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Global shape information increases but color information decreases the composite face effect

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Abstract. The separation of visual shape and surface information may be useful for understanding holistic face perception—that is, the perception of a face as a single unit (Jiang, Blanz, & Rossion, 2011, *Visual Cognition*, **19**, 1003–1034). A widely used measure of holistic face perception is the composite face effect (CFE), in which identical top face halves appear different when aligned with bottom face halves from different identities. In the present study the influences of global face shape (ie contour of the face) and color information on the CFE are investigated, with the hypothesis that global face shape supports but color impairs holistic face perception as measured in this paradigm. In experiment 1 the CFE is significantly increased when face stimuli possess natural global shape information than when cropped to a generic (ie oval) global shape; this effect is not found when the stimuli are presented inverted. In experiment 2 the CFE is significantly decreased when face stimuli are presented with color information than when presented in grayscale. These findings indicate that grayscale stimuli maintaining natural global face shape information provide the most adept measure of holistic face perception in the behavioral composite face paradigm. More generally, they show that reducing different types of information diagnostic for individual face perception can have opposite effects on the CFE, illustrating the functional dissociation between shape and surface information in face perception.

Keywords: composite face effect, composite face paradigm, color, shape, holistic face perception, visual illusion

1 Introduction

A myriad of features in the visual world contribute to perception; in investigating how the human visual system forms an integrated percept from such different features, a broad division can be made between two-dimensional surface reflectance—that is, texture, color, and luminance—versus three-dimensional shape information (Bruce & Young, 1998). This division has been integral in research on object recognition, with the dominant perspective, proposed in structurally based theories, that shape is most informative, or even sufficient, for this process (eg Biederman, 1987; Marr, 1982). However, in more recent theories the capacity for surface information to facilitate object recognition is accommodated: a ‘shape + surface’ model allows for the addition of color, and potentially texture, to contribute to object recognition (Tanaka, Weiskopf, & Williams, 2001).

Theories about the different contributions of shape and surface information have also been applied to within-category discrimination research, notably in face perception, where human faces provide a rich range of shape and surface information. Shape and texture were identified as quantifiable dimensions of a ‘face space’ (Valentine, 1991), and also have been isolated as distinct components in face perception using the image-based statistic of principal component analysis (Hancock, Burton, & Bruce, 1996). Resultantly, there is an interest in the contributions of shape and surface information to face perception, reflected not only by the number of studies designed to isolate the contributions of these sources of information (eg Itz, Schweinberger, Schulz, & Kaufmann, 2014; Lai, Oruç, & Barton, 2011; O’Toole, Vetter, & Blanz, 1999; Russell, Sinha, Biederman, & Nederhouser, 2006) but also by the generation of several resources dividing these types of information. The distinction of shape and surface information has been emphasized in the widely used Max-Planck face database (Troje & Bülthoff, 1995), and has been used as a basis in computing face image transformations (Rowland & Perrett, 1995).

A fundamental aspect of face perception is the process by which the parts of a face are integrated into a single representation—that is, holistic face perception (McKone, Martini, & Nakayama, 2003; Rossion, 2013; Tanaka & Farah, 1993; Young, Hellawell, & Hay, 1987). There is a general consensus that the composite face effect (CFE), which measures the illusion that the identical top halves of two face stimuli appear different when aligned with the bottom halves of two different identities (see figure 1a; Hole, 1994; Young et al., 1987), is the most direct and sensitive behavioral measure of holistic face perception (see Rossion, 2013, for a review).

Although most studies dividing shape and surface information have not focused on holistic face perception, there is one notable exception. Jiang and colleagues manipulated shape, surface reflectance, or both these types of information in composite face stimuli. The results showed no CFE when only surface reflectance was diagnostic of a difference of identity, and the largest CFE when both shape and surface information were diagnostic (Jiang et al., 2011). However, only the distracting bottom face halves were manipulated in this study. Therefore, these results suggest that the dissociation of shape and surface information in holistic face perception can be measured behaviorally with the CFE, but do not allow conclusions about the potential usefulness of varying the amount of shape or surface information across the whole face. Moreover, even though shape information and surface information were isolated as the diagnosticity of the bottom face halves differed between conditions, all stimuli contained both shape and color information (see figure 1 in Jiang et al., 2011). Finally, the study was not designed to isolate the role of color from that of texture information and, most importantly, the contribution of global face shape, which could be critical in holistic face perception, from the local shape of facial parts.

In the present study the impacts of global face shape and color information on holistic perception as measured in the composite face paradigm were examined with three types of common composite face stimuli: color, grayscale, and global shape-normalized (ie oval) grayscale faces. In doing so, we had the practical goal of discovering which stimuli improve the sensitivity of the CFE, given that previous studies have used composite faces with global shape normalized (eg Cassia, Picozzi, Kuefner, Bricolo, & Turati, 2009; Curby, Goldstein, & Blacker, 2013; Robbins & McKone, 2003; Soria-Bauser, Suchan, & Daum, 2011; Taubert & Alais, 2011; Zhao & Hayward, 2010) or without global shape normalized (eg de Heering, Wallis, & Maurer, 2012; Jiang et al., 2011; Laguesse & Rossion, 2013; Young et al., 1987), and with color (eg de Heering et al., 2012; Jiang et al., 2011; Laguesse & Rossion, 2013) or without color (a majority of studies, eg Cassia et al., 2009; Hole, 1994; Le Grand, Mondloch, Maurer, & Brent, 2004; Robbins & McKone, 2003; Soria-Bauser et al., 2011; Taubert & Alais, 2011; Zhao & Hayward, 2010). By testing these composite face stimuli, we limited shape information to external contour, excluding, for example, changes in the shape of internal face parts, and limited surface information to color, excluding, for example, texture information.

In a first experiment we tested the hypothesis that reducing global shape information by using shape-normalized stimuli would decrease the CFE. That shape may contribute importantly to the CFE is in line with Jiang et al. (2011). It is reinforced by the fact that, here, the manipulation concerns only global shape information—which, by definition, should influence holistic face perception—rather than shape information at the level of local parts. In a control experiment (1b) we tested whether such a reduction in the CFE would extend to inverted faces, which are not, or much less than upright faces, perceived holistically (Rossion, 2013; Sergent, 1984; Tanaka & Farah, 1993; Van Belle, de Graef, Verfaillie, Rossion, & Lefèvre, 2010; Young et al., 1987). We hypothesized that a larger CFE would not be found for stimuli containing shape information than for shape-normalized stimuli in this case, indicating that the reduction of information in shape-normalized stimuli selectively impacted holistic face perception.

Finally, in a second experiment we directly tested the role of color information on the CFE by comparing results from grayscale and color face stimuli. In contrast to shape, color information is predicted to have an antagonistic effect on the magnitude of the CFE, since the contribution of color to identity recognition may be primarily through low-level segmentation of facial parts (Yip & Sinha, 2002), and the color cues that are diagnostic of individuality in faces are resolved locally (eg color of the lips, or eyes), or at least can be resolved locally (eg skin color). Thus, in one situation an increase of visual (shape) information is expected to increase the CFE, while in the other situation an increase of visual (color) information is expected to decrease the CFE: the quality, not the quantity, of visual information is expected to have the dominant influence on holistic face perception as measured in this paradigm.

2 Experiment 1a

2.1 *Methods*

2.1.1 *Participants.* Thirty participants were recruited on a collegiate campus (mean age = 23 years, range = 19–26 years, five male) for this study, which was approved by the Biomedical Ethical Committee of the University of Louvain. Data from two participants were excluded, as these participants scored two standard deviations below the mean for accuracy (determined by an average across both stimulus sets and alignment conditions; $M = 89\%$, SD = 7.0%) on 'different' trials—that is, trials that are not relevant for the CFE but can serve as a control of performance (Rossion, 2013). Participation was voluntary, signed informed consent was given, and monetary compensation was provided.

2.1.2 *Stimuli.* Face stimuli were created from 10 full-front photographs of expressionless Caucasian faces (half male). Using Adobe Photoshop CS5, the photographs were cropped to include only the face, excluding external features (eg hair, ears), standardized by image height, converted to grayscale, and equalized for mean pixel luminance. Composite faces were created by splitting the faces into top and bottom halves just above the nostrils, and aligning the top half of one face with four bottom halves from four different identities, leaving a gap of 0.5% of the image height in between the halves, so that the top half could be clearly identified (Rossion & Retter, in press). To make the face halves correspond plausibly, the bottom face half was adjusted in two ways: the position of the nose was aligned to that of the top half, and the luminance was adjusted to minimize local luminance differences around where the halves joined. The aligned stimuli, which were about 300 pixels in height and 218 pixels in width, were thus generated. To create matching misaligned stimuli, the bottom half of each face was translated to the right by 25% of the width of the top face half (Laguesse & Rossion, 2013). These stimuli may be downloaded at http://face-categorization-lab.webnode.com/resources/stimuli-composite/.

The above process fully describes the creation of regular stimuli; a second stimulus set of oval-shaped stimuli was also generated from these exact images. In Adobe Photoshop CS5 an oval shape was drawn and used as a template to define a face area, centered over and including the full internal features of each face stimulus: the area outside of this oval was then deleted. The size of the aligned oval-shaped face stimuli subtended approximately 240 pixels in height and 200 pixels in width.

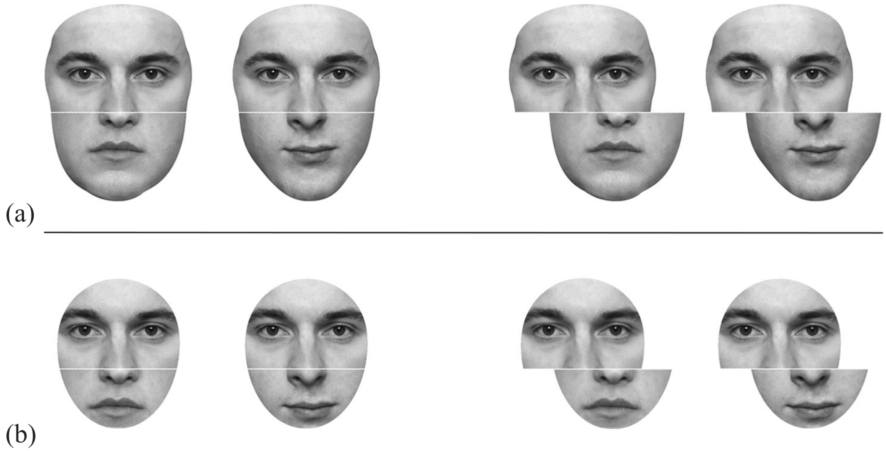

Figure 1. An example of a composite stimulus pair, in which the top face halves are identical, while the bottom halves are different. On the left side the pairs are shown aligned; on the right side the bottom halves are misaligned, a manipulation which impairs the composite face effect—that is, the illusion that the top halves are different. (a) Regular stimuli containing shape information. (b) Global shape-normalized (ie oval) face stimuli, as used in experiment 1.

2.1.3 *Procedure.* The CFE is measured with performance at matching two identical top halves of a face when they are combined with bottom face halves from different identities; performance is compared when these bottom halves are aligned with when they are misaligned (Rossion, 2013). Here, as in most studies, this measure was collected using a delayed matching task, in which participants were instructed to respond on a computer keyboard whether a probe face contained a top half identical to that of the previously presented target face. Participants were asked to respond as accurately and as quickly as possible.

Each trial consisted of (1) a black fixation cross on a white background for 200 ms; (2) a blank screen for 150 ms; (3) the target face for 200 ms; (4) a blank screen for 400 ms; (5) the probe face for 500 ms; and finally (6) a blank screen until a response was recorded (figure 2). In between trials a 1300 ms intertrial interval of a fixation cross occurred. The total duration of the experiment was approximately 15–20 min: the experiment consisted of 360 trials [approximately 1.5 s each, plus response time (RT)], representing 60 randomized presentations of six conditions in each of the two stimulus sets.

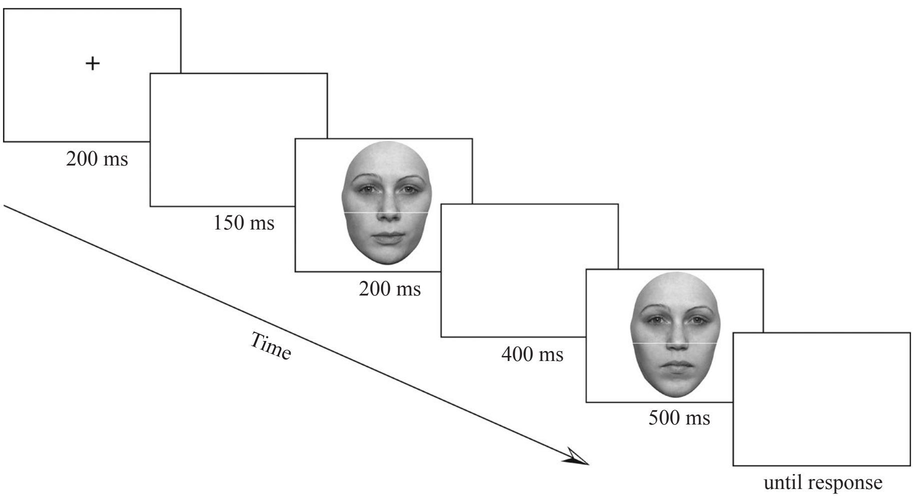

Figure 2. The timeline of a trial. The trial format was identical for all conditions; the composite aligned condition for the regular stimulus set is illustrated here.

The six kinds of trials per stimulus set were generated from two alignment factors (aligned or misaligned) and three identity factors (same, composite, or different identities); the alignment factor was held constant between target and probe faces for each trial, while the identity factor was defined as a comparison of target and probe faces. Thus, for example, both target and probe faces could be aligned and of the same identity (same aligned condition), or the target and probe faces could be both misaligned but of different identities (different misaligned condition). In the critical composite identity condition the top halves of the target and probe face were from the same identity, while uniquely the bottom halves were from different identities.

The same identity trials were used as a baseline condition. For these trials, the correct response is 'same', as in the composite identity condition, but performance is not expected to be reduced for aligned as compared with misaligned trials—that is, no CFE is expected. Therefore, the same identity trials may elucidate general differences across the stimulus sets, but are not expected to produce an effect of alignment or an interaction between these factors. Different identity trials were included so that participants' expected response was not always 'same', although these trials were not included in the analysis (Rossion, 2013).

For the two stimulus sets, regular and oval faces, the exact same target/probe pairs were used. The probe face was presented a size 5% larger than the target, to avoid low-level visual matching. Additionally, within a target/probe pair, the sex of the face always matched, and each identity was represented with equal frequency as a target or probe (8–12 repetitions each).

E-Prime 2.0 was used to run the experiment. Participants were tested individually, and seated 1 m from a computer monitor, at which distance the target aligned stimuli appeared at about 3.5×4.7 deg for regular aligned face stimuli, and at about 3.2×3.8 deg for oval aligned face stimuli.

2.1.4 *Analyses.* Measures of accuracy and RT were averaged by condition for each participant, as well as inverse efficiency (IE), defined as RT/accuracy, a measure which combines the results by condition into one variable and is used to take into account speed–accuracy trade-offs (Townsend & Ashby, 1983). Participants were instructed to respond as quickly as possible, but were given unlimited time to make a response, and so proceed to the next trial; therefore, outlying RTs above three standard deviations from the mean for each participant were excluded from the analysis. Furthermore, RT was considered for only trials for which a correct response was recorded. Grand-averaged means were computed for each condition for each of these three measures.

Statistical analyses were performed using SPSS PASW 18. The conditions of interest, composite aligned and misaligned trials, were analyzed separately for accuracy, RT, and IE, in two-way repeated-measures ANOVAs, with within-subjects two-level factors of *alignment* (aligned or misaligned) and *stimulus set* (regular or oval). When there was a significant interaction, a posteriori *t*-tests were performed to further compare aligned with misaligned trials. The baseline conditions of same aligned and misaligned trials were separately subjected to the same analyses.

2.2 *Results*

Mean accuracy rates, correct RTs, and IE are illustrated in figure 3 for the critical conditions, and the data are provided for all analyzed conditions in table 1.

2.2.1 *Accuracy.* Analysis of composite trials showed a significant main effect of *alignment* ($F_{1,27} = 32.4, p < 0.001, \eta_p^2 = 0.55$) but not of *stimulus set* ($F_{1,27} = 0.759, p = 0.39, \eta_p^2 = 0.03$). Importantly, the interaction between these factors reached significance ($F_{1,27} = 12.5, p < 0.01, \eta_p^2 = 0.32$), reflecting a larger CFE for regular than oval stimuli, as was hypothesized (oval: $t_{27} = 3.81$, $p < 0.01$, Cohen's $d = 0.95$; regular: $t_{27} = 6.55$, $p < 0.001$, Cohen's $d = 1.9$). This is also apparent in the 5.2% greater reduction in accuracy for aligned as compared with misaligned composite trials for this stimulus set (figure 3a). Analyses of same aligned and misaligned trials revealed neither a significant main effect (alignment: $F_{1,27} = 0.046$, $p = 0.83$, $\eta_p^2 = 0.002$; stimulus set: $F_{1,27} = 2.74$, $p = 0.11$, $\eta_p^2 = 0.09$) nor an interaction between these two factors ($F_{1,27} = 3.53$, $p = 0.07$, $\eta_p^2 = 0.12$)

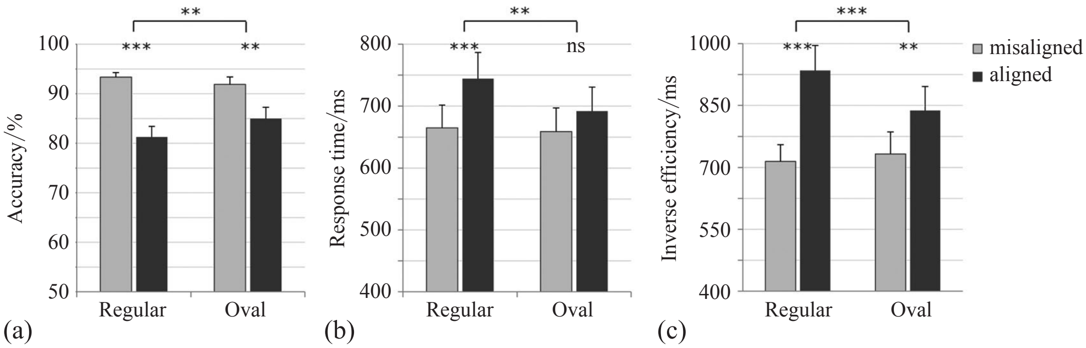

Figure 3. Experiment 1a (regular vs oval stimulus sets) results (showing one standard error) for (a) accuracy, (b) correct response time, and (c) inverse efficiency, shown for the composite conditions, aligned and misaligned.

** $p < 0.01$; *** $p < 0.001$; ns = not significant.

Table 1. Results of experiment 1a: accuracy, correct response time, and inverse efficiency, with one standard error (SE). Data are given for both stimulus sets, regular and oval, for the composite and same conditions, aligned and misaligned.

	Composite		Same	
Accuracy	(%)	(SE)	(%)	(SE)
Regular				
aligned	81.3	2.17	94.3	1.28
misaligned	93.3	0.92	95.3	0.91
Oval				
aligned	85.0	2.28	94.3	1.19
misaligned	91.9	1.51	92.9	1.30
Response time	(ms)	(SE)	(ms)	(SE)
Regular				
aligned	744	42.5	670	42.9
misaligned	665	36.8	642	37.2
Oval				
aligned	692	38.6	667	40.9
misaligned	659	38.3	660	36.5
Inverse efficiency	(ms)	(SE)	(ms)	(SE)
Regular				
aligned	935	60.5	718	52.2
misaligned	715	40.6	680	45.0
Oval				
aligned	838	58.2	712	47.6
misaligned	733	53.5	720	47.6

2.2.2 *Response time.* For composite trials, main effects of alignment ($F_{1,27} = 15.1$, $p < 0.01$, $\eta_p^2 = 0.36$) and stimulus set ($F_{1,27} = 19.0$, $p < 0.001$, $\eta_p^2 = 0.41$) were found. The effect of stimulus set is explained by faster RTs for oval trials (table 1). Critically, these effects were qualified by a significant interaction ($F_{1,27} = 12.1$, $p < 0.01$, $\eta_p^2 = 0.31$), as hypothesized, explained by the larger difference between RTs in aligned and misaligned conditions for regular than oval stimuli (oval: $t_{27} = 2.05$, $p = 0.05$, Cohen's $d = 0.23$; regular: $t_{27} = 5.08$, $p < 0.001$, Cohen's $d = 0.53$; figure 3b). Regarding the same trials, there were main effects of neither alignment ($F_{1,27} = 3.41$, $p = 0.08$, $\eta_p^2 = 0.11$) nor stimulus set ($F_{1,27} = 1.08$, $p = 0.31$, $\eta_p^2 = 0.04$). There was no interaction between these factors ($F_{1,27} = 1.59$, $p = 0.22$, $\eta_p^2 = 0.06$).

2.2.3 *Inverse efficiency.* Analysis of composite trials showed a main effect of alignment ($F_{1,27} = 32.1$, $p < 0.001$, $\eta_p^2 = 0.54$). There was also a main effect of stimulus set ($F_{1,27} = 6.12$, $p < 0.05$, $\eta_p^2 = 0.19$), as was found in RT. Most importantly, there was a significant interaction between alignment and stimulus set ($F_{1,27} = 18.6$, $p < 0.001$, $\eta_p^2 = 0.41$), reflecting, as hypothesized, a larger composite effect for regular than oval stimuli (oval: $t_{27} = 3.29$, $p < 0.01$, Cohen's $d = 0.50$; regular: $t_{27} = 7.02$, $p < 0.001$, Cohen's $d = 1.1$; figure 3c). Analyses for same trials revealed main effects of neither alignment ($F_{1,27} = 2.41$, $p = 0.13$, $\eta_p^2 = 0.08$) nor stimulus set ($F_{1,27} = 3.05$, $p = 0.09$, $\eta_p^2 = 0.10$), and no interaction between these two factors ($F_{1,27} = 3.49$, $p = 0.07$, $\eta_p^2 = 0.11$).

2.3 *Discussion*

A significantly reduced CFE for global shape-normalized (ie oval) face stimuli was found in terms of accuracy, RT, and IE. These results are in line with our hypothesis, corresponding to the theory that global shape plays an integral role in holistic face perception (Biederman & Kalocsai, 1997; Rossion, 2013).

These findings indicate that, in practice, composite face stimuli which retain global face shape (ie contour) information should be used, rather than face stimuli cropped to an oval or similar shape, as are sometimes used in composite face experiments (eg Cassia et al., 2009; Curby et al., 2013; Robbins & McKone, 2003; Soria-Bauser et al., 2011; Zhao & Hayward, 2010) or studies of face perception in general (eg holistic perception, Yovel & Duchaine, 2006; neural face perception network, Nagy, Greenlee, & Kocács, 2012; spatial frequency, Pachai, Sekuler, & Bennett, 2013; eye movement recordings, Peterson & Eckstein, 2012). Note that the modification of shape described here affects only the global contour of the face, not the shape of the internal parts or the distance between local parts (eg interocular distance). However, this modification still elicits changes between the apparent size of local parts relative to the global size and shape of the face. Therefore, a reduction of holistic face perception, which relies on these relative configurations (Tanaka & Sengco, 1997; Sekunova & Barton, 2008; Rossion, 2013), is expected to be similar, but weaker, to the reduction of holistic perception found when shape is modified more generally.

Although the results of this experiment suggest that a reduction in global face shape information decreased the CFE, it could also be argued that this effect is not attributable to holistic face perception. To demonstrate that the reduced CFE for oval faces would not be found in the same task if holistic face perception was not, or much less, implicated, we tested a second group of participants in the same experiment with inverted faces.

3 Experiment 1b

3.1 *Methods*

3.1.1 *Participants.* Thirty participants were recruited from a collegiate area (mean age = 22 years, range = 19–35 years, six male) to voluntarily participate in this experiment, which was approved by the Biomedical and Ethical Committee of the University of Louvain. None of these participants completed experiment 1. As in experiment 1, data from two participants were excluded because these participants scored two standard deviations below the mean for accuracy on unanalyzed 'different' trials (determined by an average across both stimulus stets and alignment conditions; $M = 87\%$, SD = 9.7%). All participants signed informed consent forms and received payment for their time.

3.1.2 *Stimuli.* The same sets of regular and oval stimuli as described in experiment 1a were used in this experiment (figure 1).

3.1.3 *Procedure.* The procedure was identical to that of experiment 1a, except that all stimuli were presented inverted—that is, the orientation was rotated by 180° (for trial design see figure 2).

3.1.4 *Analyses.* Analyses were performed exactly as in experiment 1a.

3.2 *Results*

Mean accuracy rates, correct RTs, and IE are illustrated in figure 4 for the critical conditions, and the data are provided for all analyzed conditions in table 2.

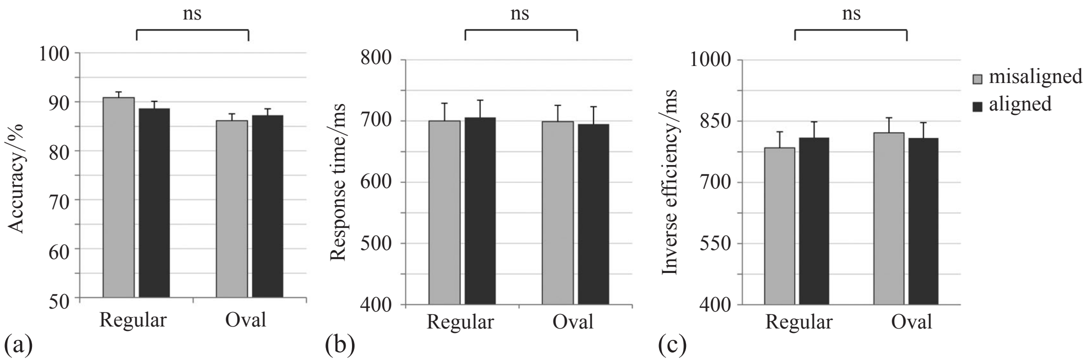

Figure 4. Experiment 1b (regular vs oval inverted stimulus sets) results (showing one standard error) for (a) accuracy, (b) correct response time, and (c) inverse efficiency, shown for the composite conditions, aligned and misaligned. There were no significant differences between misaligned and aligned trials (all ps $\geqslant 0.09$). Note: ns = not significant.

3.2.1 *Accuracy.* Analysis of composite trials showed a significant main effect of only *stimulus set* ($F_{1,27} = 6.55$, $p < 0.05$, $\eta_p^2 = 0.20$), reflecting generally higher accuracy for inverted regular than inverted oval face stimuli (figure 4). There was no significant main effect of *alignment* ($F_{1,27} = 0.214$, $p = 0.65$, $\eta_p^2 = 0.01$), and, contrary to upright faces, the interaction between these factors was not significant ($F_{1,27} = 3.70$, $p = 0.07$, $\eta_p^2 = 0.12$). Analyses of same aligned and misaligned trials also showed a significant effect of stimulus set ($F_{1,27} = 12.7$, $p < 0.01$, $\eta_p^2 = 0.32$), indicating that the advantage for inverted regular face stimuli was not unique to composite trials (table 2). There was neither a significant effect for alignment ($F_{1,27} = 0.50$, $p = 0.49$, $\eta_p^2 = 0.02$) nor an interaction between these factors ($F_{1,27} = 0.036$, $p = 0.85$, $\eta_p^2 = 0.001$).

3.2.2 *Response time.* For composite trials, no main effects of alignment ($F_{1,27} = 0.015$, $p = 0.90$, $\eta_p^2 = 0.001$) or *stimulus set* ($F_{1,27} = 0.92$, $p = 0.35$, $\eta_p^2 = 0.03$) were found. Additionally, there was no significant interaction ($F_{1,27} = 0.41$, $p = 0.53$, $\eta_p^2 = 0.02$). For same trials, there was a main effect of stimulus set ($F_{1,27} = 11.1$, $p < 0.01$, $\eta_p^2 = 0.29$), reflecting that participants were faster for regular than oval inverted face stimuli (table 2). There was no significant effect of *alignment* ($F_{1,27} = 0.000$, $p = 1.0$, $\eta_p^2 < 0.001$) and no interaction between these factors ($F_{1,27} = 0.06$, $p = 0.80$, $\eta_p^2 = 0.002$).

Table 2. Results of experiment 1b: accuracy, correct response time, and inverse efficiency, with one standard error (SE). Data are given for both stimulus sets, regular and oval inverted, for the composite and same conditions, aligned and misaligned.

	Composite		Same	
Accuracy	(%)	(SE)	(%)	(SE)
Regular				
aligned	88.6	1.83	91.6	1.47
misaligned	90.8	1.82	92.5	1.19
Oval				
aligned	87.3	1.76	89.3	1.31
misaligned	86.1	1.77	89.9	1.39
Response time	(ms)	(SE)	(ms)	(SE)
Regular				
aligned	706	28.2	691	28.2
misaligned	700	28.1	693	29.0
Oval				
aligned	695	27.1	772	28.3
misaligned	699	28.0	720	26.5
Inverse efficiency	(ms)	(SE)	(ms)	(SE)
Regular				
aligned	810	38.9	761	34.6
misaligned	785	39.4	754	34.0
Oval				
aligned	809	37.7	816	35.8
misaligned	822	36.6	807	33.0

3.2.3 *Inverse efficiency.* Composite trials showed no significant main effects (alignment: $F_{1,27} = 0.15$, $p = 0.70$, $\eta_p^2 = 0.006$; stimulus set: $F_{1,27} = 1.70$, $p = 0.20$, $\eta_p^2 = 0.06$) and no interaction between these factors ($F_{1,27} = 1.84$, $p = 0.19$, $\eta_p^2 = 0.06$). The identical analyses for same trials showed a main effect of *stimulus set* ($F_{1,27} = 21.2$, $p < 0.001$, $\eta_p^2 = 0.44$), as evidenced also in accuracy and RT, but no effect of alignment ($F_{1,27} = 0.38$, $p = 0.54$, $\eta_p^2 = 0.01$), and no interaction between these two factors ($F_{1,27} = 0.01$, $p = 0.95$, $\eta_p^2 < 0.001$).

3.3 *Discussion*

In experiment 1b there were no differences in terms of the CFE between regular or oval inverted face stimuli in accuracy, RT, or IE. In fact, there was no evidence of a CFE for either stimulus set in any of the measures recorded. There was a slight advantage for aligned over misaligned trials in accuracy for inverted regular face stimuli, with composite trials showing a 2.2% difference; however, control same trials also showed a 0.9% difference; moreover, there was no evidence of a CFE for inverted regular stimuli in RT. These results should be taken in contrast to experiment 1, in which the same stimuli produced a strong CFE with all measures.

Not finding a CFE is consistent with inversion impairing holistic face perception (Rossion, 2013; Sergent, 1984; Tanaka & Farah, 1993; Van Belle et al., 2010; Young et al., 1987). However, it is possible that if there are factors external to holistic perception influencing performance between the stimulus sets, these effects would persist when the stimuli were inverted. A recent study has proposed that experiments measuring holistic face perception with the CFE should contain inverted stimuli as controls, as tested here, that would reveal the influences of secondary cognitive factors (McKone et al., 2013). Applying this logic to the present study, a lack of significant CFE for either stimulus set (oval and regular) in the inverted orientation would imply that the results for upright faces in experiment 1a can be interpreted as a pure measurement of a CFE.

In these first experiments a possible secondary factor is that regular stimuli also contained more information, containing larger area and more variation, than oval-shaped stimuli. Hence, one could potentially attribute the decrease of the CFE for upright stimuli in experiment 1a, at least in part, to the mere reduction of information (ie differences) in the bottom halves of composite faces. Although a decreased CFE was not found for inverted face stimuli in experiment 1b, decreasing visual information was not without impact: participants were generally less accurate for inverted oval face stimuli and slower to respond for same trials. In these experiments a reduction of information corresponds to an increase in similarity, which may affect task difficulty and confound the interpretation of how useful the reduced information was for holistic face perception (Russell, Biederman, Nederhouser, & Sinha, 2007). However, the reduction of information is not the predominant factor driving the decrease of the CFE, as further evidenced in experiment 2, which will address the influence of the *addition* of information (ie color) on the CFE.

4 Experiment 2

4.1 *Methods*

4.1.1 *Participants.* Thirty participants were recruited from a collegiate area (mean age = 22 years, range = 18–29 years, three male) to voluntarily participate in this experiment, which was approved by the Biomedical and Ethical Committee of the University of Louvain. Six of these participants also participated in experiment 1a: however, there was no effect of familiarity for grayscale stimuli (the advantage of the CFE for grayscale relative to color stimuli was 5.4% in accuracy for participants who did only the color experiment, compared with 5.7% for participants who completed both experiments). Data from one participant were excluded because this participant scored two standard deviations below the mean for accuracy on unanalyzed ‘different’ trials (determined by an average across both stimulus sets and alignment conditions; $M = 89\%$, SD = 9.2%). All participants signed informed consent forms and received payment for their time.

4.1.2 *Stimuli.* The same set of regular stimuli as described in experiment 1 was used in this experiment. Additionally, a second set of stimuli was generated, identical to the first set, except that the images retained color information (figure 5).

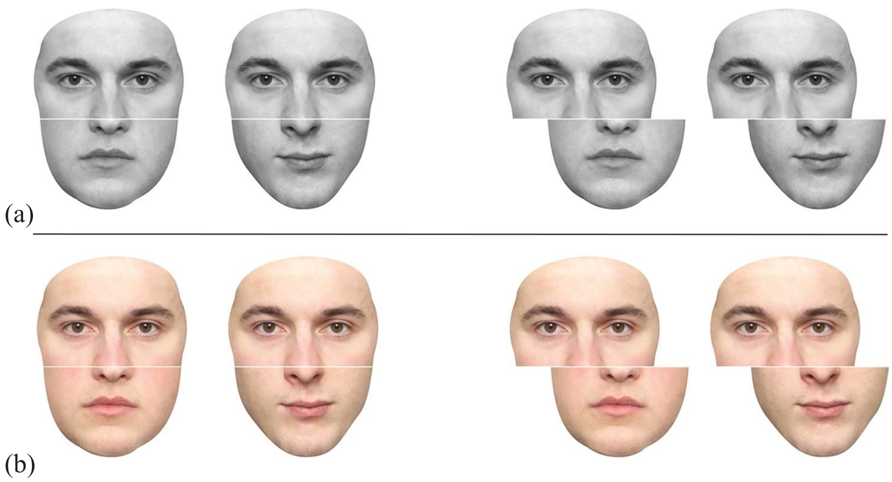

Figure 5. [In color online, see http://dx.doi.org/10.1068/p7826] The same composite stimulus pair as shown in figure 1; aligned images on the left, misaligned on the right. (a) Grayscale stimuli. (b) Stimuli with color information, as used in experiment 2.

4.1.3 *Procedure.* The procedure was identical to that of experiment 1a, except that the oval stimulus set was replaced with the color stimulus set (for trial design see figure 2). All stimuli subtended approximately 3.5 × 4.7 deg.

4.1.4 *Analyses.* Analyses were performed exactly as in experiment 1.

4.2 *Results*
Mean accuracy rates, correct RTs, and IE are illustrated in figure 6 for the critical conditions, and the data are provided for all analyzed conditions in table 3.

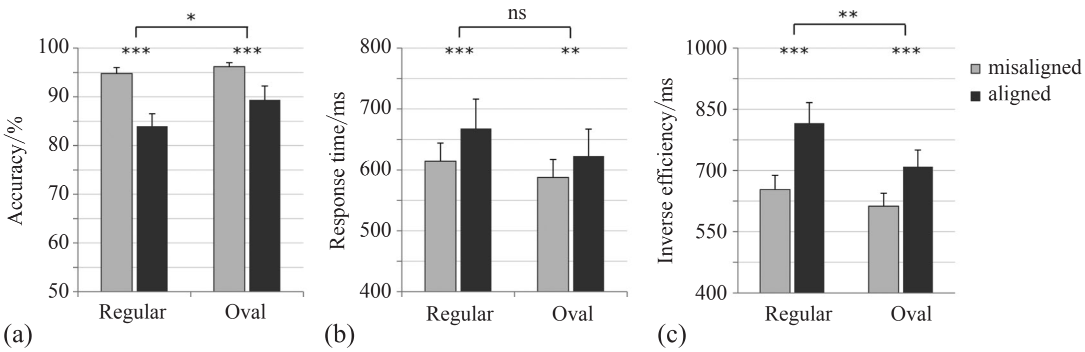

Figure 6. Experiment 2 (grayscale vs color stimulus sets) results (showing one standard error) for (a) accuracy, (b) correct response time, and (c) inverse efficiency, shown for the composite conditions, aligned and misaligned.
** ....; *** ....; ns = not significant.

4.2.1 *Accuracy.* Main effects for composite trials were significant for both *alignment* and *stimulus set* ($F_{1,28} = 33.0$, $p < 0.001$, $\eta_p^2 = 0.54$; $F_{1,28} = 15.6$, $p < 0.001$, $\eta_p^2 = 0.36$, respectively). These factors were qualified by a significant interaction ($F_{1,28} = 5.95, p < 0.05$, $\eta_p^2 = 0.18$), due to the lower magnitude of the composite effect for color stimuli (color: $t_{28} = 3.99$, $p < 0.001$, Cohen's $d = 0.44$; grayscale: $t_{28} = 6.11$, $p < 0.001$, Cohen's $d = 1.6$; figure 6a), in line with the hypothesis that grayscale stimuli would produce a larger CFE. Analysis of baseline same trials showed neither main effects (alignment: $F_{1,28} = 1.65, p = 0.21$, $\eta_p^2 = 0.06$; stimulus set: $F_{1,28} = 2.94$, $p = 0.10$, $\eta_p^2 = 0.10$), nor an interaction between these factors ($F_{1,28} = 0.075, p = 0.79$, $\eta_p^2 = 0.003$).

4.2.2 *Response times.* Regarding composite trials, there were significant main effects for alignment ($F_{1,28} = 30.6$, $p < 0.001$, $\eta_p^2 = 0.52$) and stimulus set ($F_{1,28} = 17.8$, $p < 0.001$, $\eta_p^2 = 0.39$). However, no significant interaction qualified these two factors ($F_{1,28} = 3.18$, $p = 0.09$, $\eta_p^2 = 0.10$) to support the hypothesis. For same trials, there was a main effect of stimulus set ($F_{1,28} = 8.25, p < 0.01$, $\eta_p^2 = 0.23$) due to the predominately faster response for color stimuli (table 3), but no main effect of alignment ($F_{1,28} = 0.041, p = 0.84$, $\eta_p^2 = 0.001$), and no interaction ($F_{1,28} = 1.44, p = 0.24$, $\eta_p^2 = 0.05$).

4.2.3 *Inverse efficiency.* Analysis of composite trials revealed main effects of alignment ($F_{1,28} = 33.8, p < 0.001, \eta_p^2 = 0.55$) and stimulus set ($F_{1,28} = 23.3, p < 0.001, \eta_p^2 = 0.45$). These two factors were qualified by a significant interaction ($F_{1,28} = 13.0$, $p < 0.01$, $\eta_p^2 = 0.32$), reflecting, as hypothesized, a larger composite effect for grayscale ($t_{28} = 6.60$, $p = < 0.001$, Cohen's $d = 0.98$) than color ($t_{28} = 4.10$, $p < 0.001$, Cohen's $d = 0.69$) stimuli (figure 5c). Regarding the same trials, there was a main effect of stimulus set ($F_{1,28} = 11.8$, $p < 0.01$, $\eta_p^2 = 0.30$), arising from the faster RT for color trials as described above. There was no main effect of alignment ($F_{1,28} = 0.44, p = 0.51$, $\eta_p^2 = 0.02$), and no interaction between alignment and stimulus set ($F_{1,28} = 1.21, p = 0.28$, $\eta_p^2 = 0.04$).

Table 3. Results of experiment 2: accuracy, correct response time, and inverse efficiency, with standard error (SE). Data are given for both stimulus sets, grayscale and color, for the composite and same conditions, aligned and misaligned.

	Composite		Same	
Accuracy	(%)	(SE)	(%)	(SE)
Grayscale				
aligned	84.0	2.23	96.2	0.95
misaligned	94.8	1.22	95.5	1.05
Color				
aligned	89.3	1.79	97.6	0.47
misaligned	96.2	0.84	96.5	0.68
Response time	(ms)	(SE)	(ms)	(SE)
Grayscale				
aligned	668	33.7	610	27.5
misaligned	614	29.7	601	31.8
Color				
aligned	622	30.9	586	28.3
misaligned	588	29.5	592	29.5
Inverse efficiency	(ms)	(SE)	(ms)	(SE)
Grayscale				
aligned	816	50.6	636	28.8
misaligned	653	35.0	634	36.3
Color				
aligned	709	41.3	601	29.2
misaligned	613	31.8	616	32.5

4.3 *Discussion*

The CFE was significantly reduced for color compared with grayscale face stimuli. This was reflected in measures of accuracy and IE, while there was no difference in terms of RT alone. Faster RTs were found overall for color stimuli, however, an observation which agrees with the finding that color information provides beneficial diagnostic cues for object recognition (Rossion & Pourtois, 2004), and that surface reflectance can contribute to discriminating facial identity (Russell et al., 2006), particularly for familiar faces (Itz et al., 2014).

Despite an increase in information, it is understandable that stimuli retaining color information do not enhance holistic face perception as measured by the composite face effect. In order for the CFE to measure holistic face perception, it is necessary that the two distinct facial halves are perceived as forming a whole face. However, color information is thought to facilitate low-level segmentation (eg Regan, 2000; Tanaka et al., 2001), so that it may help participants to segment the top and bottom halves in a composite face task requiring matching of the top half only. In the current experiment, stimuli were created from photographs of individual faces; although the original face photographs were equalized for mean luminance in color channels, the local color around the join of the two halves of composite stimuli often appears not to correspond smoothly (see figure 5). That is, it could be hypothesized that an addition of color information may actually have reduced the similarity of face halves, making them seem less a unified whole. Such a consideration would be especially applicable in experiments in which the color of face halves does vary naturally (eg de Heering et al., 2012; Laguesse & Rossion, 2013), but less relevant when artificial stimuli are used and face halves have more similar color information (eg Jiang et al., 2011).

An impairment of grouping facial halves due to a mismatch of color information might be mitigated if color contributed to holistic perception, since besides contributing to segmentation, color may also be beneficial for higher level processes, especially when color is diagnostic of an object category (eg Rossion & Pourtois, 2004). Although color may improve categorization of faces across groups (eg race or age groups), and may even contribute to identity recognition, this latter effect may again be due to color facilitating segmentation of facial parts (Yip & Sinha, 2002); furthermore, the color cues that are diagnostic of individuality in faces are resolved locally (eg color of the lips, or eyes), or at least can be resolved locally (eg skin color). If the natural uniformity of color within a face does contribute to perception of the face as a single unit, this advantage may not be captured in the composite face paradigm, in which face halves come from different identities.

In any case, the novel finding that color information can be detrimental for holistic face perception as measured by the CFE has a direct practical implication: grayscale rather than color face stimuli may provide a better isolation of holistic perception measured with the behavioral CFE.

5 General discussion

In summary, in experiment 1a the CFE was reduced for oval-shaped faces lacking natural global face shape information; in experiment 1b this reduction of the CFE was not found for inverted oval-shaped faces; finally, in experiment 2 the CFE was reduced for color as compared with grayscale composite face stimuli. These results can be interpreted in the context of the composite face paradigm, as well as in light of the differential contributions of shape and surface information on holistic face perception.

Importantly, the reduction of the CFE when global face shape information is reduced cannot be explained by oval stimuli containing less visual information—that is, having natural global shape information removed and a generally smaller size. If this was the case, then a CFE may have been present in experiment 1b, and in experiment 2 the CFE would have also been reduced by removing color information; that the CFE is increased when visual information is increased in one and decreased in another experiment is evidence that color and global face shape information affect face perception in different ways.

Removing global face shape information is not expected to disrupt perceptual grouping of the two face halves in this paradigm, because oval stimuli maintain a continuous and uniform contour around the face (Wagemans et al., 2012). Although regular stimuli were created so that the top and bottom face halves were the same width at the level at which they aligned, there may remain some slight disconformity of global contour between the face halves. Still, the human visual system has a high tolerance for perceiving continuous contours, and a significant CFE can still be measured with regular, shaped stimuli; this is in contrast to even a small misalignment of the bottom from the top face half, which breaks the continuity of the global contour and is sufficient to prevent holistic perception (Laguesse & Rossion, 2013).

In other measures of holistic face perception, such as the face inversion effect (FIE) (Yin, 1969), shape has been shown to be highly influential. For example, in two studies by Jiang and colleagues, modifying shape across the entire face was shown to produce a larger FIE than modification of surface reflectance or a combination of both these types of information (Jiang, Dricto, Blanz, Goebel, & Rossion, 2009; Jiang et al., 2011). Changes in only global contour were shown to produce an FIE in accuracy of about 8%–9% in adults, which was insignificantly larger than that for changes of only facial features (Mondloch, Le Grand, & Maurer, 2002). Shape may directly influence holistic perception by contributing to perceived changes in the relative distances between face parts (ie nose or eyes), which are perceived interdependently—that is, holistically, driving the 'part–whole' face effect (Tanaka & Farah, 1993; Tanaka & Sengco, 1997).

Because faces have a similar arrangement of parts, the face processing system may be sensitive to even slight changes of metric distances between parts (Biederman & Kalocsai, 1997; Haig, 1984; Le Grand, Mondloch, Maurer, & Brent, 2001), although in order to be diagnostic, these need to concern the whole face and not just a local area of the face (eg interocular distance alone, or mouth–nose distance alone, see Taschereau-Dumouchel, Rossion, Schyns, & Gosselin, 2010). Additionally, shape contributes to variation in size and contour, which can be used for identity recognition at a global scale (Jiang et al., 2011). The conclusion that shape is important for holistic perception measured behaviorally through the CFE is also consistent with neuroimaging studies showing that shape is processed in the right hemisphere, which dominantly supports holistic processing (eg Hillger & Koenig, 1991; Parkin & Williamson, 1987; Schiltz & Rossion, 2006), more sensitively (Jiang et al., 2009), and faster (Caharel, Jiang, Blanz, & Rossion, 2009; Dzhelyova & Rossion, 2014; Itz et al., 2014) than surface information.

This finding raises the question of why face stimuli are cropped to a generic (oval) shape in many studies measuring the CFE (eg Cassia et al., 2009; Curby et al., 2013; Robbins & McKone, 2003; Soria-Bauser et al., 2011; Taubert & Alais, 2011; Zhao & Hayward, 2010) and more generally in some studies investigating holistic processing with other paradigms, such as inversion (Russell et al., 2007; Yang, Shafai, & Oruç, 2014) or the face congruency paradigm (Goffaux, 2012; Richler, Cheung, Wong, & Gauthier, 2009). The reason given in such studies is usually simply so that external features are excluded (eg "to eliminate cues derived from the shape of the head or chin", Richler et al., 2009, page 2858). However, the shape of the head or chin provides important cues that contribute to holistic face perception. Although removing external features—such as hair, which may aid in low-level matching between face pairs—is recommended, it is not necessary to use an oval shape to do this, as evidenced in the present study and others (eg de Heering et al., 2012; Laguesse & Rossion, 2013; Le Grand et al., 2004).

The contribution of global, external shape information to holistic perception, however, provides a theoretical reason to use such stimuli, which are shown here to produce a larger CFE. Since the face processing system is highly sensitive to the global aspect ratio of individual faces (eg Barton, Zhao, & Keenan, 2003; Lee & Freire, 1999), the two top halves are perceived as different when associated with bottom halves that differ in global contour (ie a composite face illusion) even when the internal parts of the bottom halves do not differ. For instance, simply stretching the bottom half of one of two faces causes the visual impression that the eyes of this face are closer to each other than for the other face (figure 43a in Rossion, 2013). Another example comes from the head size illusion (Morikawa, Okumura, & Matsushita, 2012; figure 43b in Rossion, 2013), in which increasing the width of the lower part of the head influences the judgment of global size of the upper part of the head. These examples and the present data show that, if possible, the face stimuli of a paradigm measuring holistic face perception should *not* be normalized in overall shape, because this normalization reduces the contribution of holistic face perception to performance.

The contribution of color information, on the other hand, may reflect methodological factors rather than a general disadvantage of color for holistic perception. The obvious potential confound present in the composite face paradigm when using color stimuli is that a mismatch in added color information in the composite bottom from the top face halves might have disrupted the two face halves from being grouped together, as discussed following experiment 2. Therefore, it is especially important to consider the present results in a broader context.

Evidence of the role of surface information in holistic face perception has been mixed. In a previous study changes in surface information alone did not generate a CFE; however, changing surface in addition to shape information produced a larger CFE than changes to shape alone (Jiang et al., 2011). These results suggest that surface information can contribute to holistic face perception, but only weakly or through conjunction with other type of visual information. If this were the case, it would be predicted that increasing surface information would slightly increase or have no effect on the CFE. Here, in contrast, the addition of surface information reduces the CFE.

This discrepancy may be partly explained by the fact that surface (ie color plus texture) information was manipulated in this previous study, while color alone was manipulated here. Also, here, an increase in surface information may have corresponded to an increase in mismatch between composite face halves, while in that previous study the three-dimensional laser-scanned stimuli were more homogeneous (see figure 1 in Jiang et al., 2011). Moreover, in the present study the level of surface information was modulated across the whole face, not just the bottom face half. Thus, the change in the magnitude of the CFE resulting from the amount of surface information could be directly investigated across stimulus sets.

In line with the present findings, other studies have found a detrimental role for surface information in holistic face perception. For example, holistic face perception, as measured with the FIE, was decreased by a combination of surface and shape information over the whole face relative to when shape alone was modulated (Jiang et al., 2009, 2011). Additionally, color information has been found to reduce the influence of surface reflectance information on the magnitude of the FIE, despite an overall increase in performance, suggesting that color information may contribute to face identification but not to holistic face perception (Russell et al., 2007).

The impact of surface information on the CFE could be further estimated by studies which selectively impair this information through contrast reversal (Russell et al., 2006), although this has been implemented only in a couple of experiments using composite faces, and always with grayscale images (Hole, George, & Dunsmore, 1999; Taubert & Alais, 2011). In these studies the magnitude of the CFE was not significantly affected by contrast reversal,[1] suggesting that surface information is not required for holistic perception. The effect of color information itself on the CFE has not been directly addressed within a single study before to our knowledge; and although there are many studies using either color or grayscale stimuli, as exemplified in section 1, the methods and goals of these studies vary considerably, limiting a comparison.

At the neural level, surface or a combination of surface and shape produce a smaller fMRI adaptation effect than shape information alone in the right hemisphere (Jiang et al., 2009). Surface also has less influence than shape information at the early encoding of a face (ie the N170 face-sensitive event-related potential component), but later the combination of shape and surface information produces the largest face identity repetition effects measured with electroencephalography (Caharel et al., 2009; see also Dzhelyova & Rossion, 2014; Itz et al., 2014). It is possible that in these studies the methodological importance of having smoothly corresponding stimulus halves is less important than in a behavioral experiment, for which decisional factors play a role, although, again, more homogenous stimuli were used. Nevertheless, these studies indicate that the reduction of holistic perception for color stimuli found in the composite face paradigm is not necessarily reflective of holistic perception more generally, in which case surface information may be beneficial. However, the results found here are consistent with the hypothesis that if color plays a role in holistic face perception, it is a minor one, able to be outdistanced by other factors

(1) Note, however, that the study of Hole and colleagues (1999) used stimuli with external features, which may have aided in low-level matching even in an inverted control condition. In the study of Taubert and Alais (2011) oval-shaped stimuli were used, perhaps reducing the sensitivity of the measure.

In conclusion, our results demonstrate that global face shape information is highly influential, but color information may be inhibitory for holistic face perception, at least as measured behaviorally by the CFE. The practical implication of these experiments is that the behavioral CFE can best be measured with grayscale face stimuli with natural, global face shape preserved. More generally, these results are compatible with the theory that shape and surface information play at least some different roles in visual perception, and highlight the interest of utilizing holistic face perception in investigating these differences.

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