Research Article

Psychological Science
2016, Vol. 27(2) 213–222

DOI: 10.1177/0956797615617779
pss.sagepub.com

Beyond Faces and Expertise: Facelike Holistic Processing of Nonface Objects in the Absence of Expertise

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Abstract

Holistic processing—the tendency to perceive objects as indecomposable wholes—has long been viewed as a process specific to faces or objects of expertise. Although current theories differ in what causes holistic processing, they share a fundamental constraint for its generalization: Nonface objects cannot elicit facelike holistic processing in the absence of expertise. Contrary to this prevailing view, here we show that line patterns with salient Gestalt information (i.e., connectedness, closure, and continuity between parts) can be processed as holistically as faces without any training. Moreover, weakening the saliency of Gestalt information in these patterns reduced holistic processing of them, which indicates that Gestalt information plays a crucial role in holistic processing. Therefore, holistic processing can be achieved not only via a top-down route based on expertise, but also via a bottom-up route relying merely on object-based information. The finding that facelike holistic processing can extend beyond the domains of faces and objects of expertise poses a challenge to current dominant theories.

Keywords

holistic processing, composite-face effect, expertise, face perception, Gestalt

Received 8/6/15; Revision accepted 10/23/15

Unlike most everyday objects, human faces are perceived as indecomposable wholes (i.e., Gestalts), rather than as collections of independent parts (Farah, Wilson, Drain, & Tanaka, 1998; Maurer, Le Grand, & Mondloch, 2002; Rossion, 2013). Strong evidence for such holistic processing is found in studies demonstrating that people are unable to selectively attend to one part of a face without being influenced by other parts (Maurer et al., 2002; Richler & Gauthier, 2014). For instance, when the top half of Barack Obama's face is combined with the bottom half of a different person's face, people have difficulty recognizing that this new composite face has the same top half as Barack Obama's face. Instead, these two identical top halves tend to be illusorily perceived as being different from each other (i.e., the *composite-face effect*; Cheung, Richler, Palmeri, & Gauthier, 2008; Young, Hellawell, & Hay, 1987). Such failure of selective attention has also been demonstrated for perception of facial expression and gender (Calder, Young, Keane, & Dean, 2000; Zhao & Hayward, 2010), but is seldom found for nonface objects, which are primarily processed in a piecemeal manner (Chua, Richler, & Gauthier, 2015, control group; Farah et al., 1998; Richler, Bukach, & Gauthier, 2009; Richler, Mack, Palmeri, & Gauthier, 2011, Experiment 2).

Why are faces processed holistically? According to the *domain-specific hypothesis*, holistic processing is unique to the face domain and cannot be generalized to nonface objects (Kanwisher, 2000; McKone, Kanwisher, & Duchaine, 2007; Robbins & McKone, 2007). Specifically, in this view, faces are processed holistically either

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because humans have an innate face template for coding facial structure holistically (e.g., Morton & Johnson, 1991) or because human faces are "the only homogeneous stimuli for which individual-level discrimination is practised during the sensitive period" (McKone et al., 2007, p. 12). A study consistent with this hypothesis found that without intensive exposure to faces during early infancy, holistic processing for faces collapses (Le Grand, Mondloch, Maurer, & Brent, 2004).

Alternatively, according to the *expertise hypothesis*, holistic processing results from automatized attention to whole objects, which is developed with extensive experience in discriminating them (i.e., expertise; Diamond & Carey, 1986; Gauthier & Tarr, 1997; Richler, Wong, & Gauthier, 2011). Specifically, in this view, people process faces holistically because they have learned to individuate faces by attending to multiple facial parts together, probably because diagnostic information is usually distributed over whole faces (Chua, Richler, & Gauthier, 2014). Holistic processing can be generalized to nonface objects via the same mechanism—and "all that is required is a history of attention to parts" (Chua et al., 2015, p. 728). Studies consistent with this prediction have shown that holistic processing for nonface objects emerges following extensive training in individual-level discrimination (Chua et al., 2015; A. C.-N. Wong, Palmeri, & Gauthier, 2009).

Although these influential hypotheses differ in the posited origin of holistic processing, they share one fundamental constraint for its generalization: Nonface objects cannot elicit facelike holistic processing in the absence of expertise. Specifically, the domain-specific hypothesis predicts no facelike holistic processing for nonface objects, and the expertise hypothesis predicts no facelike holistic processing for objects without any training. A strong version of this constraint is that without training, people cannot process nonface objects holistically at all (Bukach, Phillips, & Gauthier, 2010; Robbins & McKone, 2007; A. C.-N. Wong et al., 2009). A weak version is that novices may process nonface objects holistically, but cannot process them as holistically as they do faces (Farah et al., 1998; Rossion, 2013). Here, we report evidence that violates both versions and indicates the need for a broader view of holistic processing than is offered by current hypotheses.

We adopted an information-based approach to investigate what underlies holistic processing and whether holistic processing can generalize beyond faces and objects of expertise. Our rationale is that if certain information conveyed in faces underlies holistic processing, then nonface objects conveying the same type of information should be processed holistically as well. The information that supports holistic face processing may be embedded in faces physically (e.g., facial shape information; Zhao, Bülthoff, & Bülthoff, 2015) or at a more abstract level (e.g., Gestalt information that integrates different parts into a whole; Curby, Goldstein, & Blacker, 2013). Many studies have investigated which physical information mediates holistic face processing (e.g., Cheung et al., 2008; Jiang, Blanz, & Rossion, 2011; Zhao et al., 2015). Surprisingly, although faces are frequently referred to as Gestalts (for details, see Table S1 in the Supplemental Material available online), little research has investigated whether holistic face processing is supported by the Gestalt information present in faces, and whether similar Gestalt information suffices to activate holistic processing for nonface objects in the absence of expertise.

We hypothesized that holistic face processing is supported by information similar to that underlying Gestalt perception of objects. This hypothesis derives from the fact that holistic processing, as revealed by the composite-face effect, mirrors two core aspects of Gestalt perception: (a) The whole has new, emerging properties that do not exist in the parts (i.e., emergence), and (b) perception of the whole reduces the accessibility of the constituent parts (Poljac, de-Wit, & Wagemans, 2012; Pomerantz & Portillo, 2011; Suzuki & Cavanagh, 1995; Wagemans et al., 2012). According to this hypothesis, embedding facelike Gestalt information in nonface objects should elicit holistic processing spontaneously without any training, and, more important, manipulating such Gestalt information should affect holistic processing accordingly.

We devised two experiments to test our hypothesis. Experiment 1 investigated whether salient Gestalt information elicits facelike holistic processing of nonface objects in novices. We created line-pattern stimuli that conveyed Gestalt information analogous to that in human faces. Specifically, their top and bottom parts were fused together by Gestalt principles of connectedness, closure, and continuity. Moreover, replacing the bottom part of a line pattern with a different one formed a new line pattern (i.e., emergence), just as switching a bottom half of a face changes the face's whole appearance. We then tested whether these pattern stimuli were processed as holistically as human faces. Experiment 2 investigated whether weakening the Gestalt information in the line patterns would reduce holistic processing. To attenuate the saliency of Gestalt information (i.e., to reduce connectedness, closure, and continuity), we replaced all lines in the line patterns with dots, creating dot patterns.

The procedures for the experiments were approved by the Ethical Review Board of the University of Tübingen; signed informed consent was obtained from each participant before the experiments. On the basis of prior research (Cheung et al., 2008; Richler, Tanaka, Brown, & Gauthier, 2008; Zhao et al., 2015), we aimed to collect data from 20 participants in each experiment. We allowed 22 people to register in case some might not show up, and we stopped data collection after testing all those who did show up.

Experiment 1a: Can Nonface Objects Elicit Facelike Holistic Processing Without Training?

Method

Participants. Twenty-two people participated in this experiment (10 males and 12 females; mean age = 26 years, *SD* = 4).

Stimuli

Composite faces. Face stimuli were created from 20 Caucasian faces (10 males, 10 females; gray-scale images) in the face database of the Max Planck Institute for Biological Cybernetics (Blanz & Vetter, 1999; Troje & Bülthoff, 1996). Twenty face pairs were formed by using each face as a target face once and as a gender-matched paired face once. Each pair was a unique combination of two faces (i.e., any two pairs differed in at least one face). Each face image was cut into a top part and a bottom part (each 270 × 135 pixels). Within the pairs, tops and bottoms were combined to create composite faces (Fig. 1a). For each of the 20 pairs of faces, 8 pairs of composite faces were created following the design illustrated in Figure 1c. Thus, there were 160 pairs of composite faces in total. A 1-pixel black line was added to each composite face to clearly separate the top and bottom parts. Stimuli used for practice trials were created using the same method with additional faces from the database.

Composite patterns. Twenty pairs of line patterns were created; within each pair, one pattern served as the target (Fig. 1b). Each line-pattern stimulus was cut into a top part and a bottom part (each 270 × 135 pixels). Within each pair of line patterns, both the two top parts and the two bottom parts differed from each other, but they could be swapped without disrupting the Gestalt information connecting the top and bottom parts (i.e., connectedness, closure, and continuity between lines). Aligning the top part of one line pattern with the bottom part of the paired line pattern formed a new line pattern, changing the appearance of the top part (i.e., emergent features were exhibited; Fig. 1b). The composite-pattern stimuli were created using the same method as for the faces. For each of the 20 pairs of line patterns, we created 8 pairs of composite patterns following the design illustrated in Figure 1c, so there were 160 pairs of test stimuli in total. Stimuli used for practice trials were created the same way with additional pairs of line patterns (see Fig. S1 in the Supplemental Material for all line-pattern stimuli).

Procedure. Participants performed two composite tasks, one with faces and one with line patterns (order counterbalanced across participants). On each trial, we presented 1 of the 160 pairs of faces or line patterns sequentially with an intervening mask (Figs. 1a and 1b). The target face or line pattern was always presented as the first stimulus. Participants made a same/different judgment about the top parts of the two faces or line patterns. Trials were presented in random order in each task, with an intertrial interval of 1 s (blank screen). Participants were instructed to attend to the top parts only and to ignore the bottom parts. For each task, participants completed eight practice trials before the experimental trials.

We used a complete design of the composite task to measure holistic processing (Richler, Cheung, & Gauthier, 2011). With this design (Fig. 1c), the first stimulus in a trial (i.e., the target face or line pattern) was always aligned. The second was either aligned (*aligned condition*) or misaligned (*misaligned condition*). For misaligned faces and line patterns, we shifted the top part to the right and the bottom part to the left by 33 pixels each. The top parts of the two stimuli (i.e., targets) in a trial were either the same (*same condition*) or different from each other (*different condition*). Finally, the irrelevant bottom parts were also manipulated. In the *congruent condition*, the bottom parts were the same in the *same* condition and were different in the *different* condition. In the *incongruent condition*, they were different in the *same* condition and were the same in the *different* condition. This design yielded 160 trials per stimulus type (2 alignment conditions × 2 congruency conditions × 2 same/different conditions × 20 exemplars of target stimuli).

Data analysis. Response sensitivity (d') was calculated using hit and false alarm rates. Statistically, holistic processing is indexed by both a higher response sensitivity in the congruent condition than in the incongruent condition (i.e., congruency effect) and a larger congruency effect in the aligned condition than in the misaligned condition (i.e., Congruency × Alignment interaction; Fig. 1d). We focus here on these indices, and report additional results in the Supplemental Material.

Results

Response sensitivity (d') for all conditions is shown in Figure 2. A 2 (alignment) × 2 (congruency) × 2 (task) repeated measures analysis of variance (ANOVA) revealed a main effect of congruency, $F(1, 21) = 41.84$, $p < .001$, $\eta_p^2 = .67$; sensitivity was higher on congruent than on incongruent trials ($M = 2.40$, $SE = 0.14$, vs. $M = 1.84$, $SE = 0.18$). The interaction between congruency and alignment was also significant, $F(1, 21) = 25.81$, $p < .001$, $\eta_p^2 = .55$; the congruency effect was larger in the aligned conditions than in the misaligned conditions. These results indicate that both the faces and the line patterns were processed holistically. The three-way interaction of alignment, congruency, and task was not significant, F(1,

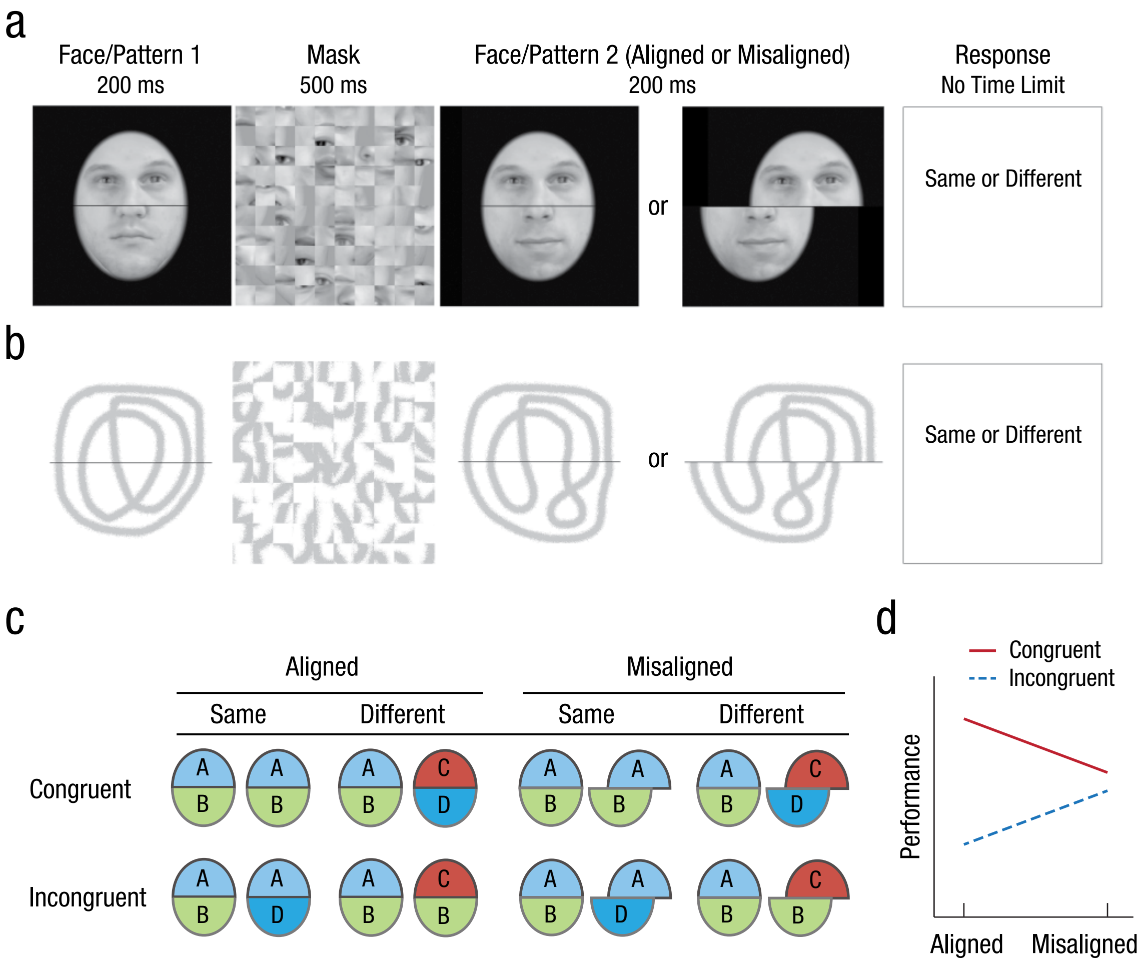

Fig. 1. Stimuli, experimental design, and predicted performance in Experiment 1. On each trial (a, b), participants viewed a face or a line pattern, which was followed by a mask and then a second face or line pattern. Participants indicated whether the top parts of the two faces or patterns were the same or different. According to the 2 × 2 × 2 experimental design (c), the top and bottom parts of the second stimulus were aligned or misaligned, the top parts of the first and second stimuli were the same or different, and the relation between the bottom parts of the first and second stimuli was congruent or incongruent with the relation between the top parts. If participants processed the stimuli holistically, as predicted, performance in the congruent conditions would be better than performance in the incongruent conditions when the top and bottom parts of the second stimulus were aligned, but not when they were misaligned (d).

21) = 3.80, p = .065, η_p^2 = .15, which suggests that the line patterns were processed as holistically as the human faces, despite their dramatically different appearance.

Separate analyses for each task showed that holistic processing was evident for both faces and line patterns. For the face task, the congruency effect, $F(1, 21)$ = 26.35, p < .001, η_p^2 = .56, and the interaction between congruency and alignment, $F(1, 21)$ = 7.97, p = .010, η_p^2 = .28, were both significant. Moreover, the congruency effect was significant only in the aligned condition, $t(21)$ = 5.41, p < .001, Cohen's d = 1.15, and not in the misaligned condition, $t(21)$ = 2.00, p = .059, Cohen's d = 0.43. These results indicate holistic face processing: Participants could not selectively attend to the top parts without any interference from the task-irrelevant bottom parts within a whole-face context. The same results held for the line-pattern task. Both the congruency effect, $F(1, 21)$ = 26.30, p < .001, η_p^2 = .56, and the interaction between congruency and alignment, $F(1, 21)$ = 22.80, p < .001, η_p^2 = .52, were significant. Again, a significant congruency effect was observed in the aligned condition, $t(21)$ = 5.95, p < .001, Cohen's d = 1.27, but not in the misaligned condition, $t(21)$ = 0.96, p = .348, Cohen's d = 0.20. Therefore, line patterns elicit facelike holistic processing, even without any training, when they convey salient Gestalt information.

Experiment 1b: Replicating Facelike Holistic Processing With Separate Face and Pattern Tasks

The similar holistic processing observed for faces and line patterns in Experiment 1a might have arisen because

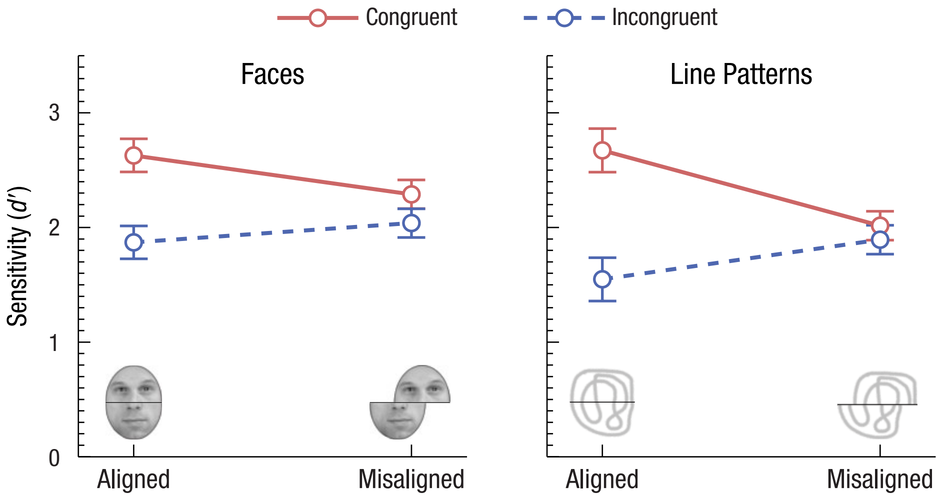

Fig. 2. Results from Experiment 1a: response sensitivity as a function of congruency and alignment in the composite-face task (left) and the composite-pattern task (right). Error bars represent ±1 *SEM*.

both tasks were tested in one session, which might have biased participants to use similar attention strategies for the two types of stimuli (Richler et al., 2009; Weston & Perfect, 2005). To address this issue, we tested participants with faces and line patterns in separate sessions.

Method

Participants. Twenty people participated in this experiment (8 males and 12 females; mean age = 29 years, *SD* = 7).

Stimuli and procedure. The stimuli, tasks, and procedure were similar to those in Experiment 1a. To eliminate any potential influence of task context on holistic processing, we had participants perform the face and line-pattern tasks at different sessions separated by about 2 months. They did not know beforehand that they would perform the same task with faces and patterns.

Results

Experiment 1b replicated the results of Experiment 1a (Fig. 3). A 2 (alignment) × 2 (congruency) × 2 (task) ANOVA revealed a significant congruency effect, $F(1, 19) = 55.83$, $p < .001$, $\eta_p^2 = .75$; sensitivity was higher on congruent than on incongruent trials ($M = 2.45$, $SE = 0.13$, vs. $M = 1.87$, $SE = 0.15$). The interaction between congruency and alignment was also significant, $F(1, 19) = 44.64$, $p < .001$, $\eta_p^2 = .70$; the congruency effect was larger in the aligned conditions than in the misaligned conditions. The significant three-way interaction, $F(1, 19) = 9.78$, $p = .006$, $\eta_p^2 = .34$, suggests that holistic processing was even more prominent for line patterns than for faces. Thus, the facelike holistic processing observed in Experiment 1a cannot be attributed to the contextual influence of performing the two tasks within one session. These results provide convincing evidence that line patterns with salient Gestalt information suffice to elicit facelike holistic processing.

Separate analyses showed that both faces and line patterns were processed holistically. The congruency effect was significant for both faces, $F(1, 19) = 15.01$, $p = .001$, $\eta_p^2 = .44$, and line patterns, $F(1, 19) = 42.27$, $p < .001$, $\eta_p^2 = .69$. The Congruency × Alignment interaction was marginally significant for faces, $F(1, 19) = 4.12$, $p = .057$, $\eta_p^2 = .18$, and significant for line patterns, $F(1, 19) = 85.53$, $p < .001$, $\eta_p^2 = .82$. The congruency effect was significant in the aligned conditions of the face task, $t(19) = 3.60$, $p = .002$, Cohen's $d = 0.80$, and the line-pattern task, $t(19) = 8.39$, $p < .001$, Cohen's $d = 1.88$, but was not significant in the misaligned conditions, $t(19) = 0.92$, $p = .367$, Cohen's $d = 0.21$, and $t(21) = 0.85$, $p = .404$, Cohen's $d = 0.19$, respectively. These results demonstrate that salient Gestalt information that groups different parts into a whole may underlie holistic processing for both faces and nonface line patterns. The pattern task also showed overall lower performance in the misaligned condition than in the aligned condition, $F(1, 19) = 4.59$, $p = .045$, $\eta_p^2 = .19$.

Experiment 2: Does Attenuating Gestalt Information Reduce Facelike Holistic Processing?

Experiment 2 investigated whether manipulation of Gestalt information affects holistic processing. To this end, we created dot patterns (Fig. 4b) derived from the

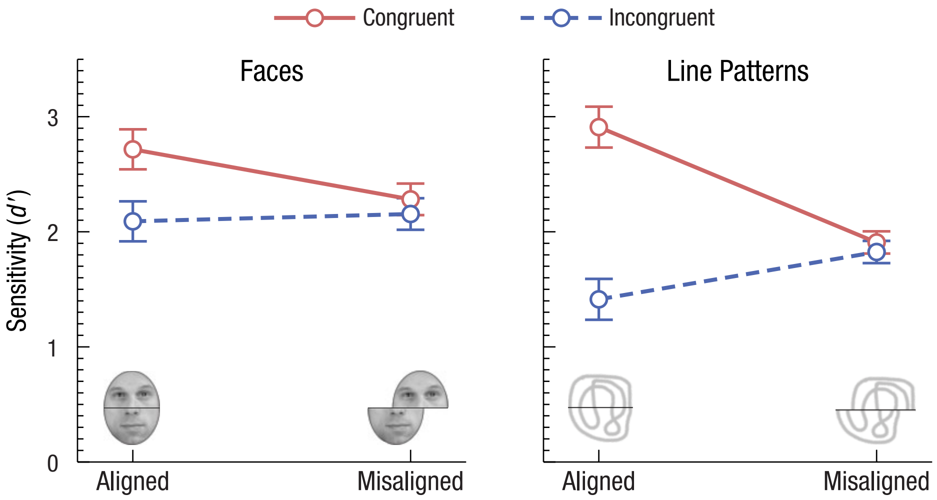

Fig. 3. Results from Experiment 1b: response sensitivity as a function of congruency and alignment in the composite-face task (left) and the composite-pattern task (right). Error bars represent ±1 *SEM*.

original line patterns, thereby weakening their Gestalt information. We then compared performance for the dot patterns, line patterns, and faces.

Method

Participants. Twenty-two people participated in this experiment (9 males and 13 females; mean age = 25 years, *SD* = 4).

Stimuli and procedure. The face stimuli were the same as in Experiment 1a (Fig. 4a). The dot-pattern stimuli were created by replacing the lines in the line patterns with dots, which reduced the saliency of their Gestalt information, such as connectedness, closure, and continuity between top and bottom parts (Fig. 4b). The procedure was the same as in Experiment 1, except that both faces and dot patterns were presented for 450 ms to avoid floor performance on the dot-pattern task (Fig. 4).

Results

The dot patterns were processed as holistically as the human faces (Fig. 5). A 2 (alignment) × 2 (congruency) × 2 (task) ANOVA revealed a significant congruency effect, $F(1, 21) = 26.51$, $p < .001$, $\eta_p^2 = .56$, reflecting greater sensitivity on congruent than on incongruent trials ($M = 2.63$, $SE = 0.12$, vs. $M = 2.21$, $SE = 0.13$). The interaction

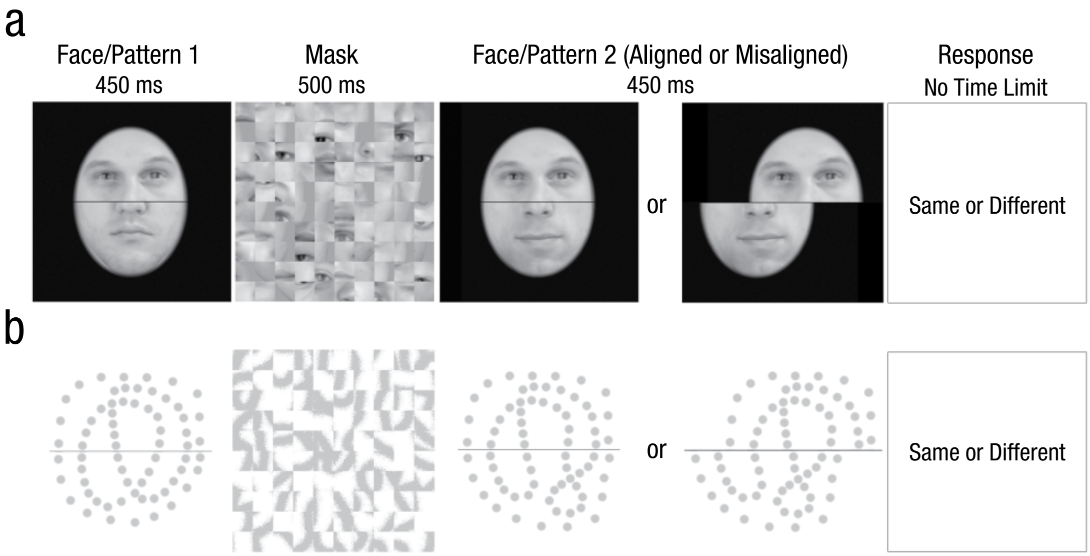

Fig. 4. Illustration of the stimulus sequences of the (a) composite-face task and (b) composite-pattern task used in Experiment 2.

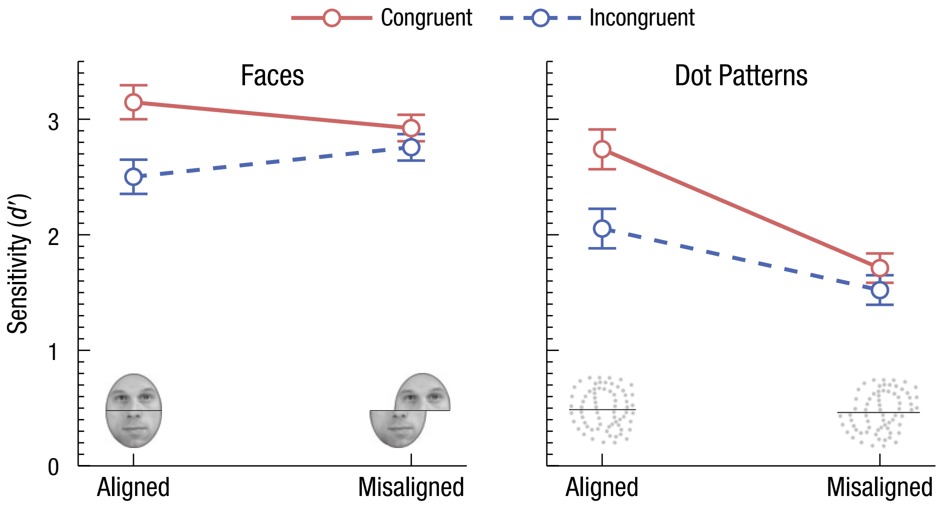

Fig. 5. Results from Experiment 2: response sensitivity as a function of congruency and alignment in the composite-face task (left) and the composite-pattern task (right). Error bars represent ±1 *SEM*.

between congruency and alignment was also significant, $F(1, 21) = 11.94$, $p < .001$, $\eta_p^2 = .36$, reflecting a larger congruency effect in the aligned conditions than in the misaligned conditions. These patterns of response fit nicely with holistic processing. The three-way interaction was not significant, $F(1, 21) = 0.01$, $p = .930$, $\eta_p^2 < .01$, which suggests that holistic processing of faces and dot patterns is qualitatively similar.

Separate analyses revealed that both the faces and the dot patterns were processed holistically (Fig. 5). The congruency effect was significant for both faces, $F(1, 21) = 14.64$, $p < .001$, $\eta_p^2 = .41$, and dot patterns, $F(1, 21) = 14.53$, $p = .001$, $\eta_p^2 = .41$, as was the interaction between congruency and alignment, $F(1, 21) = 9.17$, $p = .006$, $\eta_p^2 = .30$, and $F(1, 21) = 6.39$, $p = .020$, $\eta_p^2 = .23$, respectively. Again, the interactions were driven by a significant congruency effect in the aligned conditions—faces: $t(21) = 4.37$, $p < .001$, Cohen's $d = 0.93$; dot patterns: $t(21) = 4.00$, $p < .001$, Cohen's $d = 0.85$—but not in the misaligned conditions—faces: $t(21) = 1.46$, $p = .160$, Cohen's $d = 0.31$; dot patterns: $t(21) = 1.49$, $p = .152$, Cohen's $d = 0.32$. Therefore, as was the case with faces, when the top and bottom parts of dot patterns formed a Gestalt, participants were unable to selectively attend to one part and ignore the other. As found with the line patterns in Experiment 1b, the dot-pattern task showed overall lower performance in the misaligned than in the aligned condition, $F(1, 21) = 28.10$, $p < .001$, $\eta_p^2 = .57$. This might have been because the misaligned top and bottom parts of the line and dot patterns formed unexpected novel patterns (Fig. 1b and Fig. 4b).

Manipulating Gestalt information affected the magnitude of holistic processing (Fig. 6), which suggests a causal role of object-based Gestalt information in eliciting holistic processing. The *holistic-processing effect* was calculated by subtracting the congruency effect (i.e., d' in the congruent condition minus d' in the incongruent condition) in the misaligned condition from the congruency effect in the aligned condition (Chua et al., 2014; Richler, Cheung, & Gauthier, 2011). We found a larger holistic-processing effect for line patterns ($M = 1.20$, $SE = 0.13$; Experiments 1a and 1b combined) than for dot patterns ($M = 0.50$, $SE = 0.20$; Experiment 2), $t(62) = 3.00$, $p = .004$, Cohen's $d = 0.74$. Thus, weakening the connectedness, closure, and continuity information in line patterns reduces holistic processing of those patterns.

Finally, the holistic-processing effect was not stronger for the human faces than for the line- or dot-pattern stimuli (Fig. 6). Across the experiments, the holistic-processing effect for faces remained constant (Experiment 1a: $M = 0.51$, $SE = 0.18$; Experiment 1b: $M = 0.50$, $SE = 0.25$; Experiment 2: $M = 0.48$, $SE = 0.16$), $F(2, 63) = 0.01$, $p = .993$. The magnitude of this effect was equivalent to that for the dot patterns, $t(21) = 0.09$, $p = .930$, but smaller than that for the line patterns, $t(41) = 3.60$, $p < .001$, Cohen's $d = 0.56$.

General Discussion

The present study demonstrates, for the first time to our knowledge, that the visual system can process certain objects as holistically as faces without extensive training. When line and dot patterns are designed to exhibit Gestalt information analogous to that in faces, they elicit the same composite effect as observed for faces. This indicates that the way people perceive faces is similar to the way they see these geometric patterns. The finding that holistic processing for line patterns was even stronger than that for faces suggests that faces are not special when it comes to holistic processing and do not

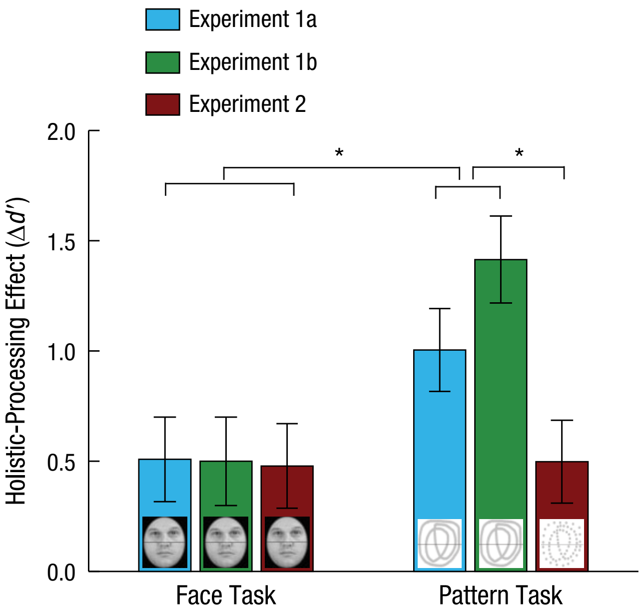

Fig. 6. Magnitudes of the holistic-processing effect as a function of task in Experiments 1a, 1b, and 2. Error bars represent ±1 *SEM*. Asterisks indicate significant differences ($^*p < .01$).

represent the ultimate form of a Gestalt (cf. Rossion, 2013). Therefore, facelike holistic processing is not limited to faces and objects of expertise; it can be achieved via routes other than the activation of an innate face template (McKone et al., 2007) or learned attention to object parts (Chua et al., 2015). These results challenge influential theories of holistic processing: Neither the domain-specific hypothesis nor the expertise hypothesis predicts such facelike holistic processing of nonface objects in novices (e.g., Richler, Wong, & Gauthier, 2011; Robbins & McKone, 2007).

Whereas previous studies have highlighted a top-down route to holistic processing (e.g., expertise), our study reveals a bottom-up route—which has been long missing from prevailing theories. The top-down route is demonstrated by findings showing that holistic processing can be turned on or off following different training regimens. For instance, extensive training in individuating objects can turn initially isolated parts into perceptual wholes, resulting in holistic processing for objects of expertise (e.g., Boggan, Bartlett, & Krawczyk, 2012; Y. K. Wong & Gauthier, 2010). Conversely, learned *inattention* to elements of ordinarily perceived Gestalts (e.g., faces) can tear the wholes into parts, eliminating holistic processing (Chua et al., 2014). Here, we have provided convincing evidence for a bottom-up route: Object-based Gestalt information can activate holistic processing in individuals who lack expertise. Such a bottom-up route also influences holistic processing of faces (e.g., Curby et al., 2013; Zhao et al., 2015), which suggests that face perception is governed by the same perceptual grouping principles that apply to nonface objects.

Our results show that the Gestalt information that “glues” different parts into a whole underlies the bottom-up route to holistic processing. Two lines of evidence support this conclusion. First, we found that salient Gestalt information elicited spontaneous facelike holistic processing. Second, manipulating the Gestalt information in our stimuli causally modulated holistic processing. When the interconnection between parts was weakened by using dots instead of continuous lines in our pattern stimuli, holistic processing was attenuated (Fig. 6). Similarly, disrupting the Gestalt cues that group facial parts together (e.g., similarity and continuity of background colors) reduces holistic processing of faces (Curby et al., 2013; Zhao et al., 2015). These complementary findings indicate that holistic processing of faces and of nonface objects is mediated by similar object-based Gestalt information (e.g., connectedness between elements, closure, good continuation, emergence of new properties when parts are changed; Wagemans et al., 2012).

We propose that holistic processing is implemented by both the bottom-up and the top-down routes (see also Zhao et al., 2015). Whereas object-based Gestalt information provides a perceptual basis for holistic processing (i.e., bottom-up route), observer-based experience shapes what constitutes perceptual Gestalts and how sensitive the visual system is to them (i.e., top-down route). This dual-route account addresses some long-standing issues about holistic processing, expertise, and the domain-specificity of faces: why objects other than faces and objects of expertise are sometimes processed holistically, and why holistic processing sometimes breaks down for certain types of faces and objects of expertise (e.g., Robbins & McKone, 2007; Zhao et al., 2015). For instance, expert-level training does not necessarily make observers sensitive to all information about their objects of expertise (Chua et al., 2014, 2015), which probably explains why dog experts do not process dogs’ bodies holistically (Robbins & McKone, 2007) and why people do not process the human body holistically despite having lifelong experience individuating persons (Bauser, Suchan, & Daum, 2011). Therefore, whether objects contain Gestalt information that observers are sensitive to determines whether those objects are processed holistically.

Our study also indicates the usefulness of an information-based approach in investigating what makes faces special and what does not (Diamond & Carey, 1986; Farah et al., 1998). This approach not only can help reveal what type of information underlies holistic processing (Farah, Tanaka, & Drain, 1995; Zhao et al., 2015), but also can shed light on what underlying information elicits face-selective responses in the brain. For instance, the right fusiform gyrus, which responds preferentially to faces, is also tuned to curvilinear patterns with more elements in the upper than the lower part, and this suggests that its neural selectivity to faces is driven by these low-level geometric regularities (Caldara & Seghier, 2009; Caldara et al., 2006). By linking visual information shared by faces and nonface objects, this approach offers one effective way to bridge the gap between face perception and general visual object processing.

In sum, facelike holistic processing can be generalized to objects beyond the domains of faces and objects of expertise, and can be achieved via object-based Gestalt information (i.e., a bottom-up route). Contrary to prevailing theories, neither faces nor expertise is necessary or sufficient to activate holistic processing (i.e., holistic processing does not always require faces or expertise, and faces and objects of expertise are not always processed holistically). Therefore, theories emphasizing either faces or expertise may paint an incomplete picture about what holistic processing actually is and what underlies it. For a complete understanding of holism in visual perception, future research should go beyond modeling face perception alone to unravel the computational mechanisms of holistic processing, and should go beyond investigating face-selective cortical areas to identify its neural underpinnings.

Author Contributions

M. Zhao designed and conducted the experiment, analyzed the data, and drafted the manuscript. I. Bülthoff and H. H. Bülthoff contributed to the experimental design, provided experimental materials, and provided a critical review of the manuscript. All authors approved the final version of the manuscript for submission.

Acknowledgments

We are grateful to Mike Burton, Alice O'Toole, and Jennifer Richler for very helpful comments on an earlier version of this manuscript. We thank Amelie Haugg for her assistance with data collection.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

Funding

This research was supported by the Max Planck Society. Part of H. H. Bülthoff's research was supported by the Brain Korea 21 PLUS program through the National Research Foundation of Korea, funded by the Ministry of Education.

Supplemental Material

Additional supporting information can be found at http://pss.sagepub.com/content/by/supplemental-data

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