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The role of holistic processing in face perception: Evidence from the face inversion effect

Jessica Taubert *, Deborah Apthorp, David Aagten-Murphy, David Alais

School of Psychology, The University of Sydney, Sydney, New South Wales 2006, Australia

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ABSTRACT

A large body of research supports the hypothesis that the human visual system does not process a face as a collection of separable facial features but as an integrated perceptual whole. One common assumption is that we quickly build holistic representations to extract useful second-order information provided by the variation between the faces of different individuals. An alternative account suggests holistic processing is a fast, early grouping process that first serves to distinguish faces from other competing objects. From this perspective, holistic processing is a quick initial response to the first-order information present in every face. To test this hypothesis we developed a novel paradigm for measuring the face inversion effect, a standard marker of holistic face processing, that measures the minimum exposure time required to discriminate between two stimuli. These new data demonstrate that holistic processing operates on whole upright faces, regardless of whether subjects are required to extract first- or second-level information. In light of this, we argue that holistic processing is a general mechanism that may occur at an earlier stage of face perception than individual discrimination to support the rapid detection of face stimuli in everyday visual scenes.

1. Introduction

In one of the processes thought to contribute to human face perception, the human visual system integrates facial features into a gestalt whole (referred to as holistic face processing). This claim has received support from several sources. In behavioral studies, a number of experimental paradigms have been widely used to provide evidence for holistic processing; two examples include the composite effect and the part-whole effect. In composite effect tasks, subjects are usually required to decide whether two identical top halves are the same (Goffaux & Rossion, 2006; Le Grand, Mondloch, Maurer, & Brent, 2004; McKone, 2008). The empirical evidence suggests this is more difficult when the two top halves are paired with different bottom halves, indicating that perception of the identity of features in one half of a face is changed by a whole-face context. The part-whole effect describes the difficulty subjects have recognizing familiar faces from isolated features (Davidoff & Donnelly, 1990; Donnelly & Davidoff, 1999; Tanaka & Farah, 1993; Tanaka & Sengco, 1997). Both the composite effect and the part-whole effect suggest that features seen in a whole-face context are integrated, rather than being represented and processed independently from one another. These behavioral observations converge with neurophysiological data from single-cell (Freiwald, Tsao, & Livingston, 2009; Tsao, Freiwald, Tootell, & Livingstone, 2006) and event-related potential (Jacques, d'Arripe, & Rossion, 2007) studies to support the idea that faces are processed holistically (Farah, Wilson, Drain, & Tanaka, 1998; McKone, Kanwisher, & Duchaine, 2007). Although there have been many demonstrations of holistic processing acting on judgments of face identity, there have been few attempts to understand whether holistic-processing effects generalize to earlier analyses of faces. Here we examine holistic face processing using the face inversion effect (FIE; Yin, 1969), and find evidence that this processing may also underpin face detection.

Human faces are hierarchical visual stimuli in the sense that they convey at least two levels of information. The most basic attributes that are repeated in every face (i.e., two eyes, above a nose, above a mouth) provide "first-order information" and this can be used to distinguish faces from other visual objects (face detection). We know that infants track face-like patterns for longer periods of time than non-face patterns (Farroni et al., 2005; Goren, Sarty, & Wu, 1975; Johnson, Dziurawiec, Ellis, & Morton, 1991; Valenza, Simion, Cassia, & Umiltà, 1996) and that adults look at faces first and for longer periods of time than other complex objects (Crouzet, Kirchner, & Thorpe, 2010), but our ability to detect faces in our visual environment remains poorly understood (for a review see Tsao & Livingstone, 2008). Because all faces share the same first-order configuration, the identification of an individual face requires information about the ways that one face differs from any other.

* Corresponding author. Current address: Yerkes Primate Research Center, Emory University, Atlanta, Georgia 30329, USA.

E-mail address: jtauber@emory.edu (J. Taubert).

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“Second-order information” refers to the variance that exists between faces, such as the distance between the eyes (Diamond & Carey, 1986; Freire, Lee, & Symons, 2000). Our expert ability to discriminate between faces, therefore, reflects a high sensitivity to second-order information.

In their 2002 review, Maurer et al. concluded that there were three stages of processing associated with face recognition:

(1) face detection (based on first-order information),
(2) holistic processing (the integration of facial features following detection), and finally,
(3) face discrimination (based on second-order information extracted from the holistic representation).

We agree there is evidence that second-order sensitivity is a consequence of holistic processing (for more recent reviews see Rossion, 2008, 2009), but question whether there is support for the assertion that we detect faces before holistic processing takes place. Our aim in this paper was to address the role of holistic processing in face detection.

Certainly holistic processing can be decoupled from sensitivity to second-order information. Studies examining familiarity have routinely found that the processes underlying individual discrimination are very different for familiar and unfamiliar faces (Bruce et al., 1999; Burton, Jenkins, Hancock, & White, 2005; Megreya & Burton, 2006; Van Belle, Ramon, Lefévre, & Rossion, 2010). Familiar face discrimination can tolerate changes in viewpoint and expression that dramatically alter the retinal image, whereas unfamiliar face discrimination cannot (for a review see Hancock, Bruce, & Burton, 2000). By contrast, holistic processing (as indexed by the inversion and composite effects) has been shown to operate on both familiar (Carey, Diamond, & Woods, 1980; Young, Hellawell, & Hay, 1987) and unfamiliar faces (Diamond & Carey, 1986; Le Grand et al., 2004; Yin, 1969), regardless of viewpoint (McKone, 2008) or expression (Calder, Young, Keane, & Dean, 2000). The same dissociation between discrimination performance and holistic processing is clear from studies of contrast-reversed faces. Contrast-reversal does not disrupt holistic processing (Hole, George, & Dunsmore, 1999) but impairs the ability to discriminate between two faces that differ in their spacing among features (Kemp, McManus, & Piggot, 1990). These and other findings are inconsistent with the conventional view that holistic processing is the mechanism that underpins accuracy in all face discrimination tasks (e.g. Konar, Bennett, & Sekuler, 2010; Taubert, 2009; Zhao & Hayward, 2010).

In a recent review, Tsao and Livingstone (2008) emphasized the importance of face detection and suggested that holistic processing may operate at an automatic face-detection stage that precedes individual discrimination. The current paper tests the hypothesis that holistic processing acts on detection judgments using the FIE – a well established decrement in face discrimination performance that has been associated with a loss of holistic processing (Busey & Vanderkolk, 2005; Diamond & Carey, 1986; Robbins & McKone, 2007; Yin, 1969). When faces are turned upside down, sensitivity to global second-order cues, specifically the spaces between features, is reduced (Bartlett & Searcy, 1993; Collishaw & Hole, 2000; Freire et al., 2000; Rhodes, Brake, & Atkinson, 1993; Rossion & Boremanse, 2008; Van Belle, De Graef, Verfaillie, Rossion, & Lefévre, 2010). This results in poor discrimination between individual faces in inverted trials compared to upright trials. It is widely accepted by most researchers that the FIE reflects the inability to perceive inverted faces holistically (Farah, Tanaka, & Drain, 1995; Rossion, 2008, 2009; Sergent, 1984). Thus, if holistic processing were important for extracting first-order information in the first instance, then inversion should also impair face detection (the discrimination of faces from non-face objects).

Previous studies that have examined the role of inversion on face detection tasks have employed Mooney faces – luminance thresholded photographs of faces that, despite increased ambiguity, are perceived as whole faces rather than collections of unrelated blobs (Mooney, 1957). It is clear from the literature that Mooney faces are harder to perceive when inverted than when presented upright (George, Jemel, Fiori, & Renault, 1997; Kanwisher, Tong, & Nakayama, 1998; Latinus & Taylor, 2005; McKone, 2004). This implies that holistic processing acts on face detection; however, Mooney faces are impossible to discriminate at the individual level and thus previous studies of Mooney faces have not been able to compare face detection with individual face discrimination. A compelling demonstration that holistic processing facilitates face detection would need to compare performance on two tasks; one where discrimination was based on first-order information and one where discrimination was based on second-order information because it is the size of the FIE that is attributed to holistic processing (Rossion, 2008, 2009; also see McKone & Yovel, 2009; Robbins & McKone, 2007). By carefully matching stimuli and procedures as much as possible, we have optimized the comparison across tasks to strengthen our conclusions.

Historically, the FIE has been measured using performance (accuracy and/or the time taken to respond correctly). In this study we avoided correct response time because face detection is an inherently easier task than face discrimination and could produce spurious reaction time differences. Instead, we describe a novel procedure for measuring the FIE where the outcome variable is the minimum presentation time (i.e., the number of video frames) that a subject requires to accurately discriminate between two stimuli. Based on the previous observations of the FIE, and the assumption that inversion decreases processing speed, we expected that the discrimination threshold would be increased when upright stimuli were turned upside down. In Experiment One, subjects completed two tasks (with order counterbalanced). In one task, subjects needed to use first-order information to discriminate a face from a scrambled face (the detection task). In the other, subjects needed to use second-order information to discriminate a face from another face (the discrimination task). The difference we claim exists between these detection and discrimination tasks, however, depends on the assumption that scrambled faces are not registered by the visual system as faces. Because the effects of face inversion are large relative to those associated with non-face objects (Robbins & McKone, 2007; Rossion, 2008, 2009), Experiment Two was run to demonstrate a reduced inversion effect when subjects were asked discriminate between two scrambled faces.

2. Methods

2.1. Subjects

Ten Caucasian adult humans (three male) were tested in Experiment One. Nine adults (four male) served as subjects for a control experiment, hereby referred to as Experiment Two. Five of the subjects who participated in Experiment One also participated in Experiment Two. All subjects had normal or corrected-to-normal vision.

2.2. Visual stimuli

Stimuli were presented on a Dell Trinitron 17 in. CRT monitor with a pixel resolution of 1024×768 and a 100 Hz refresh rate, controlled by a Mac Pro 1.1 computer with a dual-core Intel Xeon processor. Stimuli were programmed in Matlab v.7.4 using the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997) and the

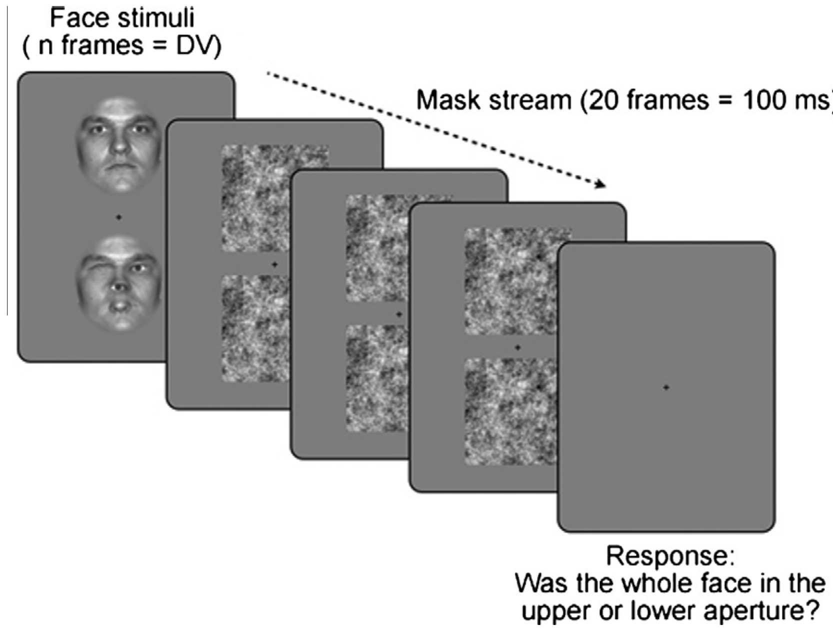

Fig. 1. A schematic diagram of the procedure for the face detection phase of Experiment One. Faces were displayed for a brief number of video frames (10 ms per frame), followed by a 200 ms noise mask composed of randomly-generated noise frames, filtered to contain a 1/*f* distribution of spatial frequency in the Fourier domain. The subject's task was to determine whether the whole face appeared above or below fixation, and their response drove a two-up, one-down staircase procedure so that the threshold duration (in units of 10-ms video frames) could be determined for doing the task. Whole faces were randomly selected from a set of twelve male face images, and scrambled faces were always matched to the whole face for feature location but were selected randomly from a set of nine possible feature-scrambled configurations.

luminance output of the monitor was linearised in software. The face displays were presented within elliptical cosine-ramped apertures with a width of 3.6° and height of 3.9° (see Fig. 1), and were viewed from a distance of 57 cm.

In this study we used twelve 128-pixel square (4°) greyscale face images (male, Caucasian). Scrambled images were created by removing 60×34 pixel patches centered on the eyes, mouth and bridge of the nose with a raised cosine function such that the subsequent replacement of the patches, in random order, resulted in a blended feature scramble. Scrambled faces used for the experiment were chosen such that all features were moved from their original spots and both left and right eyes never occurred in the top positions; these criteria were to ensure all scrambled stimuli were manipulated to the same extent. Face stimuli were standardised to have identical average luminance and root mean square contrast. The mask stream was constructed of a series of 192-pixel (6°) square patches of randomly-generated noise filtered with a 1/*f* frequency spectrum (see Fig. 1). These helped to ensure any transients from the onset of stimuli were also masked. Maximum and minimum luminances were 74.4 and 0.5 cd/m^2, and mean luminance was 37 cd/m^2. During the experiment, face stimuli were randomly offset from trial to trial by between 1 and 32 pixels from their original positions (centered 100 pixels above and below fixation) to avoid the effects of low-level retinotopic feature matching.

2.3. Procedure

The first experiment consisted of a distinct detection and discrimination phase. Both phases required the subject to maintain central fixation while attending to test space above and below the fixation cross, with subjects selecting the correct test space with a key press. In the detection task, each trial presented subjects with a whole and scrambled face from the same individual. These two stimuli were presented briefly in the upper and lower apertures (randomised with respect to position) and were followed immediately by the noise mask for 200 ms. Subjects were required to indicate the location of the whole face stimulus (upper or lower aperture). The number of video frames (each frame had a duration of 10 ms) that the test face was presented for was manipulated by a two-up, one-down adaptive staircase procedure (Levitt, 1971). For each trial, two randomly-interleaved staircases were run, and the mean of the last five turning points of each staircase provided the threshold for that condition. The discrimination phase proceeded similarly, with the exception of the presentation of a 'study face' stimulus for five seconds prior to the start of the each set of trials. After the inspection period, subjects pressed a key to begin each trial, after which the study face would appear in either the upper or lower aperture, and a distracter face in the other. Subjects were required to indicate in which test space the study face appeared. Study faces and distracters were chosen from separate sets, which were randomly determined for each subject from the original set of twelve faces. The procedure for Experiment Two was precisely the same as it was for the discrimination phase of Experiment One, except all the faces were scrambled instead of whole. To keep the discrimination task in Experiment Two as similar as possible to the discrimination task in Experiment One, the scrambled faces used in Experiment Two all had the same arrangement of features.

3. Results

3.1. Experiment One

The data are plotted in Fig. 2a and were analyzed using a two-factor repeated-measures ANOVA. There was no main effect of task, indicating that subjects needed as much time (number of video frames) to perform the detection task as they did to do the discrimination task ($F(1, 9) = 0.79$, $MSE = 3.31$, $p = 0.40$). The significant main effect of orientation demonstrates that subjects needed more time to do the inverted trials compared to upright trials ($F(1, 9) = 21.07$, $MSE = 2.89$, $p < 0.01$). Critically, the interaction

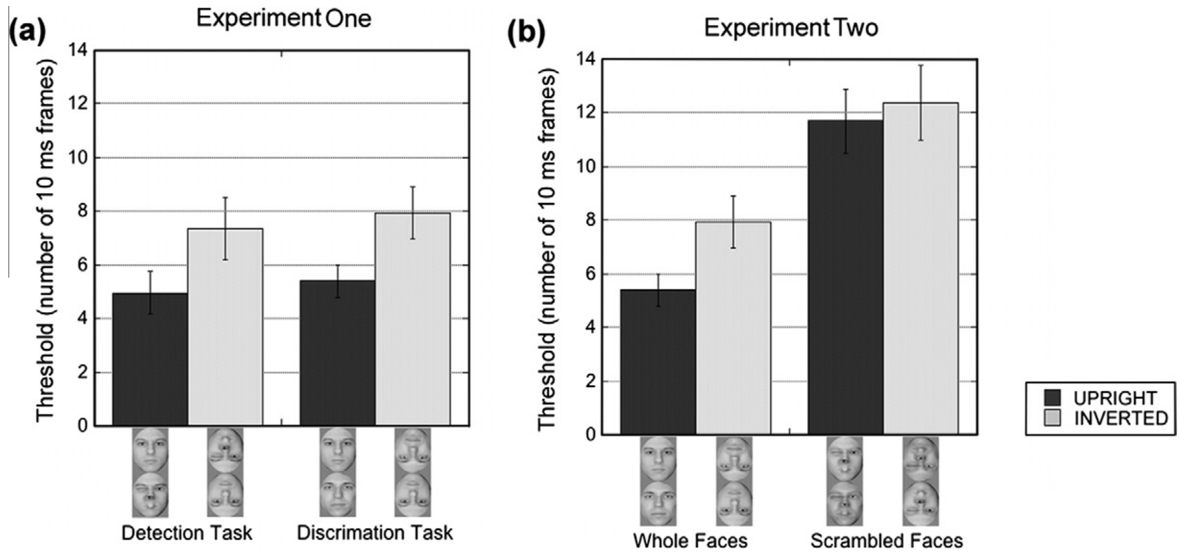

Fig. 2. Data from Experiments One and Two. (a) The plot shows group averages of the duration (in video frames: 10 ms per frame) required for threshold-level performance in the detection and discrimination tasks (errors represent ±1 *SEM*). (b) Performance in the discrimination task (Experiment One: whole faces) is presented next to the results of Experiment Two (scrambled faces) illustrating that the speed advantage for the upright orientation is not seen when discriminating scrambled faces (errors represent ±1 *SEM*).

between task and orientation was not significant, showing that inverted visual stimuli increased equivalently the length of time required to do the task in both the detection and discrimination conditions ($F(1, 9) = 0.05$, $MSE = 1.03$, $p = 0.84$). This conclusion was corroborated by two significant planned contrasts (using the Bonferroni correction) that discretely tested the effect of inversion on the detection ($M_{diff} = 2.40$; $t(9) = 3.85$, $p = 0.004$) and discrimination ($M_{diff} = 2.54$; $t(9) = 4.03$, $p = 0.003$) tasks (see Fig. 2a). Two other tests confirmed that when the stimuli were upright there was no difference between tasks ($M_{diff} = 0.44$; $t(9) = 0.67$, $p = 0.518$) and likewise when the stimuli inverted the discrimination threshold was the same for the detection and discrimination tasks ($M_{diff} = 0.58$; $t(9) = 0.89$, $p = 0.403$).

3.2. Experiment Two

A power analysis was performed to compute the required sample size for Experiment Two. Using the outcome of the discrimination task in Experiment One, the results of this analysis indicated that 8 degrees of freedom were necessary to find a significant advantage for upright, scrambled faces ($\alpha = 0.05$, $N = 9$).

The results of Experiment Two (Fig. 2b) confirm that the inversion effects reported in Experiment One are face-selective. The FIE associated with the discrimination of a target face from a distractor face reported in Experiment One was not replicated when the same subjects were later asked to discriminate scrambled faces at the individual level ($M_{diff} = 0.69$; $t(8) = 0.80$, $p = 0.45$). Effect size, calculated using Cohen's *d* for repeated factors, showed that the effect of inversion on discrimination measured in Experiment One (whole faces, $d = -2.17$) was bigger than in Experiment Two (scrambled faces, $d = -0.38$).

4. Discussion

Subjects needed to view the visual display for a longer period of time to discriminate between two inverted whole faces compared to two upright whole faces. The direction of this difference is consistent with the FIE, a widely accepted marker of holistic processing (see Rossion 2008, 2009). Further confirmation that our results reflect holistic processing is the magnitude of the effect for whole faces compared to scrambled stimuli, illustrated by the results of Experiment Two. Effectively we are reporting a FIE measured in presentation time rather than identification accuracy. Experiment Two also confirms that subjects did not respond to our scrambled faces as if they were faces. This finding contributes to the existing literature in two important ways. First, it provides a new method for testing the FIE which will be useful in future experiments where floor or ceiling performance might mask an otherwise meaningful difference between upright and inverted trials. Second, and more importantly, evidence of reduced time required to discriminate two upright faces compared to two inverted faces strongly suggests that one of key benefit of building holistic representations is processing speed.

The primary aim of this paper, however, was to test whether holistic processing operates at an early face-detection stage. Our data are consistent with this claim and the conclusions of previous studies of Mooney faces (George et al., 1997; Kanwisher et al., 1998; Latinus & Taylor, 2005; McKone, 2004), clearly showing an advantage for upright stimuli over inverted stimuli in the face detection task. We recommend caution when interpreting this result as inversion effects can occur for any perceptual judgment (Valentine, 1988; Yin, 1969) but, in support of our study, we also point to the striking similarity in size of the two inversion effects found in Experiment One. Assuming the generally accepted view that the magnitude of the inversion effect is a marker of holistic processing (McKone & Yovel, 2009; McKone et al., 2007; Robbins & McKone, 2007; Rossion, 2009; Yin, 1969), this result implies that holistic representations are built at a stage when first-order information is being used to distinguish faces from other competing objects. We propose that holistic processing is a general mechanism that may occur at an early stage of face perception to distinguish faces from other competing objects. This position is consistent with a number of recent empirical findings that have suggested that the initial representation of a face is holistic (Jacques & Rossion, 2006; Rossion, 2009; Rossion, Dricot, Goebel, & Busigny, 2011).

We also report no effect of task on the outcome of Experiment One. In other words, there was no difference in the duration required to detect a face or to discriminate between two faces. In the detection task, subjects were presented with two faces that differed only in their arrangement of features and were asked to locate the whole face. In the discrimination task, subjects were first given a specific individual to locate and were then presented with two different whole faces. We argue that these are fundamentally different tasks, an opinion supported by the outcome of Experiment Two, which implies that scrambled faces are not processed as faces. Assuming the difference between the detection and discrimination tasks we have described, the null effect of task reported in Experiment One leaves some question as to whether these two processes (face detection and face discrimination) are independent and sequential as proposed by Tsao and Livingstone (2008; also see Bruce & Young, 1987; Dakin & Watts, 2009; Haxby, Hoffman, & Gobbini, 2000; Maurer, Le Grand, & Mondloch, 2002). We would argue in favor of independence because these are fundamentally different processes; face detection requires extracting what is common to all faces from a visual scene, whereas the identification of an individual requires an analysis of how one face differs from every other face. Given these demands, a face detector should not be able to accomplish face discrimination or individual recognition.

In related research, studies of monkey neurophysiology support the idea that detection precedes discrimination. Matsumoto, Okada, Sugase-Miyamoto, Yamane, and Kawano (2005) and Sugase et al. (1999) reported that the population response of neurons in IT represented information in faces at different categorical levels at different time periods. Faces were distinguished from other non-face objects in the 90–140 ms window, whereas individual discrimination took place later, in the 140–190 ms window. However, these results were based on recordings taken from 45 neurons distributed throughout the IT cortex. In 2006 Tsao et al. used functional magnetic resonance imaging (fMRI) to identify areas in monkey IT that were selectively activated by faces and then recorded the individual responses of neurons in these areas while the monkeys viewed face and non-face stimuli. This study also found that responses in IT could be differentiated across time, with responses to face stimuli occurring later. Thus there is empirical support for the idea that face detection precedes face discrimination although there is no evidence of the dissociation in this study. These current data indicate that after 50 ms sufficient information is available for the face processing system to perform accurate face detection or to discriminate between individual faces. The implication is that this paradigm may be insensitive to the difference in time frame between detecting and discriminating a face. Future research might consider measuring other outcome variables, such as reaction time, in order to more closely examine the timing of different object-processing stages.

Regardless of whether face processing is hierarchical or not, these results converge with other recent advances (Calder et al., 2000; Konar et al., 2010; Zhao & Hayward, 2010) to overturn the view that holistic processing takes place at the identity encoding stage, to extract second-order information from a face (for influential reviews see Maurer et al., 2002; McKone et al., 2007; McKone & Yovel, 2009; Rossion & Gauthier, 2002). Our data imply that holistic processing is a general mechanism that might be used to extract face-like first-order information from a scene. From this perspective, the holistic representation built when a face is detected would then also be available to facilitate the extraction of second-order information. For this reason, we expect that holistic processing would influence any task that requires a subject to detect a face, discriminate between two faces, or recognise a face.

Admittedly, these data alone cannot rule out the possibility that inversion acts on face detection and later impairs holistic processing (resulting in a decrease in our sensitivity to second-order information). However, we maintain that the simplest explanation for the data presented in this paper is that inversion impairs a single process, the integration of facial features, which reduces sensitivity to both first-order and second-order information. As a consequence our ability to detect a face among non-face objects, or discriminate between two faces, is compromised. Overall, these findings suggest that there is genuine theoretical progress to be made by re-evaluating the contribution that holistic processing makes to face perception.

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