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Inverted faces are (eventually) processed holistically

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ABSTRACT

Face inversion effects are used as evidence that faces are processed differently from objects. Nevertheless, there is debate about whether processing differences between upright and inverted faces are qualitative or quantitative. We present two experiments comparing holistic processing of upright and inverted faces within the composite task, which requires participants to match one half of a test face while ignoring irrelevant variation in the other half of the test face. Inversion reduced overall performance but led to the same qualitative pattern of results as observed for upright faces (Experiment 1). However, longer presentation times were required to observe holistic effects for inverted compared to upright faces (Experiment 2). These results suggest that both upright and inverted faces are processed holistically, but inversion reduces overall processing efficiency.

1. Introduction

Face recognition is a critical skill for survival: extracting information about identity is necessary for deciding whether an individual is a known ally or enemy. Face recognition presents a significant perceptual challenge because all faces contain very similar features in the same basic configuration. Thus, beyond the presence of specific features or the absolute location of these features, subtle differences in the spatial relations between features are thought to be necessary for face recognition (Diamond & Carey, 1986; Maurer, Le Grand, & Mondloch, 2002). Indeed, there are several demonstrations that face recognition is particularly sensitive to configural relations. For example, recognizing an individual face feature is better in the context of a whole face compared with viewing that feature in isolation (Tanaka & Farah, 1993), and recognizing an individual feature is impaired when the spatial relations between features in the test face differ from the study face (Tanaka & Sengco, 1997).

It has been argued that face inversion effects provide further evidence that face perception relies more strongly on configural information than perception of other objects. According to this view, inversion disproportionately impairs face perception relative to other objects (Yin, 1969) because inversion disrupts the perception of metric distances between features (e.g., interocular distance) more so than the perception of individual local features (e.g., Barton, Keenan, & Bass, 2001; Farah, Tanaka, & Drain, 1995; Rhodes, Brake, & Atkinson, 1993; Tanaka & Farah, 1993; but see Riesenhuber, Jarudi, Gilad, & Sinha, 2004; Yovel & Kanwisher, 2004).

Because face perception in particular relies on configural cues, face perception is more impaired by inversion than the perception of objects, which is assumed to rely more on processing of individual parts or features. A corollary of this explanation is the assumption that configural information is not used in the perception of inverted faces, which suggests that upright and inverted faces are processed in qualitatively different ways. More specifically, upright faces are believed to be processed holistically, a processing style that maximizes the ability to utilize configural information because individual features are processed together, whereas inverted faces may be processed more like objects, where individual parts are processed relatively independently (see Rossion (2008), for a review).

However, there is debate in the literature about how to interpret differences in performance between upright and inverted faces. In fact, this debate spans decades. For example, Valentine (1988) argued that the effect of inversion did not constitute evidence for a unique process involved in face recognition. It is indisputable that inversion influences performance on a variety of face perception tasks (see Maurer et al. (2002), Rossion (2008) and Rossion and Gauthier (2002), for reviews), but this does not necessarily mean that upright and inverted faces are processed qualitatively differently, only that there is an advantage for upright faces (e.g., Loftus, Obert, & Dillon, 2004; Riesenhuber et al., 2004; Valentine & Bruce, 1988). Supporting this alternative view, Sekuler and colleagues (2004) demonstrated that subjects use the same information with equivalent contributions of non-linear mechanisms to process upright and inverted faces, but that this information is used more efficiently when faces are presented upright. They conclude that inversion produces a quantitative change in

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performance but that perception of both upright and inverted faces depends on a holistic processing style (as shown by the non-linear contributions to performance). This stands in stark contrast to other studies showing that holistic processing is abolished or dramatically reduced for inverted faces (e.g., Goffaux & Rossion, 2006, 2007; Hole, 1994; Michel, Rossion, Han, Chung, & Caldara, 2006; Rossion & Boremanse, 2008).

In the most recent of these studies, Rossion and Boremanse (2008) had participants match top halves of sequentially presented composite faces, where the top half of one face was paired with the bottom half of another face (composite task; Hole, 1994; Young, Hellawell, & Hay, 1987). For upright faces, participants were more accurate to say that two face halves were the same when the face composite was misaligned (alignment effect). However, this effect was greatly reduced when faces were rotated past 60° (including 180°, corresponding to an inverted face; see also Goffaux & Rossion, 2006). Because of the non-linear relationship between the alignment effect and orientation, the authors concluded that inversion qualitatively changes how faces are processed.

However, there is a limitation to the interpretation of these results because the version of the composite task Rossion and Boremanse used, called the *partial design* (Gauthier & Bukach, 2007), has been shown to be susceptible to response biases that may have nothing to do with whether faces are processed holistically or not but nevertheless can have an impact on whether evidence for holism is observed (see Cheung, Richler, Palmeri, & Gauthier, 2008; Richler, Cheung, & Gauthier, submitted for publication). Specifically, in the partial design, holistic processing is inferred from an *alignment effect*, where participants are more accurate on "same" trials when faces are misaligned vs. aligned. However, because performance is measured in terms of accuracy, differences in response bias for aligned vs. misaligned trials can influence performance. Moreover, in the partial design, the irrelevant face half is always different. Thus, the possible influence of the relationship between the target and distractor parts is not taken into account.

In contrast, in the *complete design*, performance on all combinations of same and different target and irrelevant parts is considered and holistic processing is inferred from a *congruency effect*: performance is better on *congruent trials* (both parts same or both parts different) compared with *incongruent trials* (one part same, one part different; Cheung & Gauthier, 2010; Cheung et al., 2008; Farah, Wilson, Drain, & Tanaka, 1998; Gauthier, Curran, Curby, & Collins, 2003; Richler, Gauthier, Wenger, & Palmeri, 2008; Richler, Tanaka, Brown, & Gauthier, 2008; Richler, Mack, Gauthier, & Palmeri, 2009). In other words, the irrelevant, to-be-ignored part influences performance, revealing that participants cannot selectively attend to that part because faces are processed as wholes. Because interference measured by congruency effects can arise with non-face objects in novices under certain experimental conditions or task contexts (Richler, Bukach, & Gauthier, 2009; Wong & Gauthier, 2010), an alignment manipulation is often included, and the interaction between congruency and alignment is considered more diagnostic of expertise-driven holistic processing: the congruency effect decreases with misalignment, suggesting that when the meaningful face configuration is disrupted, holistic processing is disrupted as well (e.g., Cheung et al., 2008; Richler, Tanaka, et al., 2008). Importantly, performance in the complete design is measured in terms of sensitivity (d'), independent of response biases. Indeed, significant response biases reported in the composite task have been shown to influence the alignment effect measured using the partial design (Cheung et al., 2008; Richler et al., submitted for publication) but not holistic processing measured using the complete design (Cheung et al., 2008; Richler, Mack, et al., 2009; Richler et al., submitted for publication).

The goal of the following experiments is to explore whether processing of upright and inverted faces differs qualitatively (e.g., Rossion & Boremanse, 2008) or whether the effect of inversion is quantitative, perhaps because we have relatively more expertise recognizing upright faces (e.g., Sekuler et al., 2004). Experiment 1 compares performance in the complete design of the composite task for upright vs. inverted faces and shows that conclusions about holistic processing of inverted faces depend on the version of the composite task being used. Specifically, we find that inversion significantly influences response bias. Experiment 2 adds a presentation time manipulation to the composite task (see Richler, Mack, et al., 2009) to explore whether upright and inverted faces differ in the amount of processing time required to observe holistic effects.

2. Experiment 1

2.1. Methods

2.1.1. Participants

Fifty-four members of the Vanderbilt Community were paid for participation. Data were excluded if average performance in one of the two experimental blocks was below chance. Data from 13 participants were excluded according to this criterion.

2.1.2. Stimuli

Twenty female faces from the Max Planck Institute Database (Troje & Bulthoff, 1996) were converted to gray-scale and cut in half to produce 20 face tops and 20 face bottoms 256 × 128 pixels in size. Face halves were randomly combined on every trial. A white line 3 pixels thick separated face halves, resulting in faces that were 256 × 259 pixels. The white line was added to make it unambiguous where the top half ends and the bottom half begins, which, if anything, should facilitate selective attention to one half. Faces were cropped in an oval window inside a black rectangle (see Fig. 1) on a gray background to eliminate cues derived from the shape of the head or the chin. Misaligned faces were created by moving the top half of the face to the right by 35 pixels and the bottom half of the face to the left by 35 pixels, such that the edge of one face half fell in the center of the other face half. Inverted faces were made in the same manner except face tops and bottoms were flipped upside down. As in previous studies (Rossion & Boremanse, 2008; Sekuler et al., 2004), the same set of faces were used for upright and inverted faces.

2.1.3. Procedure

On each trial (see Fig. 1), a study composite was presented (800 ms), followed by a random pattern mask (500 ms). Then the test composite was presented with a square bracket cueing whether the target part was the top or bottom half of the test composite. Participants responded by keypress if the cued part of the test face was the same or different as the corresponding part of the study composite. The test face was presented until a response was made or for a maximum of 2500 ms. Timeouts were extremely rare and these trials were not included in the analyses. The study face was always aligned and the test face was either aligned or misaligned. Alignment was only manipulated at test because previous work has shown that alignment at study does not impact holistic processing of faces (Richler, Tanaka, et al., 2008).

There were 10 trials for each combination of cued part (top/bottom), correct response (same/different), congruency (congruent/incongruent), alignment (aligned/misaligned), and orientation (upright/inverted) for a total of 320 trials. Orientation was blocked and order was counterbalanced across participants. All other factors were randomized.

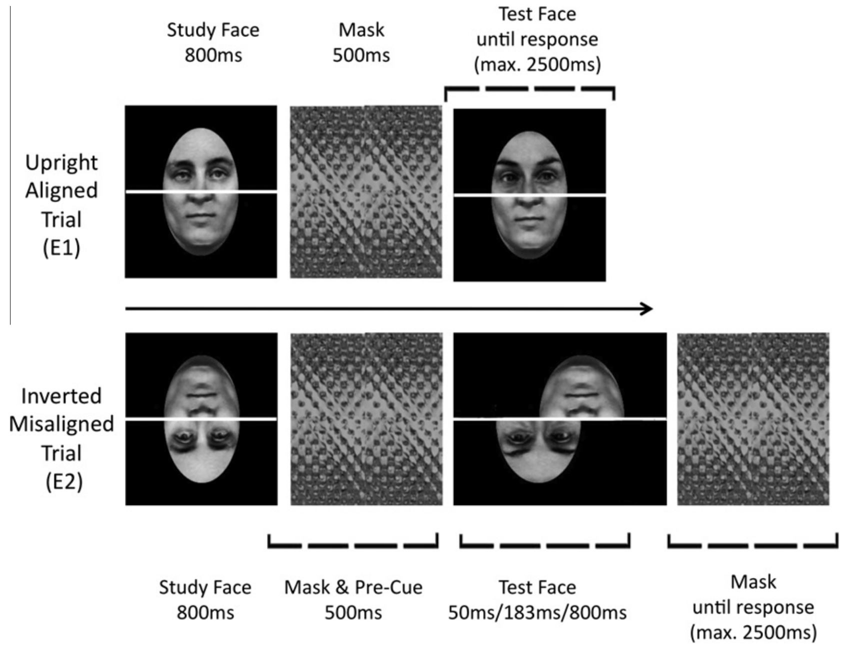

Fig. 1. Example of an upright aligned top trial from Experiment 1 (top) and an inverted misaligned bottom trial from Experiment 2 (bottom). The dashed square bracket cues whether participants will be making a response about the top or bottom half of the composite image. In Experiment 1 the cue appeared at the onset of the test face. In Experiment 2, the cue appeared 500 ms prior to the presentation of the test face and remained on the screen for the remainder of the trial.

2.2. Results

2.2.1. Complete design – sensitivity (d')

Sensitivity (d') for Experiment 1 is plotted in Fig. 2 (top panel). A $2 \times 2 \times 2$ repeated-measures ANOVA on sensitivity (d') with factors Orientation (upright/inverted), Alignment (aligned/misaligned), and Congruency (congruent/incongruent) revealed that performance was significantly better for upright vs. inverted faces ($F_{1,40} = 55.59$, $MSE = .381$, $p < .001$), and on congruent vs. incongruent trials ($F_{1,40} = 38.67$, $MSE = .590$, $p < .001$). There was also a significant Alignment × Congruency interaction ($F_{1,40} = 13.69$, $MSE = .330$, $p = .001$), such that the magnitude of the congruency effect decreased with misalignment. Critically, the three-way interaction between Orientation, Alignment and Congruency did not reach significance, indicating that the Alignment × Congruency interaction that indexes holistic processing did not differ between upright and inverted faces ($F_{1,40} = 1.90$, $MSE = .193$, $p > .1$, $\eta_p^2 = .045$). This was further supported by separate 2×2 ANOVAs for upright and inverted faces, which show that there was a significant Alignment × Congruency interaction for both upright ($F_{1,40} = 12.55$, $MSE = .297$, $p < .01$) and inverted ($F_{1,40} = 5.11$, $MSE = .226$, $p < .05$) faces.

2.2.2. Complete design – correct response times (RT)

Correct RTs for Experiment 1 are plotted in Fig. 2 (bottom panel). Due to a programming error, RT data were unavailable for two participants. A similar $2 \times 2 \times 2$ repeated-measures ANOVA on correct RTs revealed that correct RTs generally mirrored the d' data: performance was slower on misaligned vs. aligned trials ($F_{1,38} = 32.12$, $MSE = 5595.90$, $p < .001$), and on incongruent vs. congruent trials ($F_{1,38} = 8.88$, $MSE = 3629.42$, $p < .01$). There was a significant interaction between Alignment and Congruency ($F_{1,38} = 12.59$, $MSE = 2112.78$, $p = .001$), such that the difference in RT based on congruency decreased with misalignment. The interaction between Orientation and Congruency approached significance ($F_{1,38} = 3.65$, $MSE = 1979.81$, $p = .064$), with a trend toward a smaller congruency effect for inverted faces. Critically, there was no interaction between Orientation, Alignment and Congruency, such that the Alignment × Congruency interaction that indexes holistic processing did not differ between upright and inverted faces ($F_{1,38} = .013$, $MSE = 2787.58$, $p > .9$, $\eta_p^2 = .000$). This was further supported by separate 2×2 ANOVAs for upright and inverted faces, which show a significant Alignment × Congruency interaction for both upright ($F_{1,38} = 5.014$, $MSE = 2850.88$, $p < .05$) and inverted ($F_{1,38} = 6.03$, $MSE = 2049.47$, $p < .05$) faces.

2.2.3. Complete design – response bias (c)

Response bias (c) in Experiment 1 is plotted in Fig. 3. A similar ANOVA on response bias (c) revealed that participants were more likely to respond "different" on incongruent trials ($F_{1,40} = 18.55$, $MSE = .061$, $p < .001$). This main effect of Congruency was modulated by an interaction with Alignment ($F_{1,40} = 7.09$, $MSE = .048$, $p = .011$) and an interaction with Orientation ($F_{1,40} = 5.37$, $MSE = .050$, $p < .05$). As can be appreciated from Fig. 3, the bias to respond "different" on incongruent trials was greater on aligned vs. misaligned trials, and for upright vs. inverted faces.

2.2.4. Partial design – accuracy on "same" trials when the irrelevant part is different

We also analyzed the complete design data in the manner used in partial design experiments, including only incongruent trials where the correct response was "same" (i.e., target part same, irrelevant part different). Performance as measured in the partial design is plotted in Fig. 4. A 2×2 repeated-measures ANOVA on accuracy with factors Orientation (upright/inverted) and Alignment (aligned/misaligned) revealed a significant main effect of Alignment ($F_{1,40} = 4.11$, $MSE = 151.89$, $p < .05$). One-tailed[1] paired-samples t-tests revealed a significant alignment effect for upright faces ($t_{40} = 1.73$, $p < .05$) but not for inverted faces.

A similar ANOVA on correct RTs for partial design trials did not yield any significant effects.

[1] One-tailed tests were used because finding no significant effect or a significant effect in the opposite direction (better performance on aligned vs. misaligned trials) would both be interpreted as no evidence for holistic processing in the partial design.

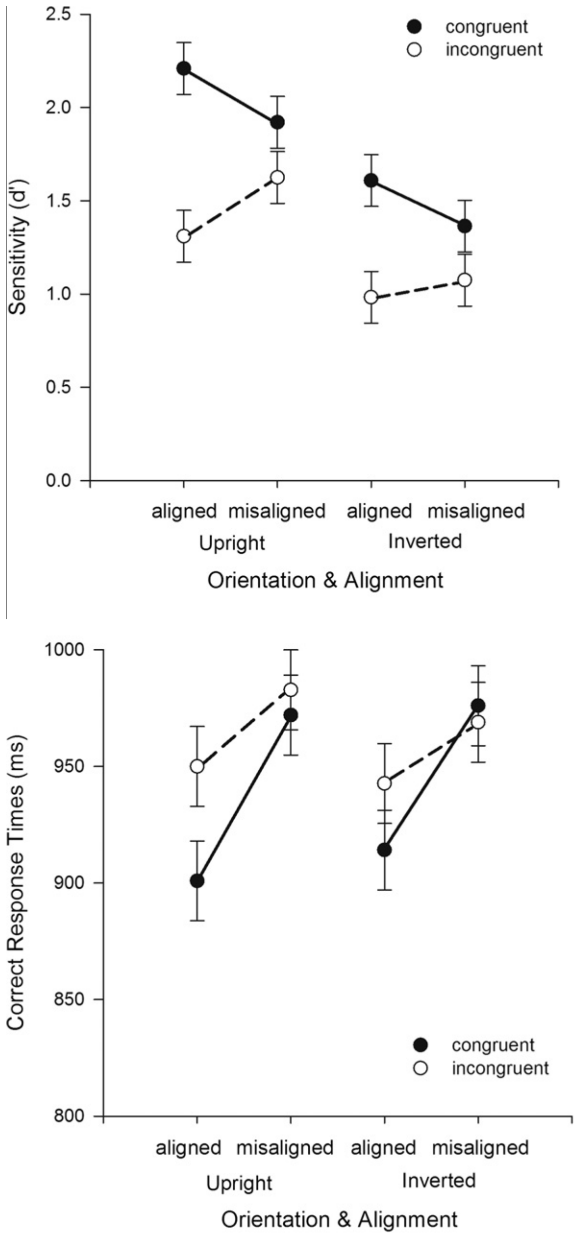

Fig. 2. Sensitivity (d'; top panel) and correct response times (ms; bottom panel) on congruent and incongruent trials as a function of alignment (aligned/misaligned) and orientation (upright/inverted) in Experiment 1. Error bars show 95% confidence intervals of the within-subjects effects.

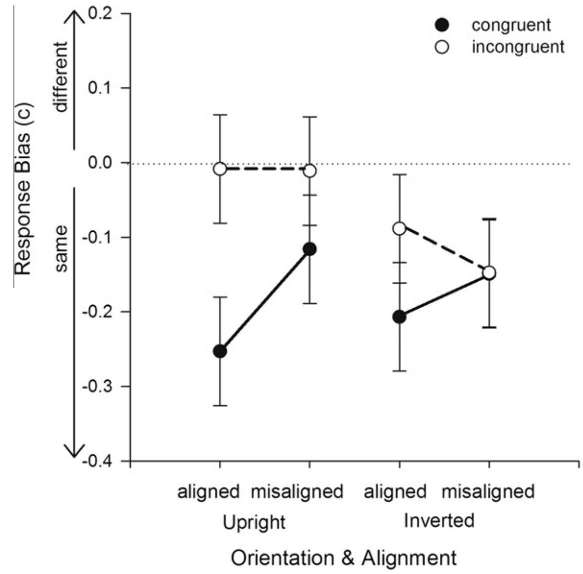

Fig. 3. Response bias (c) for congruent and incongruent trials as a function of alignment (aligned/misaligned) and orientation (upright/inverted) in Experiment 1. Positive values indicate a bias to respond "different" and negative values indicate a bias to respond "same". Error bars show 95% confidence intervals of the within-subjects effects.

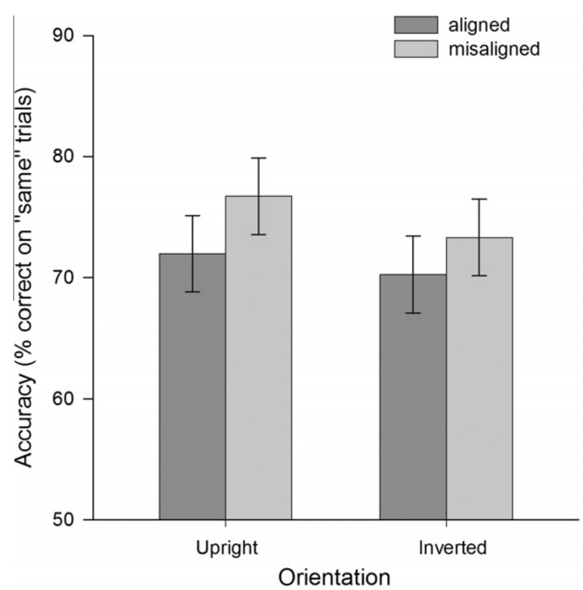

Fig. 4. Accuracy (percent correct) on "same" trials where the irrelevant part was different for aligned and misaligned trials as a function of orientation (upright/inverted) in Experiment 1. Error bars show 95% confidence intervals of the within-subjects effects.

2.3. Discussion

The results of Experiment 1 support a quantitative account of face inversion, not a qualitative difference: overall performance was worse for inverted vs. upright faces, but inverted faces still produced a congruency effect that was modulated by alignment, which is indicative of holistic processing (e.g., Cheung et al., 2008; Richler, Tanaka, et al., 2008). Importantly, the magnitude of this effect was equivalent for upright and inverted faces – the congruency by alignment interaction was not modulated by face orientation in either sensitivity or RT, and as can appreciated by the effect sizes, the effect of orientation on this interaction was negligible in both cases. These results are consistent with studies suggesting that inversion influences overall performance because processing becomes less efficient, but does not prevent or eliminate holistic processing (Sekuler et al., 2004; Valentine & Bruce, 1988).

Experiment 1 also provides yet another demonstration that conclusions about holistic processing are dramatically affected by the version of the composite task used. Analyses of a subset of the data based on the partial design trials yielded a very different conclusion than the complete design, namely that holistic processing is absent for inverted faces. But importantly, upright and inverted faces differed in terms of response biases when measured using the full set of data in the complete design. Although there is not yet a comprehensive account for why differences in response bias arise in the composite task, what is critical is that these biases lead to differences in performance in the partial design that are not driven by true differences in perceptual discriminability (Cheung et al., 2008; Richler et al., submitted for publication).

Although the relationship between response bias and the alignment effect is not straightforward or transparent, correlation analyses revealed that differences in response bias based on alignment, congruency and orientation predicted the difference in the magnitude of the alignment effect in accuracy between upright and inverted faces (r_{41} = .696, p < .001). In other words, differences in response bias significantly contributed to differences in the partial design measure of holistic processing between upright and inverted faces. In contrast, response bias did not predict differences in the congruency × alignment interaction based on orientation in the complete design (r_{41} = .226, p = .156).

3. Experiment 2

The results of Experiment 1 are consistent with the conclusions of Sekuler et al. (2004) and suggest that inverted faces are processed using the same cues and strategies as are used for upright faces (see also Willenbockel et al., 2010). However, to the extent that there is a difference between upright and inverted faces, our results suggest that this difference may arise from less efficient processing of inverted than upright faces. Previous work has shown that holistic processing of upright faces is observed for the most rapid presentation time (50 ms) that permits above chance performance (Richler, Mack, et al., 2009). One consequence of the relative inefficiency of processing inverted compared to upright faces may be that holistic effects require longer exposure durations with inversion because longer presentation times are required for performance to rise above chance. Indeed, when the task is to individuate whole faces, performance in a backward-masking paradigm suggests that information is available to recognize upright faces after only 30 ms encoding, while inverted faces require an additional 30 ms (Curby & Gauthier, 2009).

Experiment 2 tests whether effects of exposure duration differ between upright and inverted faces in a selective attention task. Novel objects (Greebles) were also included, because there are reasons to expect that limiting exposure duration could influence selective attention to parts of non-face objects, either because of global dominance effects (e.g., Kimchi, 1998) or because distractor parts need to be processed before they can produce interference (e.g., Lavie, 1995). By including novel objects, we can compare failures of selective attention due to expertise-driven holistic processing with failures of selective attention that might occur for any object class when presentation time is limited. In addition, previous work assessing the time course of holistic processing of faces (Richler, Mack, et al., 2009) did not include misaligned trials, so holistic processing was assessed by the congruency effect alone. Here we revisit how holistic processing of upright faces is influenced by manipulations of presentation time using a more reliable measure of holistic processing (congruency × alignment interaction).

3.1. Methods

3.1.1. Participants

Participants were 102 Vanderbilt undergraduates who were compensated with course credit. Thirty-three participants were assigned to the upright faces group, 36 participants were assigned to the inverted faces group, and 33 participants were assigned to the novel object group. Data from 23 participants were discarded for below chance performance (six from the upright faces group, nine from the novel object group, and eight from the inverted faces group).

3.1.2. Stimuli

Face stimuli were the same as those used in Experiment 1.

Stimuli for the object group were images of 20 asymmetrical computer-generated novel objects (Greebles), made up of 10 Greebles from two different families (the families are defined by common central shape). Asymmetrical Greebles (Rossion, Kung, & Tarr, 2004) were created by transforming all of an original group of symmetrical Greebles (Gauthier & Tarr, 1997) in the same manner to produce asymmetrical configurations of parts common to all objects. Greebles were converted to gray-scale and divided into top and bottom parts (256 × 128 pixels), which were randomly combined on every trial with the exception that tops and bottoms were always combined within the same family. A white line 3 pixels thick separated top and bottom halves resulting in Greeble composites that were 256 × 259 pixels. Misaligned Greebles were made by moving the top part of the Greeble 35 pixels to the right and the bottom half of the Greeble 35 pixels to the left so that the edge of the bottom half of the Greeble fell on the center of the top half.

3.1.3. Procedure

The trial sequence was identical regardless of whether composites were upright faces, inverted faces, or Greebles (see Fig. 1).

On each trial a study composite was presented (800 ms), followed by a random pattern mask (500 ms). A square bracket was presented simultaneously either above or below the mask cueing whether the target part would be the top or bottom half of the test composite. Unlike Experiment 1, the cue in Experiment 2 was presented prior to the presentation of the test composite. This change was designed to ensure that participants knew which part to attend to prior to the presentation of the test composite, which in some cases was only presented very briefly. The cue remained on the screen for the remainder of the trial. The test composite was presented at one of three presentation durations (50 ms, 183 ms, 800 ms) and was either aligned or misaligned. A second random pattern mask was presented following the exposure of the test composite, at which point participants were instructed to respond by key-press if the cued part of the test composite was the same or different as the corresponding part of the study composite.

There were 10 trials for each combination of cued part (top/bottom), correct response (same/different), congruency (congruent/incongruent), alignment (aligned/misaligned) and exposure duration (50 ms/183 ms/800 ms) for a total of 480 trials. Experimental trials were presented in a random order.

3.2. Results – sensitivity (d')

Sensitivity (d') for each stimulus group as a function of congruency and alignment at each exposure duration is plotted in Fig. 5. A 2 × 2 × 3 × 3 mixed-factors ANOVA was conducted with Congruency (congruent/incongruent), Alignment (aligned/misaligned), and Exposure Duration (50 ms/183 ms/800 ms) as within-subjects factors and Stimulus (upright faces/inverted faces/novel objects) as a between-subjects factor. There was a significant main effect of Congruency ($F_{1,76}$ = 106.56, MSE = .249, p < .001) that was modulated by significant interactions with Alignment ($F_{1,76}$ = 28.97, MSE = .184, p < .001) and Exposure Duration ($F_{2,152}$ = 7.84, MSE = .225, p < .001). There were also significant main effects of Alignment ($F_{1,76}$ = 10.75, MSE = .210, p < .01) and Exposure Duration ($F_{2,152}$ = 416.40, MSE = .298, p < .001). Critically, there was a main effect of Stimulus ($F_{2,76}$ = 12.60, MSE = 1.40, p < .001) and Stimulus interacted with Congruency ($F_{2,76}$ = 15.10, MSE = .249, p < .001). In addition, there were significant three-way interactions

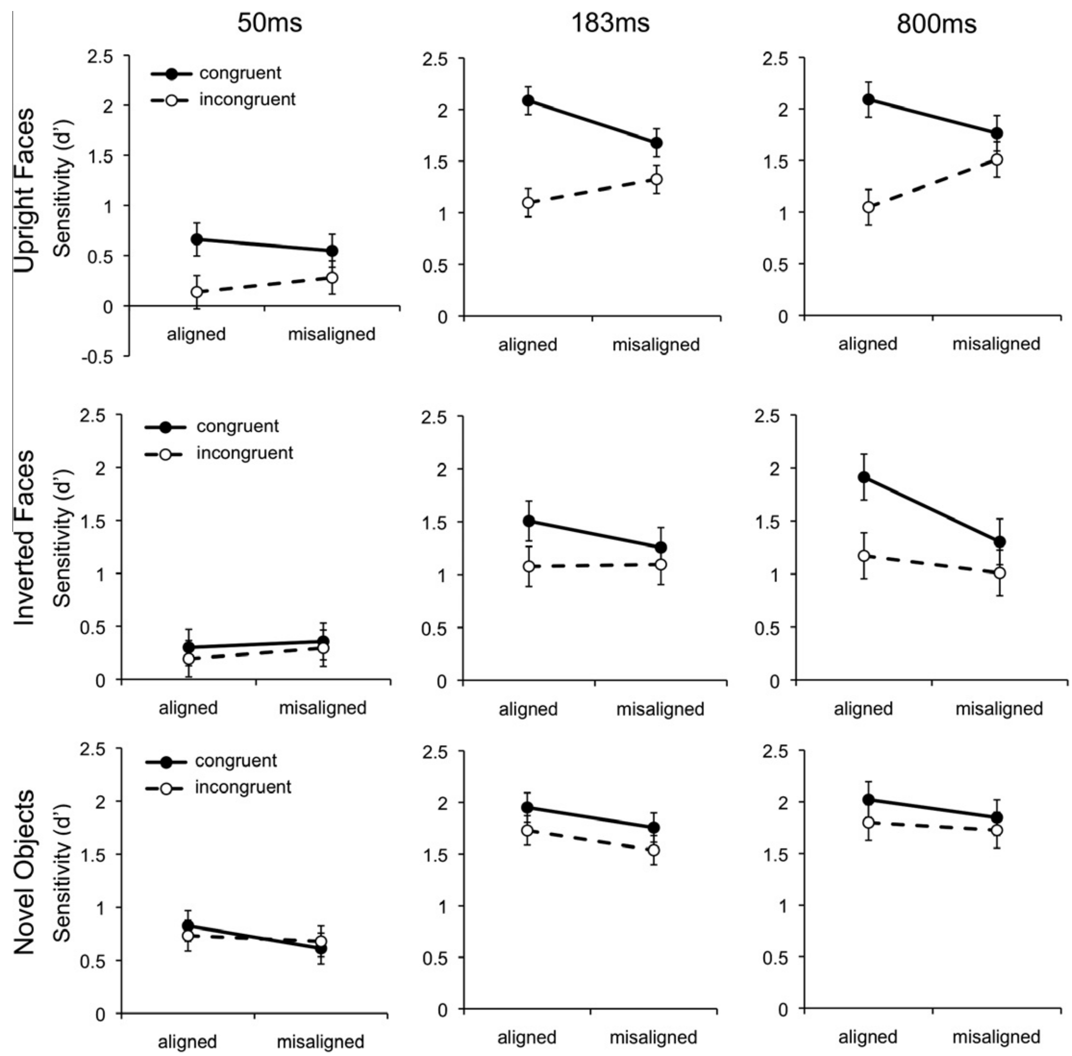

Fig. 5. Sensitivity (d') for congruent (black) and incongruent (white) trials as a function of alignment for upright faces (top row), inverted faces (middle row) and novel objects (bottom row) at each exposure duration in Experiment 2. Holistic processing is indexed by an interaction between congruency and alignment (congruency effect is larger on aligned vs. misaligned trials). Error bars show 95% confidence intervals of the congruency × alignment interaction.

between Congruency, Alignment and Stimulus ($F_{2,76}$ = 6.07, MSE = .184, p < .01) and between Alignment, Exposure Duration and Stimulus ($F_{4,152}$ = 3.35, MSE = .188, p = .012).

To better understand the nature of these effects, we conducted separate 2 × 2 × 3 repeated-measures ANOVAs (Congruency × Alignment × Exposure Duration) for each stimulus group. To evaluate holistic processing specifically, we also examined the congruency × alignment interaction at each exposure duration for each stimulus group.

3.2.1. Sensitivity (d') – upright faces

Overall performance improved with increasing exposure durations ($F_{2,52}$ = 193.46, MSE = .254, p < .001). Performance was better on congruent vs. incongruent trials ($F_{1,26}$ = 142.28, MSE = .186, p < .001), and the magnitude of the congruency effect was larger on aligned vs. misaligned trials ($F_{1,26}$ = 35.99, MSE = .177, p < .001). This Congruency × Alignment interaction was further modulated by an interaction with Exposure Duration ($F_{2,52}$ = 3.299, MSE = .152, p < .05).

Post-hoc tests for holistic processing at each exposure duration revealed a significant alignment × congruency interaction (decrease in congruency effect with misalignment) at exposure durations of 183 ms ($F_{1,26}$ = 23.06, MSE = .118, p < .0001, $\eta_p^2 =$ .470) and 800 ms ($F_{1,26}$ = 22.37, MSE = .188, p < .0001, $\eta_p^2 =$ .462) but not at 50 ms (p > .1, $\eta_p^2 =$ .090).

3.2.2. Sensitivity (d') – inverted faces

Overall performance increased with longer exposure durations ($F_{2,54}$ = 133.24, MSE = .285, p < .001). Performance was also better on congruent vs. incongruent trials ($F_{1,27}$ = 23.76, MSE = .316, p < .001) and aligned vs. misaligned trials ($F_{1,27}$ = 8.55, MSE = .195, p < .01). Critically, similar to upright faces, there was a significant congruency × alignment interaction such that the congruency effect decreased with misalignment ($F_{1,27}$ = 7.12, MSE = .189, p = .013).

There were also significant Exposure duration × Alignment ($F_{2,54}$ = 7.81, MSE = .195, p = .001) and Exposure duration × Congruency ($F_{2,54}$ = 6.11, MSE = .214, p < .01) interactions. As can be appreciated from Fig. 5 (middle row), there were no differences in performance based on congruency or alignment at 50 ms.

Post-hoc tests for holistic processing revealed a significant congruency × alignment interaction (decrease in congruency effect with misalignment) at 800 ms ($F_{1,27}$ = 4.52, MSE = .311, p < .05, $\eta_p^2 =$ .143) but not at 50 ms or 183 ms ($ps > .1, \eta_p^2 < .08$).

3.2.3. Sensitivity (d′) – novel objects

Overall performance increased with longer exposure durations ($F_{2,46}$ = 104.20, *MSE* = .364, *p* < .001). Performance was also better on aligned vs. misaligned trials ($F_{1,23}$ = 7.75, *MSE* = .209, *p* = .011) and congruent vs. incongruent trials ($F_{1,23}$ = 5.46, *MSE* = .241, *p* < .05). Although the interaction between Congruency and Exposure duration was not significant, examination of Fig. 5 (bottom row, first column) suggests that there was no effect of congruency at 50 ms, and this was confirmed in a post-hoc test ($F_{1,23}$ = .017, *MSE* = .218, *p* > .8).

Critically, unlike upright and inverted faces, the congruency × alignment interaction was not significant ($F_{1,23}$ = .743, *MSE* = .186, *p* > .3, $\eta_p^2 = .031$), nor was this interaction significant at any exposure duration ($ps > .2,\ \eta_p^2 < .05$).

3.3. Results – response bias (c)

Response bias (c) as a function of congruency and alignment for each stimulus group at each exposure duration is plotted in Fig. 6. A 2 × 2 × 3 × 3 mixed-factors ANOVAs was conducted with Congruency (congruent/incongruent), Alignment (aligned/misaligned) and Exposure Duration (50 ms/183 ms/800 ms) as within-subjects factors and Stimulus (upright faces/inverted faces/novel objects) as a between-subjects factor. There were significant main effects of Alignment ($F_{1,76}$ = 15.10, *MSE* = .321, *p* < .001) and Exposure Duration ($F_{2,152}$ = 58.26, *MSE* = .284, *p* < .001) and a significant Alignment × Exposure Duration interaction ($F_{2,152}$ = 7.15, *MSE* = .078, *p* = .001). This interaction was further modulated by a significant interaction with Stimulus ($F_{4,152}$ = 7.32, *MSE* = .078, *p* < .001). Stimulus also interacted with Congruency ($F_{1,76}$ = 6.77, *MSE* = .053, *p* < .01) and Exposure Duration ($F_{4,152}$ = 4.09, *MSE* = .284, *p* < .01) and there was a significant four-way interaction between all factors ($F_{4,152}$ = 2.57, *MSE* = .045, *p* < .05).

To better understand the nature of these effects, we conducted separate 2 × 2 × 3 repeated-measures ANOVAs (Congruency × Alignment × Exposure Duration) for each stimulus group.

3.3.1. Response bias (c) – upright faces

Participants were more likely to respond "same" on aligned vs. misaligned trials ($F_{1,26}$ = 6.14, *MSE* = .339, *p* < .05), congruent vs. incongruent trials ($F_{1,26}$ = 11.84, *MSE* = .066, *p* < .01) and at exposure durations of 50 ms ($F_{2,54}$ = 28.74, *MSE* = .280, *p* < .001).

There were also significant interactions between Exposure duration and Alignment ($F_{2,52}$ = 3.65, *MSE* = .078, *p* < .05) and Exposure Duration and Congruency ($F_{2,52}$ = 3.39, *MSE* = .044, *p* < .05). As can be appreciate from Fig. 6 (top row), these interactions reflect the fact that participants were more likely to respond "same" on aligned trials at 50 ms and 183 ms but not 800 ms, and were more

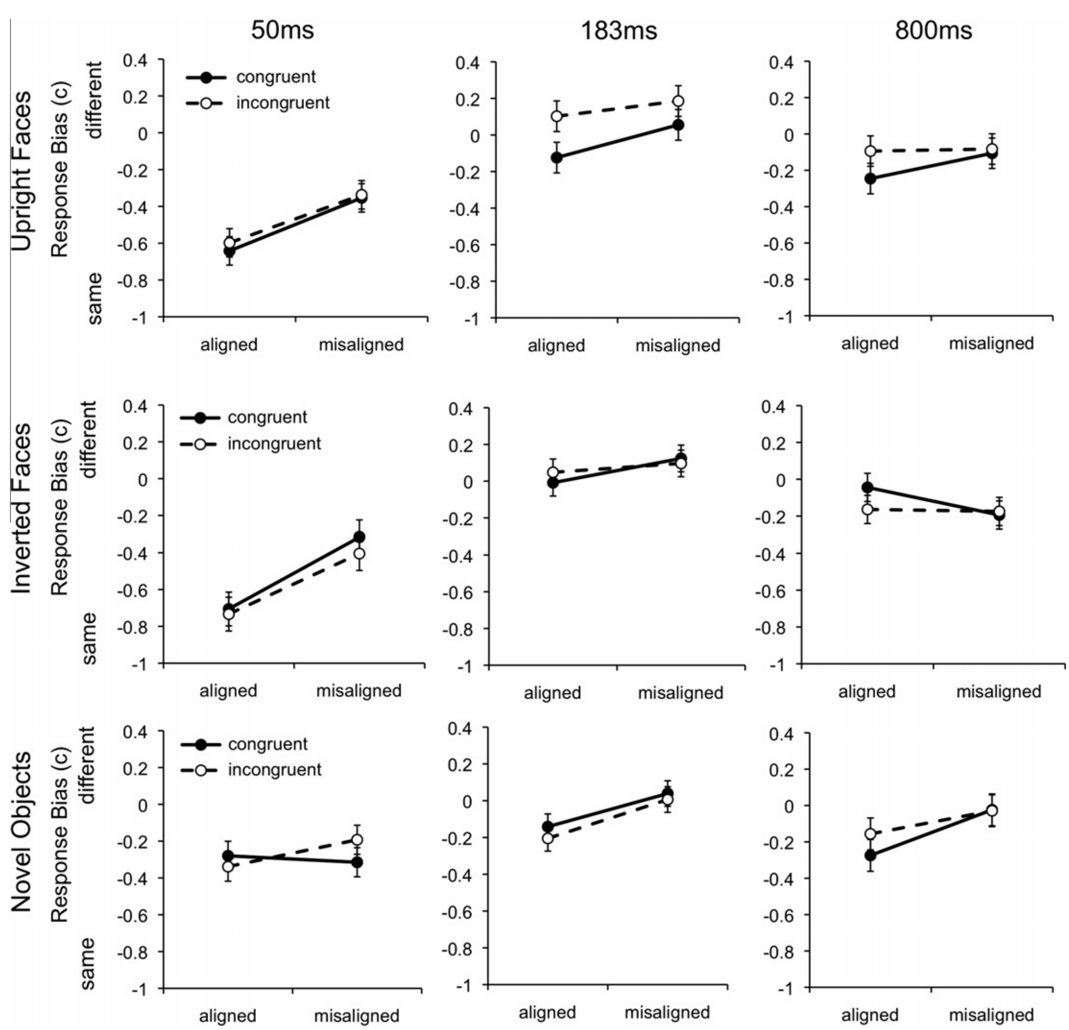

Fig. 6. Response bias (c) for congruent (black) and incongruent (white) trials as a function of alignment for upright faces (top row), inverted faces (middle row) and novel objects (bottom row) for each exposure duration in Experiment 2. Negative values indicate a bias to respond "same", and positive values indicate a bias to respond "different". Error bars show 95% confidence intervals of the congruency × alignment interaction.

likely to respond "same" on congruent trials at 183 ms and 800 ms but not 50 ms.

3.3.2. Response bias (c) – inverted faces

Participants were more likely to respond "same" at exposure durations of 50 ms ($F_{2,54}$ = 27.92, *MSE* = .379, $p < .001$). There was also an interaction between Exposure duration and Alignment ($F_{2,54}$ = 14.22, *MSE* = .097, $p < .001$). As can be appreciated from Fig. 6 (center row), this interaction arises because participants were more likely to respond "same" on aligned vs. misaligned trials only at the fastest exposure duration.

3.3.3. Response bias (c) – novel objects

Participants were more likely to respond "same" on aligned vs. misaligned trials ($F_{1,23}$ = 17.33, *MSE* = .089, $p < .001$), and at exposure durations of 50 ms ($F_{2,46}$ = 6.38, *MSE* = .177, $p < .01$). There was also a significant Alignment × Congruency × Exposure duration interaction ($F_{2,46}$ = 3.55, *MSE* = .039, $p < .05$). As can be appreciated from Fig. 6 (bottom row) this interaction arises because participants are more likely to respond "same" on congruent misaligned trials at 50 ms only.

3.4. Discussion

Our results replicate Richler, Mack, et al. (2009): congruency effects for upright faces were observed beginning at exposure durations of 50 ms. Moreover, the current experiment extends these findings by showing that the interaction between congruency and alignment, which has been argued to be more diagnostic of expertise-driven holistic processing than the congruency effect alone (Richler, Bukach, et al., 2009), does not arise until exposure durations of 183 ms. On the one hand this may suggest that the failure of selective attention observed at 50 ms is not driven by holistic processing unique to objects of perceptual expertise. However, congruency effects were not observed for either inverted faces or novel objects at 50 ms. This argues against the possibility that participants were simply unable to selectively attend when the presentation of the test image was brief because they did not have time to focus attention on the relevant part; if this were the case we would expect interference effects for all three stimulus groups. Instead, it may be that at 50 ms overall performance is too low for the difference in congruency effects between aligned and misaligned faces to be observed. Indeed, looking at Fig. 5 (top row, first column) there does appear to be a larger congruency effect for aligned vs. misaligned trials.

Richler, Mack, et al. (2009) found that participants were more likely to respond "same" at the fastest exposure durations for upright faces when encoding time was limited at test. The present results extend these findings by showing that this bias for responding "same" at rapid exposure durations is not unique to upright faces; regardless of the stimulus type, participants were more likely to respond "same" at the most rapid exposure duration (50 ms). Moreover, participants were also more likely to respond "same" on aligned trials regardless of stimulus type, although this effect was modulated by exposure duration for upright and inverted faces.

In contrast to upright faces, although average performance at 50 ms was above chance for inverted faces (t_{27} = 6.08, $p < .001$) and novel objects (t_{23} = 9.50, $p < .001$), there were no effects of congruency. This is somewhat surprising: at 50 ms performance was above chance, indicating that participants could encode the target parts, but interference from the irrelevant part did not occur. This is consistent with predictions regarding failures of selective attention for non-face objects based on the load theory of selective attention, which suggests that failures of selective attention require time for attention to spread to the irrelevant distractor part (e.g., Lavie, 1995).

So why did we observe interference at 50 ms for upright faces? On the one hand this may reflect the fact that holistic processing occurs because face features are encoded together into a single face template (e.g., Farah et al., 1998; Tanaka & Farah, 1993). However, we did not observe interference at 50 ms for inverted faces, despite the fact that inverted faces are processed holistically at longer exposure durations. One intriguing possibility is that, for inverted faces, while the target parts were successfully encoded at the most rapid exposure duration, inefficient processing due to inversion delayed the encoding of non-attended face parts, resulting in no interference. This would be consistent with the view that holistic processing arises because face parts that are encoded and represented independently are not treated independently during perceptual decisions (Richler, Gauthier, et al., 2008; Richler, Tanaka, et al., 2008). Presumably upright faces are encoded in the same manner as inverted faces, but the efficiency with which upright faces are processed does not allow for the resolution necessary to observe this effect; although they may be encoded separately, both the target and distractor part in upright faces can be encoded within 50 ms. Indeed, face identification performance is above chance for upright faces but not inverted faces when encoding time is limited to less than 50 ms (Curby & Gauthier, 2009).

Although there was an effect of congruency for novel objects (Greebles), the congruency × alignment interaction was never significant. This replicates previous work showing that although task context can induce interference effects measured by congruency for novel objects, novel objects are not processed holistically (Richler, Bukach, et al., 2009). More importantly, the absence of a congruency × alignment interaction at any exposure duration for novel objects suggests that the pattern of performance observed for inverted faces is not simply due to failures of selective attention that may occur for any object class when exposure duration is limited.

4. General discussion

Both experiments characterize holistic processing of inverted faces. In Experiment 1, a congruency effect that was modulated by alignment was observed for inverted faces. Inverted faces are not processed in a qualitatively different manner than upright faces. The most striking difference between upright and inverted faces was in terms of a quantitative difference in overall performance, consistent with the notion that inversion reduces efficiency of processing without changing the nature of processing itself (Sekuler et al., 2004). Experiment 1 also demonstrated that conclusions about whether or not inverted faces are processed holistically depend on the version of the composite task being used: the partial design analyses revealed no evidence for significant holistic processing of inverted faces. By contrast, analyses using the complete design revealed significant holistic processing in terms of discriminability and significant response biases. These response bias differences predict differences in the measure of holistic processing used in the partial design. Therefore, previously reported differences in holistic processing between upright and inverted faces using the partial design (Goffaux & Rossion, 2006; Rossion & Boremanse, 2008) could well arise due to differences in response bias that contaminate this measure of holistic processing.

In Experiment 2, longer exposure durations were required to observe evidence of holistic processing for inverted faces compared to upright faces. These results are consistent with neuroimaging data showing that although activity in the fusiform face area is reduced for inverted vs. upright faces (Gauthier, Tarr, Anderson, Skudlarski, & Gore, 1999; Yovel & Kanwisher, 2005), this region still responds preferentially to *both* upright and inverted faces (Kanwisher, Tong, & Nakayama, 1998) compared to other objects (e.g., houses). However, neural responses (as measured by ERP) are delayed for inverted faces vs. upright faces (e.g., Bentin, Allison, Puce, Perez, & McCarthy, 1996). Differences in the exposure durations necessary for holistic effects between upright and inverted faces may be a consequence of differences in processing latency despite the same underlying processing mechanism.

These results also speak to the ongoing debate regarding the locus of holistic effects in face recognition. Although the prominent view is that holistic processing arises because faces are encoded as a single unit or gestalt in a "face template" (e.g., Farah et al., 1998; Tanaka & Farah, 1993), it is also possible that holistic effects arise because face parts that are encoded and represented independently are combined non-independently when perceptual decisions are made (Richler, Gauthier, et al., 2008; Richler, Tanaka, et al., 2008). Our results are most consistent with this latter view: the delayed emergence of holistic effects for inverted faces compared to upright faces suggests that even though the target face part was encoded at the most rapid exposure duration, allowing for above chance performance, no interference was observed because the irrelevant part was not adequately encoded. In contrast, interference is observed for upright faces at the most rapid exposure duration because, although parts are still encoded independently, the increased efficiency with which upright face parts are processed allows both the target and distractor to be encoded. Although this interpretation is speculative, it is difficult to discern how these results could be explained if holistic processing arises due to encoding of a holistic representation.

This is not to say that inversion does not have unique consequences for face perception. Certainly, inversion influences the perception of faces more so than other objects (see Rossion (2008), Rossion and Gauthier (2002), and Valentine (1988) for reviews). Our results simply imply that the inversion effect for faces is not due to a qualitative difference in processing (see also Sekuler et al., 2004; Willenbockel et al., 2010). Instead, inversion may reduce overall processing efficiency and disrupt the ability to extract relevant information about identity without influencing whether or not faces are being processed in a holistic fashion. This is consistent with a suggestion made by Hole, George, Eaves, and Rasek (2002), whereby recognizing geometrically distorted faces relies on whatever configural information has been retained. In other words, configural or holistic processes are still at work when faces are presented in distorted or unusual ways, they are just less successful.

Inverted faces are processed holistically, but upright faces are still processed more efficiently overall. This supports an expertise account of face perception: Although we are experts with faces in general, we have the most experience with upright faces, and this difference in relative expertise influences performance by boosting processing efficiency or the ability to use featural cues when faces are upright. Indeed, laboratory-trained Greeble experts have been shown to perform better with inverted Greebles than novices (Gauthier, Williams, Tarr, & Tanaka, 1998), suggesting that training with upright objects transfers to some extent to inverted objects. Thus, although overall levels of performance differ, processes relating to expertise such as holistic processing may be engaged for objects of expertise presented in unusual orientations.

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References

Barton, J. S. S., Keenan, J. P., & Bass, T. (2001). Discrimination of spatial relations and features in faces: Effects of inversion and viewing duration. *British Journal of Psychology, 92*, 527–549.

Bentin, S., Allison, T., Puce, A., Perez, A., & McCarthy, G. (1996). Electrophysiological studies of face perception in humans. *Journal of Cognitive Neuroscience, 8*, 551–565.

Cheung, O. S., & Gauthier, I. (2010). Selective interference on the holistic processing of faces. *Journal of Experimental Psychology: Human Perception and Performance, 36*, 448–461.

Cheung, O. S., Richler, J. J., Palmeri, T. J., & Gauthier, I. (2008). Revisiting the role of spatial frequencies in the holistic processing of faces. *Journal of Experimental Psychology: Human Perception and Performance, 34*, 1327–1336.

Curby, K. M., & Gauthier, I. (2009). The temporal advantage for individuating objects of expertise: Perceptual expertise is an early riser. *Journal of Vision, 9*, 1–13.

Diamond, R., & Carey, S. (1986). Why faces are not special: An effect of expertise. *Journal of Experimental Psychology: General, 115*, 107–117.

Farah, M. J., Tanaka, J. W., & Drain, M. (1995). What causes the face inversion effect? *Journal of Experimental Psychology: Human Perception and Performance, 21*, 628–634.

Farah, M. J., Wilson, K. D., Drain, M., & Tanaka, J. W. (1998). What is "special" about face perception? *Psychological Review, 105*, 482–498.

Gauthier, I., & Bukach, C. M. (2007). Should we reject the expertise hypothesis? *Cognition, 103*, 322–330.

Gauthier, I., Curran, T., Curby, K. M., & Collins, D. (2003). Perceptual interference supports a non-modular account of face processing. *Nature Neuroscience, 6*, 428–432.

Gauthier, I., & Tarr, M. J. (1997). Becoming a "Greeble" expert: Exploring mechanisms for face recognition. *Vision Research, 37*, 1673–1682.

Gauthier, I., Tarr, M. J., Anderson, A. W., Skudlarski, P., & Gore, J. C. (1999). Activation of the middle fusiform 'face area' increases with expertise in recognizing novel objects. *Nature Neuroscience, 2*, 568–573.

Gauthier, I., Williams, P., Tarr, M. J., & Tanaka, J. (1998). Training "Greeble" experts: A framework for studying expert object recognition processes. *Vision Research, 38*, 2401–2428.

Goffaux, V., & Rossion, B. (2006). Faces are "spatial" – Holistic face perception is supported by low spatial frequencies. *Journal of Experimental Psychology: Human Perception and Performance, 32*, 1023–1039.

Goffaux, V., & Rossion, B. (2007). Face inversion disproportionately impairs the perception of vertical but not horizontal relations between features. *Journal of Experimental Psychology: Human Perception and Performance, 33*, 995–1002.

Hole, G. J. (1994). Configurational factors in the perception of unfamiliar faces. *Perception, 23*, 65–74.

Hole, G. J., George, P. A., Eaves, K., & Rasek, A. (2002). Effects of geometric distortions on face-recognition performance. *Perception, 31*, 1221–1240.

Kanwisher, N., Tong, F., & Nakayama, K. (1998). The effect of face inversion on the human fusiform face area. *Cognition, 68*, B1–B11.

Kimchi, R. (1998). Uniform connectedness and grouping in the perceptual organization of hierarchical patterns. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 1105–1118.

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human Perception and Performance, 21*, 451–468.

Loftus, G. R., Obert, M. A., & Dillon, A. M. (2004). Linear theory, dimensional theory, and the face-inversion effect. *Psychological Review, 111*, 835–863.

Maurer, D., Le Grand, R., & Mondloch, C. J. (2002). The many faces of configural processing. *Trends in Cognitive Science, 6*, 255–260.

Michel, C., Rossion, B., Han, J., Chung, C.-S., & Caldara, R. (2006). Holistic processing is finely tuned for faces of our own race. *Psychological Science, 17*, 608–615.

Rhodes, G., Brake, S., & Atkinson, A. P. (1993). What's lost in inverted faces? *Cognition, 47*, 25–57.

Richler, J. J., Bukach, C. M., & Gauthier, I. (2009). Context influences holistic processing of non-face objects in the composite task. *Attention, Perception & Psychophysics, 71*, 530–540.

Richler, J. J., Cheung, O. S., & Gauthier, I. (submitted for publication). Beliefs alter holistic face processing... if response bias is not taken into account.

Richler, J. J., Gauthier, I., Wenger, M. J., & Palmeri, T. J. (2008). Holistic processing of faces: Perceptual and decisional components. *Journal of Experimental Psychology: Learning, Memory and Cognition, 34*, 328–342.

Richler, J. J., Mack, M. L., Gauthier, I., & Palmeri, T. J. (2009). Holistic processing of faces happens at a glance. *Vision Research, 49*, 2856–2861.

Richler, J. J., Tanaka, J. W., Brown, D. D., & Gauthier, I. (2008). Why does selective attention to parts fail in face processing? *Journal of Experimental Psychology: Learning, Memory and Cognition, 34*, 1356–1368.

Riesenhuber, M., Jarudi, I., Gilad, S., & Sinha, P. (2004). Face processing in humans compatible with a simple shape-based model of vision. *Proceedings in Biological Sciences, 271*(Suppl. 6), S448–S450.

Rossion, B. (2008). Picture-plane inversion leads to qualitative changes of face perception. *Acta Psychologica, 128*, 274–289.

Rossion, B., & Boremanse, A. (2008). Nonlinear relationship between holistic processing of individual faces and picture-plane rotation: Evidence from the face composite illusion. *Journal of Vision, 8*, 1–13.

Rossion, B., & Gauthier, I. (2002). How does the brain process upright and inverted faces? *Behavioral and Cognitive Neuroscience Reviews, 1*, 63–75.

Rossion, B., Kung, C.-C., & Tarr, M. J. (2004). Visual expertise with nonface objects leads to competition with the early perceptual processing of faces in the human occipitotemporal cortex. *Proceedings of the National Academy of Sciences, 101*, 14521–14526.

Sekuler, A. B., Gaspar, C. M., Gold, J. M., & Bennett, P. J. (2004). Inversion leads to quantitative, not qualitative, changes in face processing. *Current Biology, 14*, 391–396.

Tanaka, J. W., & Farah, M. J. (1993). Parts and wholes in face recognition. *The Quarterly Journal of Experimental Psychology, 46A*, 225–245.

Tanaka, J. W., & Sengco, J. A. (1997). Features and their configuration in face recognition. *Memory & Cognition, 25*, 583–592.

Troje, N., & Bulthoff, H. H. (1996). Face recognition under varying poses: The role of texture and shape. *Vision Research, 36*, 1761–1771.

Valentine, T. (1988). Upside-down faces: A review of the effect of inversion upon face recognition. *British Journal of Psychology, 79*, 471–491.

Valentine, T., & Bruce, V. (1988). Mental rotation of faces. *Memory and Cognition, 16*, 556–566.

Willenbockel, V., Fiset, D., Chauvin, A., Blais, C., Arguin, M., Tanaka, J. W., et al. (2010). Does face inversion change spatial frequency tuning? *Journal of Experimental Psychology: Human Perception and Performance, 36*, 122–135.

Wong, Y. K., & Gauthier, I. (2010). Holistic processing of musical notation: Dissociating failures of selective attention in experts and novices. *Cognitive, Affective & Behavioral Neuroscience, 10*, 541–551.

Yin, R. K. (1969). Looking at upside-down faces. *Journal of Experimental Psychology, 81*, 141–145.

Young, A. W., Hellawell, D., & Hay, D. C. (1987). Configurational information in face perception. *Perception, 16*, 747–759.

Yovel, G., & Kanwisher, N. (2004). Face perception: Domain specific, not process specific. *Neuron, 44*, 889–898.

Yovel, G., & Kanwisher, N. (2005). The neural basis of the behavioral face-inversion effect. *Current Biology, 15*, 2256–2262.