Faces in commonly experienced configurations enter awareness faster due to their curvature relative to fixation

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ABSTRACT

The extent to which perceptually suppressed face stimuli are still processed has been extensively studied using the continuous flash suppression paradigm (CFS). Studies that rely on breaking CFS (b-CFS), in which the time it takes for an initially suppressed stimulus to become detectable is measured, have provided evidence for relatively complex processing of invisible face stimuli. In contrast, adaptation and neuroimaging studies have shown that perceptually suppressed faces are only processed for a limited set of features, such as its general shape. In this study, we asked whether perceptually suppressed face stimuli presented in their commonly experienced configuration would break suppression faster than when presented in an uncommonly experienced configuration. This study was motivated by a recent neuroimaging study showing that commonly experienced face configurations are more strongly represented in the fusiform face area. Our findings revealed that faces presented in commonly experienced configurations indeed broke suppression faster, yet this effect did not interact with face inversion suggesting that, in a b-CFS context, perceptually suppressed faces are potentially not processed by specialized face recognition mechanisms. Rather, our pattern of results is consistent with an interpretation based on processing of elementary visual properties such as convexity.

INTRODUCTION

The extent to which invisible stimuli are still processed has become a popular line of research over the last decades (Dehaene & Changeux, 2011; Hesselmann & Moors, 2015). One particularly compelling paradigm to render visual stimuli invisible is continuous flash suppression (CFS) (Tsuchiya & Koch, 2005). In CFS, a salient dynamic pattern composed of various colored shapes is presented to one eye while another stimulus is presented to the other eye. Due to the dynamic nature of the mask, the other stimulus is perceptually suppressed and invisible to observers for a time period in the order of seconds. CFS has been implemented in various ways to study processing of perceptually suppressed stimuli, one being the breaking CFS paradigm (b-CFS) (Stein, Hebart & Sterzer, 2011; Gayet, Van Der Stigchel & Paffen, 2014). Here, the contrast of the initially suppressed stimulus is gradually increased until it causes a perceptual breakthrough (i.e., becomes detectable to the observer). The breakthrough or suppression time is then used as an index of the strength of the representation of that visual stimulus during suppression. That is, as in regular binocular rivalry, stimulus strength is predicted to influence suppression durations such that stronger stimulus representations break CFS faster than weaker stimuli (Jiang, Costello & He, 2007; Stein, Hebart & Sterzer, 2011).

A number of studies have considered the degree to which face stimuli are still processed while perceptually suppressed and have used the b-CFS paradigm, amongst others, to tackle this question. A now-classic study by Jiang, Costello and He (2007) showed that upright face stimuli broke suppression faster than inverted face stimuli resembling the well-known face inversion effect for consciously presented stimuli. Following this study, several b-CFS studies have replicated this face inversion effect (Zhou et al., 2010; Stein, Hebart & Sterzer, 2011; Stein, Peelen & Sterzer, 2011; Stein & Sterzer, 2012; Stein, Sterzer & Peelen, 2012; Gobbini et al., 2013a,b; Heyman & Moors, 2014; Stein, End & Sterzer, 2014). Other studies have furthermore indicated that stimulus-related factors such as eye gaze (Stein et al., 2011; Xu, Zhang & Geng, 2011; Chen & Yeh, 2012; Gobbini et al., 2013b), facial expression (Yang, Zald & Blake, 2007; Sterzer et al., 2011; Stein & Sterzer, 2012; Capitão et al., 2014), face identity (Geng et al., 2012; Gobbini et al., 2013a), or face race (Stein, End & Sterzer, 2014) can influence suppression times. Taken together, these findings seem to suggest that, while perceptually suppressed, the representation of a face stimulus is a fairly integrated one involving the analysis of several complex features.

In apparent contrast with these b-CFS findings, a more complicated pattern of results has arisen from studies that rely on adaptation to invisible face stimuli or study the representation of invisible face stimuli using neuroimaging techniques. For example, adaptation studies have indicated that visual awareness of a face is required for adaptation to complex features such as facial expression (Yang, Hong & Blake, 2010), face race or gender (Amihai, Deouell & Bentin, 2011), face identity (Moradi, Koch &

Shimojo, 2005), face shape (Stein & Sterzer, 2011), or eye gaze (Stein, Peelen & Sterzer, 2012). The main conclusion of these studies is that adaptation effects for invisible stimuli are sometimes observed, but they are largely specific to the adapted eye and size of the stimulus. For example, Stein and Sterzer (2011) observed face shape aftereffects for fully invisible stimuli, yet these aftereffects were only observed if the test stimulus had the same size as the adaptor and was also presented to the same eye as the adaptor. This suggests that the adaptation occurred at a low level of processing, and was specific to simple features such as its exact size and shape. Similarly, neuroimaging studies have shown that neural responses to invisible face stimuli are strongly reduced in the fusiform face area (Jiang & He, 2006; Sterzer et al., 2014), although the pattern of activation still enables the successful decoding of certain stimulus distinctions (Sterzer, Haynes & Rees, 2008; Sterzer, Jalkanen & Rees, 2009).

Taken together, behavioral studies relying on adaptation and neuroimaging studies call into question whether the results obtained using the b-CFS paradigm are genuinely attributable to high-level processing of the invisible face. Rather, they suggest that the representation of the perceptually suppressed face is limited to simpler features such as its general shape. Therefore, in this study, we were interested to further study the representation of a perceptually suppressed face in a b-CFS context, capitalizing on the findings of a recent neuroimaging study. That is, Chan et al. (2010) recently showed that representations of body parts and faces were strongest in the extrastriate body area and fusiform face area, respectively, when they were presented in their commonly experienced configuration (e.g., the left side of a face presented in the right visual field). This result is intriguing since all conditions simply involved presenting the same stimulus (e.g., right or left side of a face) to a different side of the visual field. Thus, if stimulus strength influences suppression time, we would predict that perceptually suppressed face stimuli presented in their commonly experienced configuration would break suppression faster compared to those presented in the other part of the visual field. Moreover, given that the effect for the face stimuli seems to be specific to the fusiform face area, the presence of such an effect in a b-CFS setup could be indicative of the extent to which invisible face stimuli are processed during suppression. To this end, we also included a face inversion condition. That is, if a congruency effect is observed, this inversion condition will enable us to test whether this effect is dependent on specialized processing for upright faces.

METHODS

Participants

43 people participated in the experiment. All participants had normal or corrected-to-normal vision and were naïve with respect to the purposes of the study. The study was approved by the local ethics committee of the faculty (the Social and Societal Ethics Committee of the KU Leuven (SMEC)

under the approval number G-2014 08 033). All participants provided written informed consent before the start of the experiment.

Apparatus

Stimuli were shown on two 19.8-in. Sony Trinitron GDM F500-R (2048 x 1536 pixels at 60 Hz, for each) monitors driven by a DELL Precision T3400 computer with an Intel Core Quad CPU Q9300 2.5 GHz processor running on Windows XP. Binocular presentation was achieved by a custom made stereo set-up. Two CRT monitors, which stood opposite to each other (distance of 220 cm), projected to the left and right eye respectively via two mirrors placed at a distance of 110 cm from the screen. A head- and chin rest (15 cm from the mirrors) was used to stabilize fixation. The effective viewing distance was 125 cm. Stimulus presentation, timing and keyboard responses were controlled with custom software programmed in Python using the PsychoPy library (Peirce, 2007, 2009).

Stimuli

The background of the display consisted of a random checkerboard pattern to achieve stable binocular fusion. The size of the individual elements of the checkerboard was equal to 0.34°. In both eyes, a black frame (10° by 10°) was superimposed on the checkerboard pattern, onto which the stimuli would be presented. A black (eye dominance measurement) or white (main experiment) fixation cross was continuously present during the experiment (size 0.5 by 0.5°). In the eye dominance measurement phase, the target consisted of an arrow (maximal width 4°, maximal height 2°) and the CFS mask consisted of 150 squares with a randomly picked sizes between 1 and 2° and a random luminance value.

The stimuli used in the main experiment were a subset of the stimuli used in Chan et al. (2010) (see Figure 1A). That is, we only used the face configurations of their stimulus set, which consisted of four different half-face exemplars (size 3° of visual angle). For the specific details of the stimulus generation procedure, we refer to the original study. In the main experiment, the CFS mask (6° x 6°) consisted of 200 grayscale squares with a random size between 0.75° and 1.5°. In all parts of the experiments, the CFS mask refreshed its contents every 100 ms (i.e., at 10Hz).

Procedure

In the first part of the experiment, observers performed an eye dominance task according to the procedure outlined by Yang, Blake and McDonald (2010). That is, on each trial, the CFS mask was presented to one of the observer's eyes and an arrow stimulus to the other eye. The arrow stimulus gradually increased from 0% to 100% contrast over a period of 2 seconds after which it remained present at full contrast. Upon breakthrough of the arrow stimulus, participants had to indicate as quickly as possible whether the arrow was pointing to the left or right. Participants performed this task for 80 trials in total (40 trials per eye). The dominant eye was determined by taking the eye for which the mean suppression was the lowest. In all subsequent phases of the experiment, the CFS mask was always presented to the dominant eye.

In the main part of the experiment each trial consisted of a 1 second fixation phase after which the CFS mask was presented to the dominant eye and the face stimulus to the non-dominant eye (Figure 1B). The face stimulus gradually increased from 0% to 100% contrast in a period of 1 second after which it remained on screen at full contrast until the participants' response. Upon breakthrough, participants had to indicate as quickly as possible whether the face stimulus was presented to the left or right of fixation by means of a button press. Prior to the start of the main experiment, participants first completed a practice block to become acquainted with the task.

Design

The experiment consisted of a 2 x 2 x 2 full-factorial within-subjects design. Each stimulus (left or right side of a face) was presented in the left or right visual field in an upright or inverted fashion. Participants completed a total of 96 trials. The practice block consisted of 8 trials.

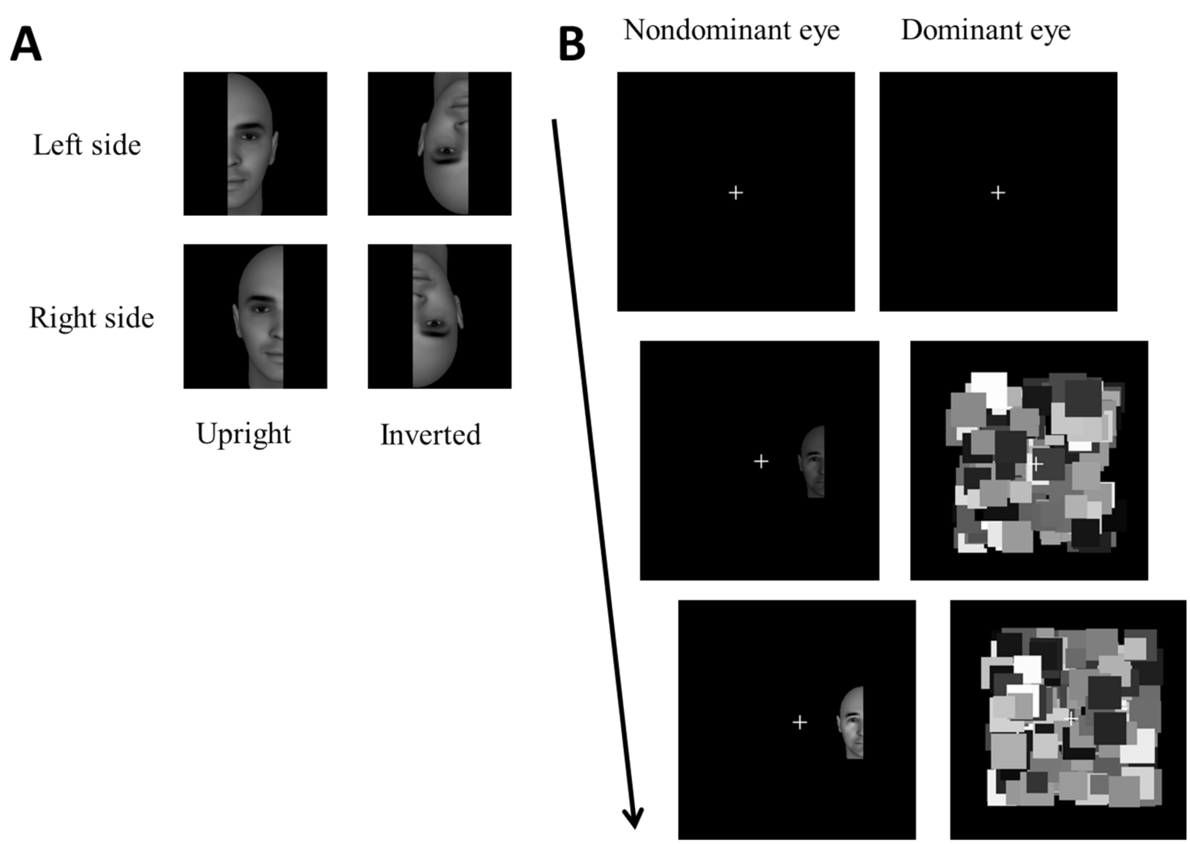

Figure 1. Stimuli and procedure. (A) Four different configurations for one face exemplar. Each configuration was presented either to the left or right side of the fixation cross. Presenting the top left stimulus to the right side of fixation would constitute an upright, congruent stimulus. (B) Trial sequence used in the experiment. Each trial started with a fixation period of 1 second after which the face stimulus was presented to the non-dominant eye and the CFS mask to the dominant eye. The face stimulus gradually increased in contrast and remained present at 100% contrast until the participants' response.

RESULTS

All analyses were performed in R, a statistical programming language (R Core Team, 2014). All statistical analyses were performed in a Bayesian framework, relying on model selection through Bayes Factors (Rouder et al., 2009, 2012). The Bayes Factor can be interpreted as a relative measure of evidence for one statistical model compared to another (e.g., a model with two main effects versus a model with two main effects and their interaction). All Bayes Factors were computed using the R package BayesFactor (Morey & Rouder, 2015) using all default settings. The statistical models for which Bayes Factors were computed are akin to classical repeated measures ANOVA models, yet including random intercepts for both subjects as well as stimulus (given that we used different face exemplars in our experiment; also knows as a crossed random effects model (Clark, 1973; Baayen, Davidson & Bates, 2008)). Following the classification proposed by Jeffreys (1961), Bayes Factors > 3 are considered to be convincing evidence for one model compared to another.

Before subjecting the data to any analysis, suppression times were first log transformed to account for their positive skew. Only correct responses were considered. Outliers were defined as suppression times that deviated more than three standard deviations from the mean suppression time (for each observer separately) and these were also excluded from the analysis. This led to a removal of 5.5% of the data. To facilitate the interpretation of the data, we converted the factors visual field and stimulus side to a single variable termed congruency. A congruent stimulus would be one that constitutes a commonly experienced configuration (e.g., right side of the face in the left visual field). For inverted stimuli, we applied the same transformation such that congruent stimuli would be the ones for which the overall configuration would be the same (e.g., an inverted left side of the face would now have to be presented in the left side of the visual field to be coded congruent). The mean suppression times for all combinations of congruency and face inversion are depicted in Figure 2. As is apparent, inverted faces yielded slower suppression times than upright faces (the well-known face inversion effect). Furthermore, face stimuli presented in commonly experienced configurations broke suppression faster than the incongruent ones, yet this main effect did not interact with stimulus inversion. This was confirmed by the Bayes Factor analysis (Table 1). That is, a model with both main effects of congruency and inversion was the best fitting model and all Bayes Factors were > 3 for this model compared to all the other models considered.

Table 1. Bayes Factor analysis.

Model	Bayes Factor
Congruency + Inversion	1
Inversion	3.6
Congruency * Inversion	5.2
All other models	> 100

Note. All Bayes Factors can be interpreted relative to the best fitting model (for which the Bayes Factor equals 1). A * denotes both main effects and the interaction between the conditions.

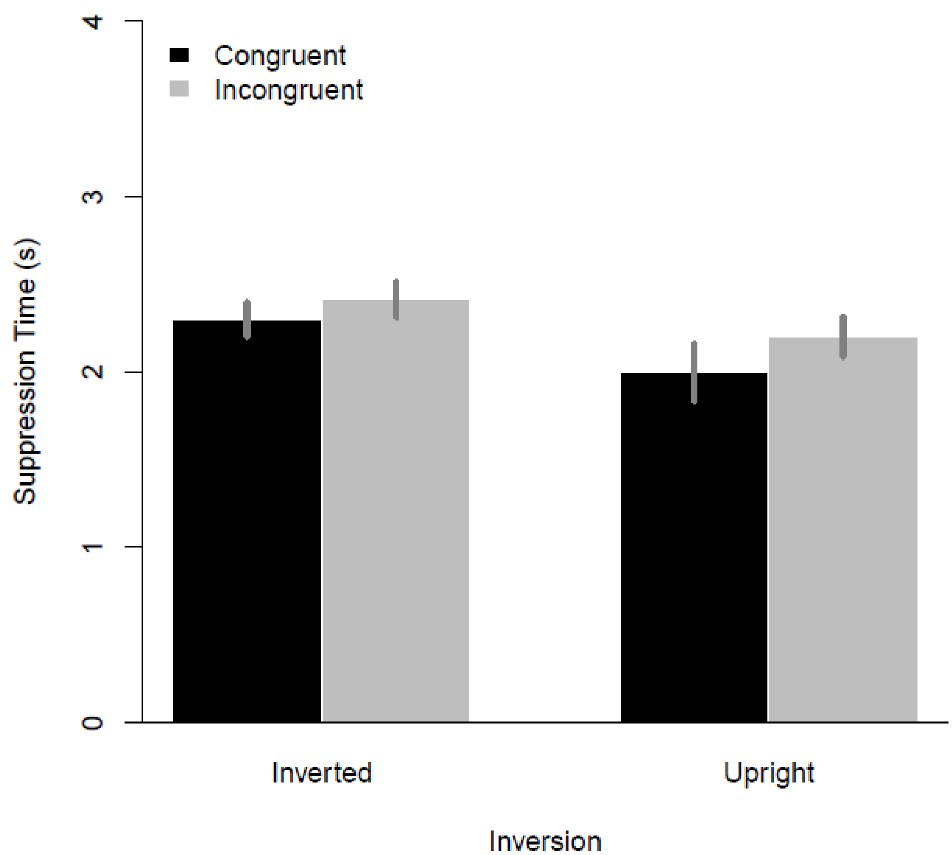

Figure 2. Mean suppression times for all conditions. Error bars denote 95% within-subject confidence intervals as described by (Morey, 2008).

DISCUSSION AND CONCLUSION

The goal of this study was to assess whether face stimuli presented in their commonly experienced configurations would break suppression faster than the same stimuli presented in other configurations. Our results indicated that this indeed was the case, yet that the effect was not specific for upright face stimuli. That is, similar configurations broke suppression faster when they were presented inverted rather than upright. This result implies that shape differences relative to fixation were responsible for the observed congruency effect rather than processing mechanisms specific for upright faces.

This study was motivated by the fact that a lot of b-CFS studies on face processing obtained evidence for relatively complex processing of invisible faces during CFS. In contrast, studies relying on adaptation or neuroimaging techniques consistently showed that processing of invisible faces is severely reduced compared to visible faces and is possibly only specific to the general face shape rather than the identity, facial expression, or other face features. Therefore, we decided to capitalize on the findings of a neuroimaging study in which it was shown that the pattern of responses in the fusiform face area was strongest for face stimuli presented in their commonly experienced configuration. If stimuli with a strong representation indeed break suppression faster, one would predict the same difference to be observed in a b-CFS setup. Moreover, given the specificity of the effect to the fusiform face area, we also predicted that the effect should be absent or at least greatly reduced for inverted faces. As highlighted above, our results indicated both an effect of the configuration as well as inversion but no interaction between those factors. This indicates that the differences in suppression time between conditions are more likely attributable to shape-specific differences between conditions rather than explanations based on genuine face processing.

One particularly important difference between the stimuli presented in both types of configurations is the curvature of the face shape relative to fixation. That is, in congruent configurations, the curved contour is convex relative to fixation compared to being concave in the incongruent configurations. Several behavioral studies have shown that convex features are often perceptually dominant in for example determining figure-ground relationships or shape similarity (Kanizsa & Gerbino, 1976; Bertamini & Wagemans, 2013). Moreover, neurophysiological recordings have shown a similar bias towards convex features in macaque area V4 (Pasupathy & Connor, 1999). Last, a recent fMRI study has shown that cortical area LOC shows higher sensitivity for convex rather than concave shapes (Haushofer et al., 2008). In the light of these studies, our findings can be interpreted as reflecting the heightened sensitivity of the visual system to convex features (relative to fixation).

This interpretation is in accord with a larger set of studies that has questioned evidence of high-level processing of stimuli suppressed through CFS. For example, Hedger, Adams and Garner (2015a) recently showed that the advantage of fearful faces breaking suppression faster than neutral ones is predicted by effective contrast of the stimuli. Furthermore, another recent study by the same group observed that attentional orienting due to threat stimuli is completely absent when threatening stimuli were rendered completely invisible (Hedger, Adams & Garner, 2015b). Other studies have cast doubt on whether invisible words can be processed (Heyman & Moors, 2014), numerosity can be extracted during suppression (Liu et al., 2013; Hesselmann et al., 2014; Hesselmann & Knops, 2014), or integration between a suppressed visual looming stimulus and a supraliminal auditory stimulus can occur (Moors et al., 2015).

In sum, the results of this study provide evidence that stimuli that are more strongly represented in the visual cortex break suppression faster than other stimuli. However, the fact that the observed congruency effect was not specific for upright face stimuli indicates that the face stimuli used in this study were presumably not processed by specialized face recognition mechanisms, but rather at a more basic level limited to more elementary properties such as convexity.

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