

## **Rapid orienting toward face-like stimuli with gaze-relevant contrast information**

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## **Abstract**

Human faces under natural illumination, and human eyes in their unique morphology, include specific contrast polarity relations that face-detection mechanisms could capitalize on. Newborns have been shown to preferentially orient to simple face-like patterns only when they contain face- or gaze-relevant contrast. We investigated whether human adults show similar preferential orienting towards schematic face-like stimuli, and whether this effect depends on the contrast polarity of the stimuli. In two experiments we demonstrate that upright schematic face-like patterns elicit faster eye-movements than inverted ones in adult humans, and that this occurs only if they contain face- or gaze-relevant contrast information in the whole stimulus or in the eye region only. These results suggest that primitive mechanisms underlying the orienting bias towards faces and eyes influence and modulate social cognition not just in infants but in adults as well.

## 1 Introduction

The status of human faces as a special class of visual objects for the human perceptual system has been confirmed in a number of studies using different methods (Kanwisher 2000). Faces provide a rich source of social information (for recognizing identity, direction of attention, communicative reference, or emotion expression), often critical for establishing social interactions (Schultz 2005). The uniqueness of faces has also been demonstrated in the ability to attract and hold attention more effectively than other objects. Faces are more likely to capture attention than other objects in visual search tasks (Langton et al 2008; Ro et al 2007, but see: VanRullen 2006) and cannot be ignored even under conditions of high perceptual load (Lavie et al 2003). In addition, neutral faces compared with objects, as well as threat-related facial expressions compared with non-threat expressions, are more effective in eliciting covert shifts of spatial attention (Bindemann et al 2007; Mogg and Bradley 1999; Pourtois et al 2004). These results are consistent with the existence of a bias to preferentially orient attention toward faces at the expense of other non-face stimuli. Further evidence suggests that this phenomenon might depend on exogenous mechanisms of orienting. For example, Theeuwes and Van der Stigchel (2006) recently discovered that faces elicit more robust inhibition of return to a previously cued location compared to non-face stimuli.

When investigating orienting towards faces, a central question to address is concerned with the characteristics of the stimuli that are necessary to efficiently attract overt and covert attention. In natural environments faces are illuminated from above, generating a specific pattern of light and shadow with the recessed regions of eyes and mouth appearing as darker on a contrasting brighter (stronger illuminated) face oval (Johnston et al 1992). This property can be represented in a schematic face-like pattern as three dark blobs overlaid on a bright oval (see Figure 1A). Similar contrast properties are also present in the human eye, with a dark pupil placed in the context of a large white sclera (Figure 1C), a feature unique to the human species (Kobayashi and Kohshima 1997). This contrast information is necessary for the processing of

gaze direction, an important signal for judging attentional state and also to indicate referential intent during face-to-face communication. Adult humans rely heavily on the unique contrast polarity of the eye when judging gaze direction (Sinha 2000), and become much less accurate when the contrast is reversed within the eye region, irrespective of the contrast polarity of the surrounding face (Ricciardelli et al 2000). In fact, some studies have demonstrated that human gaze direction perception depends on the luminance ratio of the light sclera to the pupil and the surrounding skin tone (Ando 2002, 2004). Thus, the specific contrast polarity characteristic for faces and eyes might be an important cue for detecting faces or face-like stimuli. More so, contrast polarity has been shown to play a critical role in eliciting preferential orienting in newborns.

Preferential orienting towards an upright face-like pattern (white oval with three black blobs, corresponding to eyes and mouth) is present in human newborns, indicating an inborn bias to attend to faces (Farroni et al 2005; Goren et al 1975; Johnson et al 1991). Newborns detect and direct their gaze more often towards a stimulus possessing specific face-like configuration of elements (the positioning of eyes and mouth) compared with an identical but inverted pattern (Macchi Cassia et al 2001; Valenza et al 1996). More so, they are also sensitive to the contrast polarity of face-like patterns, demonstrating preference for an upright stimulus only with normal polarity (black blobs on white oval, Figure 1A) and not with contrast polarity reversed (white blobs on black oval, Figure 1B). Importantly, when the normal contrast polarity is restored only within the eye region of the reversed contrast stimuli (smaller black blobs inside the larger white blobs representing eyes and mouth, Figure 1C), this also restores newborns' preference for an upright pattern (Farroni et al 2005). This last result can be interpreted as consistent with the idea that the newborn bias to detect face-like patterns is especially tuned to stimuli containing gaze-relevant contrast typical of the human eye (Csibra and Gergely 2006).

Although firm evidence suggests that faces capture people's attention (Hershler and

Hochstein 2005; Langton et al 2008; Theeuwes and Van der Stigchel 2006), it has been unknown whether the overt orienting bias towards face-like patterns remains in operation in adults. Its presence in adulthood would suggest that the putative subcortical visual pathway, thought to mediate orienting to faces in newborns (Johnson et al 1991), is active throughout the life-span. Further, it would support the hypothesis that these primitive mechanisms play a critical role in establishing and maintaining the social brain network during human development (Johnson 2005).

In the current set of two experiments we investigated whether the preference in orienting towards upright schematic face-like patterns can also be demonstrated in human adults. More specifically, we tested whether adults detect and orient towards an upright schematic face faster than an inverted face, and whether such an effect is dependent on the contrast polarity of the stimuli. Attentional biases in human adults can be more readily assessed by the speed than by the duration or the frequency of the visual orienting response, the measures used in infant studies. Thus, as an index of preference we recorded saccadic reaction times in a simple overt orienting task, where participants were asked to quickly shift their gaze towards peripherally flashed face-like patterns.

## **2 Experiment 1**

In Experiment 1 we directly contrasted normal and reversed contrast polarity stimuli with upright or inverted orientation. If adults retain the newborn bias to orient towards face-like patterns, they should exhibit faster saccadic responses to an upright normal contrast polarity pattern compared with inverted or reversed polarity faces.

### *2.1 Method*

*2.1.1 Participants.* Eighteen right-handed volunteers (8 males and 10 females, age range 19 to 31 years, on average 23.5 years) took part in the study. An additional participant

was excluded due to excessive eye movement artefacts. All participants signed an informed consent prior to commencing the experiment and were paid for participation. A relevant ethical clearance was obtained from the local committee at the School of Psychology, Birkbeck College.

*2.1.2 Stimuli and procedure.* Participants sat in a dimly lit booth, 70 cm away from a 19-inch computer screen (resolution of 1024 x 768, refresh rate 75 Hz). The experiment was programmed and run with Matlab 7.4 with Psychtoolbox (Brainard 1997) on an Intel MacPro computer.

We used schematic face-like patterns (each subtending a visual angle of  $4.51^\circ \times 6.36^\circ$  or  $5.52 \times 7.8$  cm), which consisted of 3 square blobs ( $0.8^\circ \times 0.8^\circ$  visual angle –  $0.98 \times 0.98$  cm), corresponding to the location of eyes and mouth, overlaid on a plain oval. Normal contrast stimuli (an upright and an inverted pattern) were composed of black squares on a bright grey oval (20% black), while patterns with reversed contrast polarity had white blobs imposed on a dark grey oval shape (80% black). Inverted schematic faces were obtained by rotating the normal and reversed polarity upright stimuli by  $180^\circ$ . A total of 4 stimuli were used, differing in contrast polarity (normal/reversed) and orientation (upright/inverted). The fixation stimulus was a black star subtending a  $1.03^\circ$  visual angle in radius (1.26 cm).

Each trial began with a central fixation point presented for a random duration of 700 to 1100 ms, followed immediately by one of four schematic face-like patterns (at 25% chance) flashed peripherally for 200 ms on the left or right side (with equal probability) of the screen. Peripheral schematic faces were positioned at fixed locations at  $8^\circ$  from the inner edge of the stimulus to the centre along the horizontal midline. The inter-trial interval varied between 800 and 1000 ms. The stimuli were displayed on a uniform grey background (50% black).

For the practice block, 10 trials were executed with a black-and-white square checkerboard (subtending visual angle of  $5.14^\circ \times 5.14^\circ$ ,  $6.3 \times 6.3$  cm) instead of face-like patterns. In total, 160 experimental trials were run, grouped in 4 blocks of 40 trials with short

breaks (less than 1 min) between consecutive blocks. There were overall 40 trials with each of four different face-like patterns. The participants' task on each trial was to make a speeded saccade from the fixation stimulus to the target stimulus as soon as it appeared on the screen, and then to re-fixate the centrally presented fixation stimulus. In most trials, the target stimulus had already disappeared by the time the participants would have foveated it.

*2.1.3 EOG data acquisition and analysis.* Saccadic reaction times were measured through electrooculography (EOG) using the Electrical Geodesics (EGI) acquisition system (500 Hz sampling rate, 0.1 – 200 Hz band-pass filter). The EEG signal was collected with 128-channel Hydrocel Nets against vertex reference. The horizontal EOG signal was reconstructed by subtracting the electrical signal from the electrode at the outer canthus of the right eye from the corresponding signal of the left side. Saccades were identified manually as a monotonic slope in either direction lasting at least 20 ms and with the slope of more than 1 $\mu$ V/ms. The first sampling point of these slopes was judged as the measurement of the latency of the saccade, identified by 2 ms temporal accuracy (cf. Csibra et al 1997). Saccadic reaction times were calculated by measuring the onset of the saccade towards the target with respect to the onset of the target stimulus. Trials with incorrect eye-movements (opposite to the target), eye-blinks, and movement artefacts accounted for less than 15% of trials for each participant (8.2% on average) and were excluded from further analysis. Also, correct saccades with latencies below 100 ms and above 350 ms were rejected as anticipatory eye movements or missed responses. These represented 2.9% of all trials on average.

## *2.2 Results and Discussion*

Overall median saccadic reaction times (see Table 1) were submitted into a 2 x 2 (contrast polarity x face orientation) repeated-measures ANOVA. The results showed that participants made faster saccades towards the upright normal contrast stimulus compared with the three other face-like patterns (significant contrast x orientation interaction:  $F(1, 17) = 7.425$ ,

$p = 0.014$ ). This was confirmed by pair-wise comparisons: saccadic latencies for upright normal contrast pattern were significantly shorter than for both inverted normal ( $t(17) = -2.556, p = 0.020$ ) and reversed contrast upright stimuli ( $t(17) = -2.836, p = 0.011$ ). Responses to upright and inverted patterns with reversed contrast polarity did not differ ( $t(17) = 0.766, p = 0.454$ ).

This result indicates that overt orienting towards upright face-like stimuli is faster than towards inverted ones, and that this effect depends on the contrast polarity of the stimuli. However, the effect, while statistically significant, was small (about 5 ms advantage). Nevertheless, we noticed that the difference in saccadic reaction times across conditions became gradually smaller during the experiment (see Table 1). Thus, we analyzed our data further to see if the size of the effect is affected by practice.

When we split the data between the first and the second half of the experiment, we found that the significant differences in latencies for the normal polarity upright compared to the other three face-like patterns were driven predominantly by responses in the first half (first two blocks) of the experiment. Separate two-way ANOVAs for each experimental half yielded a highly significant interaction in the first part ( $F(1,17) = 14.475, p = 0.001$ ), but not in the second part of Experiment 1 ( $F(1,17) = 1.575, p = 0.226$ ). This pattern of results indicates that the preferential orienting response to the upright stimulus with normal contrast polarity was gradually diminishing throughout the task. The fact that 15 out of 18 participants showed faster response to the upright than to the inverted normal contrast polarity pattern in the first half of the study ( $p = 0.013$  by two-tailed sign-test), but only 12 of them did so in the whole experiment ( $p = 0.332$ ) also suggests a transient effect that tends to disappear with practice.

Thus, although we found evidence for the preferential response in Experiment 1, the within-subject design did not allow an optimal measurement of the different factors that influence saccade latency gain, since not enough trials per condition could be executed by the time the preference started to decline.



### 3 Experiment 2

In order to accurately estimate the size of the response gain in terms of saccadic latencies, we carried out Experiment 2 in a between-subject design. Two groups of participants performed the same task as in Experiment 1, but received either only normal contrast (Experiment 2A) or reversed contrast polarity (Experiment 2B) stimuli. For an additional group (Experiment 2C), we introduced a stimulus with reversed contrast polarity, but with normal contrast properties restored in the eye region only (smaller black squares – ‘pupils’ – inserted into the larger white blobs, see Figure 1C). This stimulus has been shown to elicit preferential orienting response in newborns (Farroni et al 2005), consistent with the hypothesis that normal contrast information in the eye region alone can drive the preferential orienting towards upright face-like pattern, even in the absence of face-relevant contrast in the entire stimulus. We predicted that participants should show faster reactions to upright stimuli in Experiment 2A and 2C, but not in Experiment 2B.

#### 3.1 Method

*3.1.1 Participants.* Forty healthy participants (16 males and 24 females) were recruited, resulting in three independent samples of twelve participants (8 females, average age of 26.5 years in Experiment 2A, 7 females, average age of 25.3 years in Experiment 2B, and 7 females, average age of 27.2 years in Experiment 2C). Four participants were excluded due to excessive movement artefacts ( $n = 3$ ) or technical error ( $n = 1$ ). There were no significant differences across the three samples with respect to mean age ( $F(2,33) = 0.393, p = 0.678$ ). All participants were right-handed and had normal or corrected to normal vision.

*3.1.2 Stimuli and procedure.* The same computer setup, experimental paradigm and trial structure were used as in Experiment 1. An identical experimental protocol and design were applied across the three Experiments 2A, 2B and 2C with the only difference lying in the contrast properties of the stimuli (see below).

In Experiment 2 each trial began with a central fixation point followed by an upright or an inverted face-like pattern (at equal probability) flashed peripherally for 200 ms on the left or right side (with 50% chance) of the screen in random order. All the schematic face stimuli were of the same shape, size and position on the screen as in Experiment 1. Face-typical contrast upright and inverted stimuli were used in Experiment 2A and consisted of 3 black square blobs imposed on a bright grey oval (20% black). In Experiment 2B upright and inverted face-like stimuli with reversed contrast polarity were used (white square blobs on 80% black oval). In Experiment 2C, the participants were presented with reversed contrast polarity patterns with additional smaller dark blobs (80% black, subtending  $0.4^\circ \times 0.4^\circ$  visual angle, 0.49 cm x 0.49 cm) inserted inside the larger white squares. Inverted schematic faces were obtained by rotating the upright stimulus by  $180^\circ$ .

For the practice block, 10 trials were executed with a black-and-white square checkerboard instead of face-like patterns. The participants received two blocks of 30 experimental trials with a short break (less than 1 min) between the blocks. The participants' task on each trial was to make a speeded saccade to the target stimulus as soon as it appeared on the screen.

*3.1.3 EOG data acquisition and analysis.* The same apparatus, electrooculogram procedure and saccade identification protocol were used as in the previous experiment. Trials with incorrect eye-movements (opposite to the target), eye-blinks and movement artefacts accounted for less than 14% of trials for each participant (6% on average) and were excluded from further analysis. Also, correct responses with latencies below 100 ms (anticipatory saccades) or above 350 ms were rejected and represented less than 4.3% of the total trial number.

### *3.2 Results and Discussion*

In Experiment 2A, we recorded significantly shorter median reaction times for upright

than for inverted schematic faces ( $t(11) = 4.133, p = 0.002$ ; see Figure 1A). In addition, 11 of the 12 participants ( $p = 0.006$  by sign-test) displayed this effect. To our knowledge, this replication of the key result of Experiment 1 provides the first demonstration that human adults, and not just newborns, are sensitive to the minimal sensory difference between the upright and inverted stimulus with face-relevant contrast.

In Experiment 2B we found no significant difference in saccadic reaction times for upright and inverted stimuli ( $t(11) = 0.663, p = 0.521$ ; Figure 1B), with only half of the participants producing faster saccades to upright than to inverted patterns ( $p = 1.0$  by sign-test). This result confirms that the reversal of contrast polarity abolishes the effect of preferential orienting towards an upright face-like pattern.

In Experiment 2C, participants had shorter saccadic reaction times in response to upright than inverted stimuli ( $t(11) = 2.969, p = 0.013$ ; see Figure 1C), and 11 out of 12 participants displayed this effect ( $p = 0.006$  by sign-test). This result confirms that the presence of gaze-relevant contrast information only in the eye region of a face-like pattern facilitates overt orienting towards upright face-like stimuli.

When we directly contrasted saccadic latencies across the three experiments (2A, 2B and 2C) in a 3 x 2 (experiment x schematic face orientation) ANOVA, we found a significant interaction of experimental condition with stimulus orientation ( $F(2, 33) = 24.296, p < 0.001$ ). This confirmed that contrast polarity of the face and the eye region did modulate the difference in the latency of eye movements towards upright and inverted schematic faces.

#### **4 General Discussion**

We demonstrated in two experiments that adult humans orient their gaze faster toward upright face-like patterns compared with identical but inverted stimuli only when they contain a specific face- and gaze-relevant contrast polarity. One may suggest that such an effect could be accounted for by the higher luminance of normal contrast polarity patterns, because the low

luminance might have prevented the visual system from detecting the face-like structure of the patterns appearing in the periphery. However, the fact that faster orienting to upright than inverted patterns was also evident when only the eye region contained gaze-relevant contrast (Experiment 2C), i.e., in a stimulus which had lower luminance than the reversed contrast polarity pattern (compare Figures 1B and 1C), argues against this explanation. Note also that our results are not compatible with the 'top-heavy bias' hypothesis (Macchi Cassia et al 2004), according to which the preference to face-like patterns are driven by a non-specific preference to stimuli that have more elements in the top than in the bottom part. Despite having more elements in the upper half, the upright reversed contrast polarity stimulus, lacking the contrast properties of a human face, did not facilitate orienting, which the top-heavy bias hypothesis cannot account for.

Both face inversion and contrast polarity reversal have been previously shown to impair the recognition of individual faces. This effect is most likely due to the disruption of configural processing of the arrangement of internal elements in a face (Yin 1969). Similar effects have also been reported in neuroimaging studies (George et al 1999; Kanwisher et al 1998), suggesting that these stimulus manipulations might affect identity processing in the same way (Itier and Taylor 2002). Most importantly, face inversion and contrast reversal of face photographs were also found to impair face detection in a visual search paradigm (Langton et al 2008; Lewis and Edmonds 2003). Lewis and Edmonds (2005) found that detection of a target face in scrambled natural scenes was diminished more by luminance reversal than by inversion, possibly altering the nature of the visual search.

Recent research has also indicated the existence of attention bias to schematic faces, especially when they resemble negative facial expressions (Eastwood et al 2003; Fox et al 2001). It is important to note that these studies employed stimuli that represented faces in iconic or symbolic manner. In contrast, we provided evidence for sensitivity to the basic configuration of facial elements and face-related contrast information in highly degraded face-

like patterns. In fact, these two aspects of faces were the only characteristics of a human face that these stimuli represented. Our results suggest an interaction of contrast polarity and orientation information in the process of rapid detection of face-like patterns. In Experiment 1 we found significantly shorter saccadic latencies towards an upright pattern with normal contrast polarity than towards either inverted or reversed polarity patterns. Similarly, in Experiment 2 the preferential orienting to the upright over inverted pattern was dependent on the presence of face- or gaze-relevant contrast information (Experiments 2A and 2C). In the absence of such contrast information no preference was found (Experiment 2B).

The small magnitude and the short life of the effect imposed strong constraints on the design of our experiments. The between-subjects design of Experiment 2 allowed a more reliable measurement of the orienting effect than the within-subject design of Experiment 1, but simultaneously prevented from directly comparing saccadic responses to upright stimuli differing in contrast polarity. Also, the relatively low task difficulty may have resulted in a ceiling effect, possibly obscuring in Experiment 2 the difference in response latencies to upright normal and reversed polarity patterns found in Experiment 1. Thus, further studies are necessary to address the question of the contribution of contrast polarity information to the face inversion effect, either directly comparing the stimuli differing in their polarity in a within-subjects design, or introducing a more difficult task (e.g. manipulating presentation time or introducing masking), in which such differences could be revealed.

Our results with adults remarkably closely resemble the pattern of preferential orienting previously shown in newborns (Farroni et al 2005). The bias for orienting to face-like patterns was suggested to be based on the activity of subcortical structures (including superior colliculus) that mediate rapid and reflexive orienting of gaze to peripheral visual targets (Johnson et al 1991; Morton and Johnson 1991; Simion et al 1998). Retinal input to the superior colliculus, and direct projections to pulvinar and amygdala, provide a possible explanatory framework for a range of phenomena demonstrated by the developing social brain

(Johnson 2005). This evolutionarily old visual pathway, encompassing midbrain retinotectal projections, was suggested to mediate rapid detection of biologically relevant stimuli across several groups of vertebrates (Sewards and Sewards 2002). To date, the activity of this retinotectal pathway has been shown to mediate processing of threat-related social stimuli even in the absence of visual awareness due to the damage of primary visual areas in the brain cortex of blindsight patients (de Gelder et al 1999; Morris et al 1999). Our current findings suggest that the sensitivity of this putative mechanism to face- and gaze-relevant contrast remains present later in life. Note that our data did not provide direct evidence for the neural bases of the face bias. Further research will be required to determine whether the effect we found is critically dependent on the putative ‘quick and dirty’ subcortical visual pathway hypothesized to underlie the rapid detection and orienting of attention to important social stimuli (de Gelder 2006; Vuilleumier 2005).

What is the functional significance of such face- and gaze-sensitive biases embedded in primitive orienting mechanisms? In Experiment 1 we directly compared saccadic latencies to upright and inverted stimuli with either normal or reversed contrast polarity, predicting that a mechanism biasing to orient towards faces should be sensitive to both the orientation and the contrast polarity of elements in face-like patterns. If such a mechanism is responsive to face-relevant contrast polarity and basic configuration of elements, it should promote faster detection of relevant stimuli and enable filtering out the stimuli with irrelevant contrast information or configuration of elements. The results of Experiment 1 confirmed this prediction, with fastest responses recorded to the upright stimulus, but only with normal contrast polarity. Such a response bias could facilitate the orienting towards conspecifics in natural environments, allowing faster reactions to socially relevant signals.

In addition, the results of Experiment 2C suggest that, for newborn and adult humans alike, detecting the gaze of others is functionally so important that perceptual and motor biases facilitate rapid and preferential foveation of face-like stimuli that potentially include

information relevant to the detection of human eyes and gaze. Whether the same neural mechanisms support this bias in newborns and adults will be the subject of future research. However, at both ages the fast orienting towards a face with eyes is likely to facilitate the establishment of eye contact, which, in contrast to non-human primates where it signals threat (Emery 2000), is the most important social communicative signal in humans (Csibra and Gergely 2006; Kleinke 1986).

Our data provides a new context for the research on the uniqueness of faces for the human perceptual system and their ability to capture attention. This attentional bias seems to be active not only for natural images of faces but also for highly degraded stimuli that retain only the basic configuration of elements and contrast information relevant to the presence of eyes. Together with previous data from newborns (Farroni et al 2005) and non-human primates (Kuwahata et al 2004), our results indicate the importance of studying attention biases to faces in both developmental and evolutionary context, thus adding a new perspective to the research on processes underlying human face expertise.

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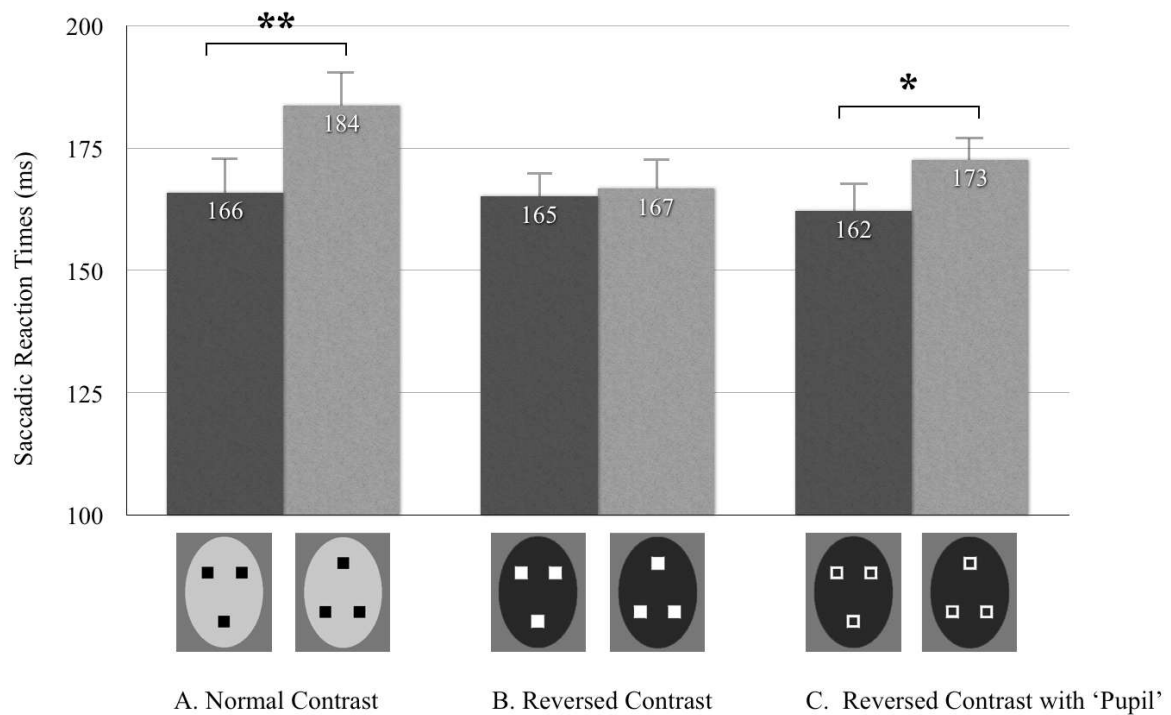
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**Table 1.** Median saccadic reaction times (ms) averaged across participants as a function of stimulus conditions in Experiment 1 (SEM in brackets).

Condition	Overall	First Half	Second Half
Normal Contrast			
<i>Upright</i>	160.67	162.89	161.67
	(5.12)	(6.06)	(5.45)
<i>Inverted</i>	165.78	169.61	165.56
	(5.72)	(5.90)	(5.68)
Reversed Contrast			
<i>Upright</i>	166.33	169.39	165.22
	(5.80)	(6.06)	(5.93)
<i>Inverted</i>	164.56	166.33	164.22
	(5.29)	(5.59)	(6.40)

Figure



**Figure 1.** Saccadic reaction times in Experiment 2. (A) Experiment 2A – normal contrast polarity, (B) Experiment 2B – reversed contrast polarity, (C) Experiment 2C – reversed contrast polarity with ‘pupils’ inserted into the ‘eyes’. Significant differences are indicated by asterisks (\*\*,  $p = .002$ ; \*,  $p = .013$ ). Error bars represent standard error of mean.