those of Schmidt, Belopolsky, and Theeuwes (2012), who did not report trajectory differences between neutral faces and non-face distractors. Considering the effect reported here is most pronounced in long-latency saccades, their choice to average all SRTs together to generate an overall trajectory measure may have masked any differences that could have been present in their data. The present finding of greater deviation away from an upright or inverted face over a non-face stimulus is also broadly consistent with studies outside of the saccadic trajectory literature that demonstrate a strong attentional bias to attend to faces. These results also support previous results suggesting that faces retain attention (Bindemann et al., 2005), such that faces caused greater deviation away at the longest saccadic latencies. Within a context in which faces are task-irrelevant however, there is little direct evidence of this attentional maintenance, and even less documenting its time course, which the present study provides. As suggested by McSorley, Haggard, & Walker, 2009, inhibition of the distractor may not be maintained indefinitely. Rather, inhibition may reach a peak, and then slowly release and return closer to baseline levels. This would manifest as an increase in saccadic trajectories away from the distractor and target, followed later by a gradual return to the participants' distractor-absent baseline level. Indeed, this was observed for scrambled distractor trials: trajectories collected from the slowest SRT bin deviated away from the distractor less than did the trajectories from the second slowest SRT bin. This was not the case for the face trajectories (upright and inverted faces combined), however, suggesting that inhibition was maintained for faces longer, likely due to stronger competition from the distractor face than the scrambled face. Similarly, the main effect of distractor faces eliciting overall more deviation than scrambled faces implies that the initial representation of a distractor face within the oculomotor system's priority map is stronger than that of a scrambled distractor. As a saccade is made to the location with the combined strongest activation within this map, this interpretation is consistent with previous findings that faces capture overt attention in oculomotor capture tasks, more so than non-face stimuli (Langton et al., 2008; Theeuwes & Van der Stigchel, 2006).

While the observed effects are described in the context of distractor inhibition, which is a common viewpoint in the field (e.g. Laidlaw & Kingstone, 2010; McSorley, Haggard, & Walker, 2009; Van der Stigchel, Meeter, & Theeuwes, 2007; Walker et al., 2006), it is worth noting that recently there has been some debate about the mechanisms underlying the deviation of saccades away from a distractor. Extracellular recordings of distractor-related activity in monkey SC failed to show early differentiation in spike rate when saccades deviated towards or away from the distractor (White, Theeuwes, & Munoz, 2012). This has led to the speculation that distractor inhibition may be related less to top-down inhibition and more to distractor-related disinhibition of the SC via the substantia nigra pars reticulata, However, in the same task, White and colleagues also found strong correlations between distractor activation and deviation just prior to saccade execution. Though this related activity may be too late to affect trajectory, it is worth noting that stimulation of the SC within that short time window has been shown to cause deviation towards the distractor (McPeek, Han, & Keller, 2003), suggesting that it is at least plausible that changes in activity (i.e., suppression) so close to saccade execution may also be responsible for saccade deviation. Others have argued that 'Mexican-hat' shaped lateral interactions could account for some instances of deviation away from the distractor (Wang, Kruijne, & Theeuwes, 2012). More research will be necessary to determine the exact mechanism behind deviation away from a distractor. Importantly, the conclusions of the present studies need not be tied to a particular manner by which inhibition is applied. The core result of the current experiments is that social stimuli are considered more relevant than non-social stimuli by the oculomotor system, which arguably increases distractor-related activity within the SC that subsequently influences oculomotor behavior.

Here, face orientation did not influence results, which has been reported elsewhere (Langton et al., 2008; Ro, Russell, & Lavie, 2001; Theeuwes & Van der Stigchel, 2006). A pilot study using a similar experimental procedure but with post-stimulus masks and briefer presentation times (to increase task difficulty) confirmed that participants were easily able to distinguish between the distractor types and were significantly more accurate at identifying the distractor type than would be expected by chance.[2] As such, it can be concluded confidently that participants were able to distinguish between the upright and inverted faces, but that face orientation did not differentially impact saccade trajectory. When face inversion effects are observed elsewhere, researchers have suggested that it may be due in part to upright faces receiving 'privileged' specialized processing by face-sensitive brain regions such as the FFA. However, face inversion effects appear to be strongest within recognition or discrimination tasks (Freire, Lee, & Symons, 2000; Yin, 1969), and have not been as consistently reported within simple face detection tasks (Bindemann & Burton, 2008; Kanwisher, Tong, & Nakayama, 1998). In the present study, faces were task-irrelevant, suggesting that participants may have merely detected them as faces rather than processed them in-depth, which could explain the lack of an inversion effect in the present results. An alternative possibility is that while differentiation between upright and inverted faces occurred within other brain regions such as the FFA, these signal differences were lost or not well represented at the level of the oculomotor system's priority map. Future research could manipulate the depth by which the distractor face stimuli are processed, thereby enabling one to better understand the role that prior processing within face-specific regions plays in determining the strength of a distractor's representation within the oculomotor system's priority map.

In summary, the current study demonstrates differential effects of face and scrambled face stimuli on saccade trajectory, suggesting that a distractor's broad social relevance can influence the strength of a distractor's interference on saccade planning within a simple target localization task. Future studies concerned with whether these effects translate to even more realistic task paradigms and to social stimuli showing different expressions will continue to provide a better understanding of what features within the environment guide a viewer's attention and actions.

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[2] Twelve naive participants (age range = 18–21 years, seven female, 11 right handed, all with corrected-to-normal or normal vision) completed a distractor-identification study. Stimuli were identical except that distractor stimuli were programmed to be presented for 75 ms, and then masked for 250 ms by a black and white random pattern mask in order to make the identification task more challenging. Further, distractors were presented on every trial and could be upright, inverted, or scrambled faces, with equal probability. No fixation onset procedure was used (e.g. no gray annulus onset). Participants maintained central fixation and indicated via key press after the trial which distractor had appeared; feedback was provided after each response. Three blocks of 64 trials were analyzed. Analyses revealed that overall, participants correctly identified the distractor significantly more often than chance, (chance performance: 33.33%; correct range: 70–90%), and for each of the three distractor types participants selected the correct distractor significantly more often than the other two options (all comparisons, *ps* < .05, Bonferroni-corrected).

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