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The effect of face orientation on holistic processing

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Abstract. Holistic processing, a hallmark of face processing, can be measured by the composite face effect: adults have difficulty recognising the top half of a face when it is aligned with a new bottom half, unless holistic processing is disrupted by misaligning the two halves. Like the recognition of facial identity, holistic processing is impaired when faces are inverted. To obtain a more refined measure of the influence of orientation on holistic face processing, we administered the composite face task to adults at each of seven orientations. In both experiment 1 (in which orientations were randomly intermixed) and experiment 2 (in which orientations were blocked), the composite face effect decreased linearly with rotation. We conclude that holistic processing is tuned to upright faces, diminishes as faces deviate from upright, and becomes insignificant once faces reach a sideways orientation. We propose a hierarchical model of face perception in which linear decreases in holistic processing underlie qualitative shifts in other aspects of face perception.

1 Introduction

Adults' expert face recognition depends on several types of processing—holistic processing (processing faces as a Gestalt), featural processing (sensitivity to differences among faces in the appearance of individual features), and second-order relational processing (sensitivity to differences among faces in the spacing of facial features) (reviewed in Maurer et al 2002). The recognition of facial identity is impaired when faces are inverted (Yin 1969) and several studies have suggested that this is caused largely by disruptions in holistic and second-order relational processing. Evidence that inversion disrupts second-order relational processing comes from studies showing that adults' accuracy in making same/different judgments about pairs of faces that differ only in the spacing of features is much more impaired by inversion than is their ability to discriminate faces that differ in the appearance of individual features or the external contour (Barton et al 2003; Freire et al 2000; Mondloch et al 2002; see also Barton et al 2001; Collishaw and Hole 2000; Leder and Bruce 2000; Rhodes et al 1993; Searcy and Bartlett 1996; but see Malcolm et al 2004 for different effects for upper and lower face regions, and Yovel and Kanwisher 2004 for evidence of similar effects of inversion for the processing of feature shape and second-order relations).

Evidence that inversion disrupts holistic processing comes from studies showing that two indications of holistic processing—the composite face effect (CFE) and the whole/part advantage—are eliminated when faces are inverted. The CFE is measured by asking adults to recognise the identity of the top half of a familiar face when that top half is aligned with the bottom half of a different face. Accuracy is low, presumably because holistic processing results in the bottom half altering the perception of the top half. Misaligning the two halves improves performance, presumably because it disrupts holistic processing (Young et al 1987). Similar results are found when adults are asked to make same/different judgments about the top halves of unfamiliar faces that are aligned with different bottom halves (Hole 1994; Le Grand et al 2004). The CFE has been demonstrated in both adults (Carey and Diamond 1994; Hole 1994; Young et al 1987) and children as young as 4–6 years of age (Carey and Diamond 1994; de Heering et al 2007; Mondloch et al 2007). The whole/part effect is measured by presenting participants with a face (eg Bob's face) and then presenting them with either a pair of faces that differ only by one feature (eg Bob's face and Bob's face with Jim's nose) or with a pair of features (eg Bob's nose and Jim's nose). Adults (Tanaka and Farah 1993) and children as young as 4–6 years of age (Pellicano and Rhodes 2003; Pellicano et al 2006; Tanaka et al 1998) are more accurate at identifying which nose is Bob's nose in the context of the whole face (whole trials) than when the nose is presented in isolation (part trials). Both the CFE and the whole/part advantage are absent when faces are inverted (Carey and Diamond 1994; Hole 1994; Tanaka and Farah 1993; Tanaka et al 1998; Young et al 1987; see also Yovel et al 2005).

Several studies have taken a more refined approach to investigate the influence of orientation on face perception. Rather than presenting faces at only two orientations (upright and inverted), faces were also presented at intermediate degrees of rotation. Some of these studies report an abrupt shift in perception as faces are rotated away from their canonical upright orientation (eg Lewis 2001), whereas others report a gradual linear decline (eg for faces blurred to remove featural information: Collishaw and Hole 2002). Several of these studies have dealt with the influence of rotation on adults' perception of the Thatcher illusion. Thatcherised faces are created by inverting the eyes and mouth in an otherwise upright face. These faces are perceived as normal when inverted, but as grotesque when upright (Thompson 1980). Studies in which Thatcherised faces have been presented at many orientations suggest that there is an abrupt shift in perception between 90° and 120°; past 90°, it is harder to see that a face has been Thatcherised (Edmonds and Lewis 2007; Lewis 2001) and Thatcherised faces look less grotesque (Murray et al 2000; Stürzel and Spillmann 2000). The three studies in which quantitative measures were taken at a number of orientations revealed further decreases in ease of perceiving grotesqueness as faces rotated beyond 135° (Edmonds and Lewis 2007; Lewis 2001; Murray et al 2000). In contrast, featurally distorted faces look slightly more bizarre as they are rotated away from upright and the effect increases linearly with rotation (Murray et al 2000). The results are mixed for studies in which sensitivity to second-order relations was measured. When the features are blurred to emphasise second-order relations, accuracy in making famous/nonfamous judgments decreases linearly with rotation (Collishaw and Hole 2002). When the spacing of features is altered directly, accuracy in sequential matching and judgments of bizarreness change little with rotation away from upright until an abrupt change around 90°–120°; past 120°, the trends reverse such that accuracy increases and judged bizarreness decreases (Murray et al 2000; Schwaninger and Mast 2005), perhaps because featural processing becomes more important. In contrast, reaction times for judgments of facedness (whether a face is scrambled or not), face familiarity, and identity matching decrease linearly with rotation (Valentine and Bruce 1988), whereas reaction times to make a gender judgment based on the internal features of familiar faces follow both linear and cubic trends, with a discontinuity around 90° and then subsequent linear increases until 150° (Stevenage and Osborne 2006). Because nonlinear trends provide evidence of qualitative shifts in perception, whereas linear trends provide evidence of quantitative shifts, the discrepancy in the literature has received much attention.

Holistic processing is a hallmark of face perception and likely contributes to the Thatcher illusion as well as to gender and identity judgments. Given that all of these judgments are impaired when faces are rotated beyond 90°, we decided to measure the influence of orientation on holistic processing directly. To our knowledge, only four studies have looked at the influence of rotation on holistic processing. Boutet and Chaudhuri (2001) presented two overlapping faces each oriented at either 45° (one rotated clockwise and the other counterclockwise) or 135°. Perceptual rivalry was evident when the faces were presented at ±45°: the features of the overlapped faces were kept distinct, forming alternating whole-face images; this did not occur when the overlapping faces were orientated at ±135°, a finding suggesting a lack of holistic processing for faces rotated 135°. In a followup study, Donnelly et al (2003) presented one upright face overlapped with a second face presented at one of five rotated orientations. Participants were asked to report which of the two faces was dominant. When the upright face contained 45% of the total visual energy (set by manipulating transparency), there was a sharp decline between 90° and 135° in the frequency with which the rotated face was selected as dominant. These two studies provide indirect evidence that holistic processing decreases between 45° and 135°. (See Martini et al 2006 for similar results showing a decreasing perceptual advantage of the more upright face in a pair when it rotates between 0° and 90°, with no further reduction between 90° and 180°.) Lewis and Glenister (2003) measured the effects of orientation on holistic processing directly by measuring the whole/part advantage for faces presented at 0°, 90°, and 180°. There was a whole advantage at 0° and 90°, but not at 180°—a pattern suggesting that holistic processing becomes impaired only when faces are rotated to somewhere beyond 90°. Because Lewis and Glenister used only three orientations, the details of how rotation affects holistic processing are unknown. Furthermore, the effect of rotation on holistic processing has not been assessed using the other measure of holistic processing—CFE.

We administered the composite face task at seven different orientations (30° intervals between 0° and 180°). We created composite faces by aligning the top half of one face with two different bottom halves. On 'same' trials the top halves were the same and the bottom halves were different. On 'different' trials both the top and the bottom halves were different. Each composite was presented in two ways—with the two halves intact and with the two halves misaligned. Previous studies have shown that when faces are intact adults' accuracy is lower on same trials than on different trials because the bottom half alters perception of the top half, causing the illusion that the top halves are different. Accuracy is increased on same trials when the two halves are misaligned, presumably because misalignment interferes with holistic processing. We predicted that the effect of orientation would vary across trial types. Because inversion impairs sensitivity to the spacing of facial features, and to a lesser extent the appearance of individual features (Barton et al 2003; Freire et al 2000; Mondloch et al 2002), we expected accuracy to decrease with rotation in three of the four conditions: misaligned same trials and both intact and misaligned different trials. In contrast, we predicted that accuracy would increase with rotation on intact same trials: rotation should impair holistic processing, making it easier for participants to recognise that the top halves are the same despite being aligned with different bottom halves. Consequently, the size of the CFE (the difference between accuracy on same trials for misaligned faces and for intact faces) was expected to decrease with orientation. Holistic processing is evident only when this CFE is significantly different from zero. Previous studies of orientation effects on face perception have revealed abrupt decreases in perceptions of grotesqueness and identity judgments, typically around 90°. To determine whether holistic processing decreases gradually and linearly, or abruptly with rotation, we also conducted trend analyses and compared the size of the CFE across pairs of adjacent orientations.

In experiment 1 we randomly intermixed the seven orientations and presented faces rotated in both a clockwise and a counterclockwise position. In experiment 2, we presented the seven orientations in separate blocks and only rotated faces counterclockwise in order to determine whether the results from experiment 1 would be replicated when the location of the top half of the face was predictable from trial to trial.

2 Experiment 1

2.1 *Method*

2.1.1 *Participants.* Twenty-four (twelve male) undergraduate students at McMaster University, Canada, participated in the experiment for course credit. All participants were Caucasian and right-handed, and passed a visual screening exam for normal vision (Mondloch et al 2002).

2.1.2 *Apparatus.* The stimuli were presented on a monochrome Radius 21-GS monitor and their presentation was controlled by Cedrus Superlab software. The experimenter initiated each trial by pressing a key on the keyboard, and the participants signalled their responses via a joystick. Before beginning each trial, the experimenter ensured that the participant was attentive and not tilting his/her head.

2.1.3 *Stimuli.* Face composites were created from grey-scale digitized images of adult Caucasian faces. Models wore no jewellery, glasses, or make-up, and a surgical cap covered their hair and ears. Using Adobe Photoshop we created composites by splitting face images in half horizontally across the middle of the nose, and then recombining the faces using the top and bottom halves of different individuals. In the 'intact' condition, the top and bottom face segments were properly aligned, and we used Photoshop to blend the images seamlessly. In the 'misaligned' condition, the top half of each face was misaligned by shifting it horizontally to the left by half a face width (see figure 1). We created 30 composite face pairs; each face half was used in only one pair and every face presented was a composite face (ie no unaltered faces were presented). Composites were created both by exchanging top and bottom halves within pairs and by aligning a top half with bottom halves of other faces. The same face composites were used in both the intact and misaligned conditions.

Each composite was presented at each of seven orientations: 0°, 30°, 60°, 90°, 120°, 150°, and 180°. For orientations other than 0° and 180°, stimuli on half of the same and half of the different trials were rotated clockwise and half were rotated counterclockwise. Stimuli in the intact condition were 9.8 cm wide and 14 cm high

Figure 1. Composite face stimuli. Two face pairs from the misaligned condition are shown in the top row, and two face pairs from the intact condition are shown in the bottom row. In each face pair, the top halves are either identical (left panel) or different (right panel). For all face pairs, the bottom halves are different. In the intact condition, when the faces are upright holistic processing creates the impression that the top halves are always different. Reprinted from *Psychological Science* 2004 **15** 765.

(5.6 deg × 8 deg of visual angle from a distance of 100 cm). Stimuli in the misaligned condition were 14.6 cm wide and 14 cm high (8.4 deg × 8 deg from a distance of 100 cm). [These stimuli were used previously by Le Grand et al (2004).]

2.1.4 *Procedure.* This study was approved by the research ethics board of McMaster University. Informed written consent was obtained from each participant prior to testing.

Participants sat in a dimly lit room 100 cm from the computer monitor. On each trial, a composite face appeared for 200 ms, and following a 300 ms interstimulus interval, a second composite face appeared for 200 ms. Participants were asked to move a joystick forward if the top halves of the two faces were the same and back if the top halves were different. They were asked to respond as quickly and as accurately as possible. Within each block, half of the trials ($n = 30$) consisted of face pairs that shared the identical top halves (same trials) and half of the trials consisted of face pairs with different top halves (different trials). On every trial the bottom halves were different. Same and different trials were randomly intermixed within each block. Intact and misaligned trials were presented in separate blocks; the orientations were randomly intermixed. Prior to each block participants were given 10 practice trials without feedback. Half of the participants were tested on misaligned trials first.

2.1.5 *Analyses.* We calculated proportion correct responses for each trial type at each of the seven orientations (see figure 2). Trials in which the top halves were the same are of primary interest. Different trials do not provide information about holistic processing because holistic processing does not interfere with accuracy when both the top and the bottom halves are different. Consequently, further analyses of different trials were not conducted. We calculated the size of the CFE (accuracy on misaligned trials – accuracy on intact trials) at each orientation for same trials only. Differential effects of orientation on performance on intact versus misaligned trials were expected to produce a decreased CFE as faces rotated away from their canonical upright orientation. To determine whether holistic processing decreases gradually with orientation or whether there is an abrupt (ie qualitative) shift in processing we conducted trend analyses. We tested the significance of linear, quadratic, and cubic trends. Although these analyses revealed only linear trends, we used a second technique to verify the lack of any abrupt shift in processing. We conducted paired t-tests with Bonferroni corrections comparing the size of the CFE for all adjacent orientations (eg 0° versus 30°, 30° versus 60°). An abrupt shift in holistic processing would be evident if there was a difference between one or two pairs (eg 60° versus 90°) but not between other adjacent pairs (eg 120° and 150°). Finally, to determine the orientation at which holistic

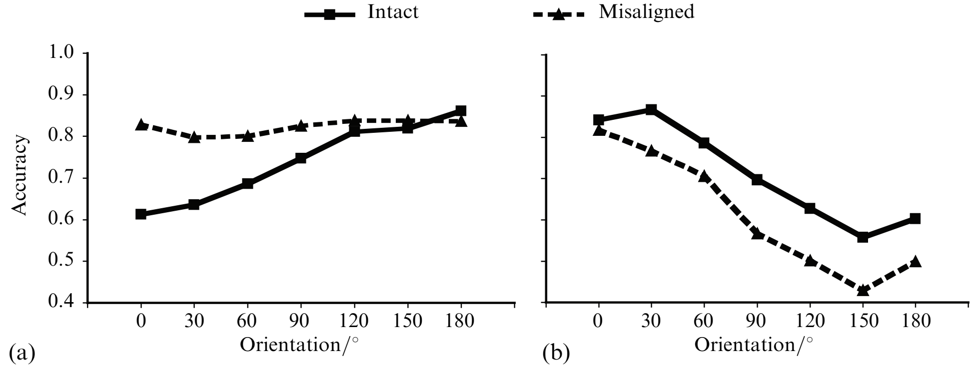

Figure 2. Mean accuracy on the composite face task in experiment 1 in which orientation varied randomly from trial to trial. Accuracy on trials in which the top halves were the same (a) and different (b) is shown separately for intact and misaligned trials at each of the seven orientations.

processing is no longer evident, we conducted single-sample t-tests with Bonferroni corrections to determine the orientation at which the CFE was no longer significantly greater than zero.

2.2 *Results*

As shown in figure 2, accuracy increased with orientation in only one condition—intact same trials. In contrast, accuracy did not vary with orientation on misaligned same trials and decreased with rotation on both intact and misaligned different trials. As shown in figure 3, there was a significant linear decrease in the size of the CFE with rotation ($F_{1,23} = 26.723$, $p < 0.001$); the quadratic and cubic trends were not significant (ps > 0.20). The lack of any abrupt change in holistic processing was confirmed by analysis of differences in the size of the CFE between adjacent orientations. Paired t-tests with Bonferroni corrections revealed that none of these pairwise comparisons was significant (all ps > 0.10). Single-sample t-tests with Bonferroni corrections revealed a significant CFE (ie higher accuracy on misaligned trials) at orientations up to 60° (ps < 0.05) (see figure 3). We note that increased accuracy on same intact trials cannot be attributed to speed–accuracy trade-offs; reaction times on same intact trials decreased as faces rotated away from the upright orientation ($F_{6,138} = 10.14$, $p < 0.0001$), providing additional evidence that making judgments about intact faces when the top halves were the same became easier as faces were rotated away from an upright orientation.

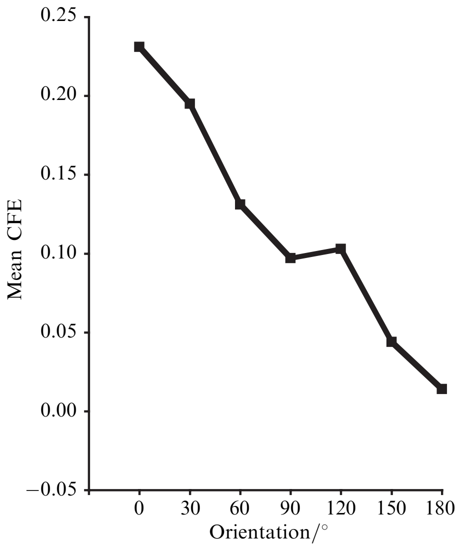

Figure 3. Mean composite face effect, CFE (accuracy on misaligned same trials minus accuracy on intact same trials) at each of seven orientations in experiment 1 in which orientation varied randomly from trial to trial.

2.3 *Discussion*

When the top halves were different, accuracy decreased as faces rotated away from upright for both intact and misaligned faces, as predicted from numerous previous studies showing decreases in performance as faces deviate from a canonical upright orientation (Collishaw and Hole 2002; Diamond and Carey 1986; Mondloch et al 2002; Yin 1969; reviewed in Valentine 1988). In contrast, when the top halves were the same, accuracy increased as orientation deviated from upright when the two halves were intact; that is, when holistic processing was engaged. It did not vary with orientation when the two halves were misaligned; that is, when holistic processing was disrupted. The CFE diminished monotonically with rotation from 0° (upright) through 180° and was statistically significant through 60° rotation. When faces were presented at 90° (sideways), there was no significant effect of alignment on accuracy. We note, however, that the lack of significant nonlinear trends indicates that the CFE continued to decrease as faces rotated beyond 90° (see figure 3). These data suggest that holistic processing is maximal for upright faces, diminishes as faces are rotated away from upright, and has little or no influence on the processing of faces once they reach or pass a sideways orientation. Reaction-time analyses complement the patterns shown with accuracy data. When faces rotated away from upright, reaction times decreased for intact same trials but did not change for misaligned same trials.

In experiment 1 we rotated faces both clockwise and counterclockwise and varied orientation randomly from trial to trial. One possible explanation for subjects' poor performance on rotated trials is that they did not know where the top half of the face would appear on any trial and that this unpredictability impaired their ability to use holistic processing efficiently. To verify that our results were not the product of the unpredictability of where the top half would be presented, we conducted a second experiment in which faces were only rotated counterclockwise and the seven orientations were presented in separate blocks.

3 Experiment 2

3.1 *Method*

3.1.1 *Participants.* Twenty-four (twelve male) undergraduate students at McMaster University, Canada, participated in the experiment for course credit. They had similar characteristics to those in experiment 1.

3.1.2 *Procedure.* The procedure was identical to that of experiment 1 with one exception. Within each condition (intact/misaligned) we blocked orientation. The order of orientation varied randomly and was unique for each participant. Prior to each block a single face was presented to indicate at which orientation the next block of faces would be presented.

3.2 *Results*

As shown in figure 4, accuracy increased with orientation in only one condition—intact same trials. As in experiment 1, accuracy did not vary with orientation on misaligned same trials and decreased with rotation on both intact and misaligned different trials. As shown in figure 5, there was a significant linear decrease in the size of the CFE with rotation away from upright ($F_{1,23} = 13.18$, $p < 0.001$). The quadratic and cubic trends were not significant (ps > 0.10). As in experiment 1, the lack of any abrupt change in holistic processing was confirmed by analysis of differences in the size of the CFE between adjacent orientations. Paired t-tests with Bonferroni corrections revealed that none of these pairwise comparisons was significant (all ps > 0.20).

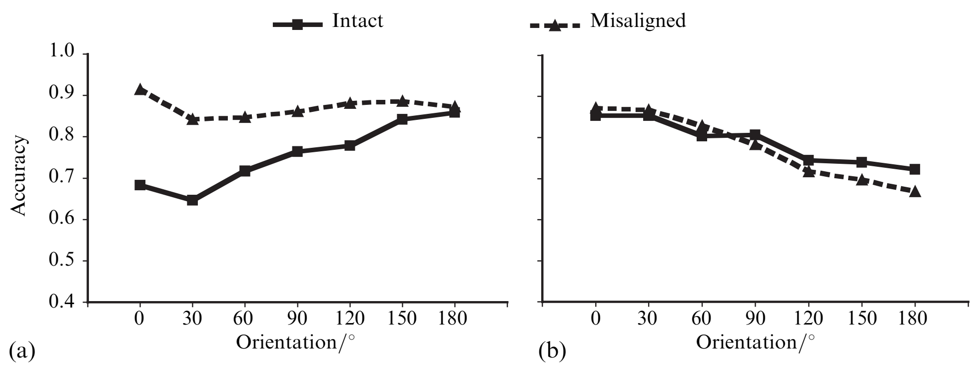

Figure 4. Mean accuracy on the composite face task in experiment 2 in which orientation was blocked. Accuracy on trials in which the top halves were the same (a) and different (b) is shown separately for intact and misaligned trials at each of the seven orientations.

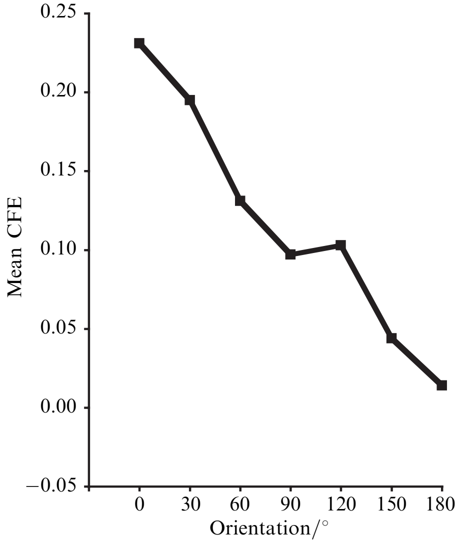

Figure 5. Mean composite face effect, CFE (accuracy on misaligned same trials minus accuracy on intact same trials) at each of seven orientations in experiment 2 in which orientation is blocked.

Single-sample t-tests with Bonferroni correction revealed a significant CFE at orientations up to 60° (ps < 0.05) (see figure 5). We note that increased accuracy on same intact trials cannot be attributed to speed – accuracy trade-offs; reaction times on same intact trials decreased as faces rotated away from the upright orientation ($F_{6,138} = 5.28$, $p < 0.0001$), providing additional evidence that making judgments about intact faces when the top halves were the same became easier as faces were rotated away from an upright orientation.

3.3 *Discussion*

The results replicate those of experiment 1 in which orientation was not blocked. When the top halves were different, accuracy decreased as faces rotated away from upright for both intact and misaligned faces. In contrast, when the top halves were the same, accuracy increased when the two halves were intact and the face was rotated away from upright. Decreasing reaction times on same intact trials as faces rotated away from an upright orientation provides further evidence that rotation decreased holistic processing, making it easier for participants to ignore the bottom halves of composite faces. Accuracy did not vary with orientation when the two halves were misaligned (ie when holistic processing was disrupted). The CFE, as measured by accuracy, decreased monotonically from 0° (upright) to 180° and was significant up to 60° rotation.

4 General discussion

The pattern of results suggests that holistic processing is tuned to upright faces. That tuning is broad, however. Holistic processing decreased linearly throughout the entire range of orientations and remained significant when faces were oriented at 30° or 60°. When faces reached a sideways orientation (90°), the CFE was present in the means but no longer statistically significant, and, with further rotation, it disappeared altogether. The results are especially convincing because the diminution of holistic processing was revealed by increased accuracy on same intact trials as the faces were rotated farther from upright, contrary to the usual decrease in accuracy of face processing with rotation (Collishaw and Hole 2002; Mondloch et al 2002; Valentine and Bruce 1988), but just as would be predicted if the holistic processing that makes these trials hard for upright faces were diminishing. The results extend the many previous reports that the CFE seen for upright faces is not present for inverted faces (Carey and Diamond 1994; Hole 1994; Young et al 1987). They are also consistent with the findings that another measure of holistic processing—the part/whole advantage—occurs for upright faces, but not for inverted faces (Lewis and Glenister 2003; Tanaka and Farah 1993; Tanaka et al 1998), although holistic processing as measured by the part/whole effect may be more robust for sideways (90°) faces (Lewis and Glenister 2003) than it was in our study.

Although in some studies a linear decrease in performance as faces rotate away from their canonical upright orientation was reported (eg Collishaw and Hole 2002; Valentine and Bruce 1989), the majority of researchers have reported an abrupt shift around 90° (eg Edmonds and Lewis 2007; Lewis 2001; Martini et al 2006; Murray et al 2000; Stevenage and Osborne 2006; Stürzel and Spillmann 2000). Our results appear at first glance to be inconsistent with the latter group of studies. We note, however, that some of the studies reporting an abrupt shift around 90° do report further decreases as faces rotate between 90° and 180° (Edmond and Lewis 2007; Lewis 2001; Murray et al 2000 for Thatcherised faces; Stevenage and Osborne 2006; but see Martini et al 2006; Murray et al 2000 for second-order relations; Schwaninger and Mast 2005). Thus there appear to be three patterns in the literature: linear decreases with rotation; abrupt changes with rotation and no further decreases; and abrupt changes accompanied by additional linear decreases.

The linear decrease in holistic processing we observed is consistent with a hierarchical model of face perception. It is likely that detecting that a stimulus is a face rather than a nonface object (ie detecting the first-order relations of two eyes above a nose, which is above a mouth) precedes the face-specific processing of cues that underlie the recognition of facial identity (eg the shape of individual features and the spacing among them). In fact, sensitivity to first-order relations shows the same type of linear trend as observed in this experiment for holistic processing (Valentine and Bruce 1988). It is also likely that holistic processing precedes and is necessary for subsequent processing of the metric differences in the spacing among facial features that differentiate individuals. Le Grand et al (2004) suggest that holistic processing may be a prerequisite for sensitivity to the spacing among facial features. Patients treated for congenital cataract that deprived them of early visual experience show no evidence of holistic processing (Le Grand et al 2004) and are less sensitive than normal controls to differences among faces in the spacing of facial features (Le Grand et al 2001). Developmentally, holistic processing is adult-like by 4 to 6 years of age (Carey and Diamond 1994; de Heering et al 2007; Mondloch et al 2007; Pellicano and Rhodes 2003, Pellicano et al 2006; Tanaka et al 1998), whereas sensitivity to the spacing among facial features is weak at 4 years of age (McKone and Boyer 2006; Mondloch et al 2006; Mondloch and Thomson 2008) and not adult-like until mid adolescence (Mondloch et al 2003). We make the following proposal. Faces rotated less than 90° from upright elicit sufficient holistic processing to support sensitivity to the spacing of facial features and thus facial identity. Beyond 60° to 90°, holistic processing continues to decline, but is already sufficiently impaired that it causes an abrupt shift in the salience of the face (Martini et al 2006) and in the ability to process small differences in the interrelation among features, such as second-order relations. These difficulties lead to abrupt changes in the ability to recognise individual faces, gender judgments, and sensitivity to the Thatcher illusion. In fact, despite a linear increase in reaction time for famous and facial identity judgments, Valentine and Bruce (1988) found a nonlinear pattern for errors consistent with this proposal. Similarly, the d' for making famous/nonfamous judgments for blurred faces in Collishaw and Hole (2002) was significant at 135°, but not at the 157.5° and 180° orientations.

This proposal leads to an interesting prediction. In the whole/part task, disrupting holistic processing by presenting features in isolation impairs recognition of features, as does altering the Gestalt by changing second-order relations (Tanaka and Sengo 1997).

Adults are no more accurate at recognising Bob's eyes when they are presented in a spatially altered version of Bob's face (eg with the mouth lowered) than they are when Bob's eyes are presented in isolation. Our model leads to the prediction of a significant interaction between orientation and condition (spatial changes/no spatial changes). When the spacing of features remains unchanged, the whole/part advantage should decrease linearly with rotation, as it did in this study. When the spacing of the features is altered, the whole/part advantage should be diminished on upright and nearly upright trials, as reported previously. At about 90°, however, the size of the whole/part advantage should match that seen in the no-spatial-change condition because holistic processing will be sufficiently impaired to cause an abrupt decrease in sensitivity to the spatial changes, thus making the two conditions equivalent.

The tuning of holistic processing for faces that are upright or nearly so is likely to result from experience. Indirect evidence comes from studies comparing the size of the CFE and of the whole/part advantage for faces of subjects' own race or ethnic group—a category with which they have had years of experience—and another race—a category with which they have had minimal experience and for which their ability to differentiate and remember individual identities is impaired. Adults process faces from their own race and ethnic group more holistically than faces from a less familiar race/ethnic group, as measured by both the whole/part advantage and the CFE (Michel et al 2006a, 2006b; Tanaka et al 2004). There may be a sensitive period for this development. Adults do not show a CFE for nonsense objects on which they have not been trained (Gauthier and Tarr 2002) and it is difficult to induce a CFE for nonface objects even with extensive training (Robbins and McKone 2007; reviewed in McKone et al 2007). Of course, such training might be more effective if it took place during early development. What remains unclear, however, is why the CFE continues to decrease beyond 90°. Adults likely have more experience with faces oriented at 30° and 60° (as they view tilted heads, for example) than with inverted faces, but it is unlikely that they have more experience with faces oriented at 120° than at 180°.

In summary, holistic processing—as indexed by the CFE—is tuned to upright faces and diminishes linearly as faces deviate from upright. The tuning to the canonical upright orientation likely depends on experience. Future studies could examine the development of orientation tuning during childhood. Although by 4 to 6 years old children's holistic processing is mature for upright human faces—as indexed by the CFE effect or the part/whole advantage (de Heering et al 2007; Mondloch et al 2007; Pellicano and Rhodes 2003; Pellicano et al 2006; Tanaka et al 1998), the details of its orientation tuning have not been studied. Future studies could also examine more directly the role of experience in the development of the orientation tuning of holistic processing by studying adults and children with categories for which they have different amounts of experience (eg human versus monkey faces).

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