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Inversion produces opposite size illusions for faces and bodies

Eamonn Walsh[a,b,*], Alexandra Vormberg[a,c,d], Josie Hannaford[a], Matthew R. Longo[a]

[a] Department of Psychological Sciences, Birkbeck, University of London, UK
[b] Department of Basic and Clinical Neuroscience, Institute of Psychiatry, Psychology & Neuroscience, King's College London, UK
[c] Ernst Strüngmann Institute (ESI) for Neuroscience in Cooperation with Max Planck Society, Germany
[d] Frankfurt Institute for Advanced Studies (FIAS), Germany

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ABSTRACT

Faces are complex, multidimensional, and meaningful visual stimuli. Recently, Araragi, Aotani, & Kitaoka (2012) demonstrated an intriguing face size illusion whereby an inverted face is perceived as larger than a physically identical upright face. Like the face, the human body is a highly familiar and important stimulus in our lives. Here, we investigated the specificity of the size underestimation of upright faces illusion, testing whether similar effects also hold for bodies, hands, and everyday objects. Experiments 1a and 1b replicated the face-size illusion. No size illusion was observed for hands or objects. Unexpectedly, a *reverse* size illusion was observed for bodies, so that upright bodies were perceived as larger than their inverted counterparts. Experiment 2 showed that the face illusion was maintained even when the photographic contrast polarity of the stimuli was reversed, indicating that the visual system driving the illusion relies on geometric featural information rather than image contrast. In Experiment 2, the reverse size illusion for bodies failed to reach significance. Our findings show that size illusions caused by inversion show a high level of category specificity, with opposite illusions for faces and bodies.

1. Introduction

Illusions and inversion effects provide an interesting window through which to study how the brain processes human faces and bodies, and whether they are processed by the brain in the same fashion. Recently, Araragi, Aotani, and Kitaoka (2012) demonstrated an intriguing face size illusion whereby an inverted face is perceived as larger than an identical upright face. The size illusion was evident for photographic faces, and cartoon faces, but was not present overall for face outlines (Araragi et al., 2012). Previous research has shown how inversion influences face processing, so that the recognition of inverted faces is more difficult than that of upright faces, suggesting that faces represent a “special” class of stimulus (Yin, 1969). Face inversion is believed to affect our ability to adopt configural processing, i.e. the perception of relations among the features of a stimulus such as a face or body (Maurer, Le Grand, & Mondloch, 2002), whilst leaving the ability to use featural processing intact (Carey & Diamond, 1977; Farah, Tanaka, & Drain, 1995; Maurer et al., 2002; Tanaka & Farah, 2003; Young, Hellawell, & Hay, 2013), though the exact nature of the mechanisms behind these processes remains controversial (McKone & Yovel, 2009; Murray, 2004; Richler, Gauthier, Wenger, & Palmeri, 2008; Richler, Tanaka, Brown, & Gauthier, 2008; Robbins & McKone, 2007; Rossion, 2008; Sekuler, Gaspar, Gold, & Bennett, 2004).

Many behavioural studies show that a face is less well recognised when inverted. An upright face is thought to be perceived holistically - whereby “the multiple parts of a face are simultaneously integrated into a single perceptual representation” (Rossion, 2008, 2009) - while an inverted face is perceived more as a collection of features (Farah, Wilson, Drain, & Tanaka, 1998). Supporting the holistic view, behavioural studies have shown that a face section is better recognised if it is presented in a whole face context than if it is presented in isolation (Tanaka & Farah, 1993), or when it is aligned with a complementary section of another face (Rossion, 2013). These effects are substantially reduced if the face is presented upside-down, demonstrating the so-called ‘face inversion effect’ (FIE), suggesting that such effects rely on internal representations derived from visual experience. While it is generally agreed that human faces undergo configural processing, a number of more recent studies have also described body inversion effects (BIE) for human bodies (Minnebusch, Suchan, & Daum, 2009; Reed, Stone, Bozova, & Tanaka, 2003; Reed, Stone, Grubb, & McGoldrick, 2006). The face inversion effect demonstrates that there is a larger inversion effect i.e. a greater cost to recognition, for faces than

* Corresponding author at: Institute of Psychiatry, Psychology & Neuroscience, King's College London, De Crespigny Park, Denmark Hill, London SE5 8AF, UK.
E-mail address: eamonn.walsh@kcl.ac.uk (E. Walsh).
URLS: http://neuroscience.iop.kcl.ac.uk/msc, https://kclpure.kcl.ac.uk/portal/eamonn.walsh.html (E. Walsh).

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other objects with a canonical upright. This holds true even when a within class discrimination task is used (Yin, 1969), and even when people are experts with those non-face objects (Carey & Diamond, 1977).

As for faces, recognition of inverted human bodies is impaired relative to upright presented bodies (Reed et al., 2003; Reed et al., 2006). The 'body inversion effect' has been shown to be as large as the FIE and considerably larger than the inversion effect for other object categories (Reed et al., 2003), such as everyday objects like houses or bottles (Minnebusch et al., 2009; Minnebusch, Keune, Suchan, & Daum, 2010; Reed et al., 2003; Robbins & Coltheart, 2012). Seitz (2002) reported better recognition performance for whole bodies compared to isolated body parts, suggesting a role for holistic processing in the perception of human bodies. Moreover, impaired face and body perception has been observed in people with prosopagnosia, providing further evidence that both stimulus types are processed configurally (Biotti, Gray, & Cook, 2017; Righart & de Gelder, 2007; Rivolta, Lawson, & Palermo, 2017).

Overall, measures of holistic processing suggest that not only faces but also bodies are "special", i.e., processed differently to other objects (Moro et al., 2012). Inversion impairs recognition and size perception for faces and at least recognition for bodies, and these inversion effects are generally thought to reflect holistic processes. The present study investigates the specificity of the size underestimation illusion reported by Araragi et al., (2012). Specifically, we were interested in whether the illusion results from the operation of configural processing in general, in which case it should also occur for body stimuli as well as faces, or whether it reflects the operation of face-specific mechanisms, in which case it should not occur for any other stimuli. We used the method of constant stimuli to measure the bias to perceive inverted stimuli as bigger than upright stimuli for faces, bodies, hands, and non-body everyday objects.

2. Experiment 1a

Experiment 1a, used a large sample (N = 124) to investigate whether the size underestimation of upright faces reported by Araragi and colleagues (Araragi et al., 2012) also holds for bodies and hands. Object stimuli were included to investigate the size of the illusion for inanimate objects.

2.1. Method

2.1.1. Participants

One hundred and forty-six psychology undergraduate students at Birkbeck, University of London took part in an in-class experiment in a group setting as part of a research methods class. Ethical approval was obtained from the Departmental Research Ethics Committee prior to testing. The data for 22 participants whose goodness of fit (R^2) was less than a threshold (< 0.2) for any condition (object, face, body, hand) were excluded from the dataset (see Analysis section below). The data for the remaining 124 participants (mean age 30.2 years, SD = 8.2; 8 left-handed by self-report; 97 female) were included in the final analysis.

2.1.2. Stimuli

The stimulus set (16 stimuli) consisted of greyscale images of 4 frontal view headless bodies (2 male and 2 female) and 4 faces (2 male and 2 female), 4 hands (2 male and 2 female), and 4 inanimate objects (globe, jug, armchair, and coffee-pot), all of which have a canonical 'upright' orientation. The face stimuli (neutral emotional expression) were selected from the Karolinska Directed Emotional Faces (KDEF) database (Lundqvist, Flykt, & Öhman, 1998, http://www.emotionlab.se/resources/kdef).

2.1.3. Design

2.1.4. Procedure

Participants were tested simultaneously in a large computer lab. Participants sat with their face approximately 40 cm in front of the monitor. In a two-alternative forced choice (2AFC) task, participants pressed either the 'q' or 'p' key on the computer keyboard with the

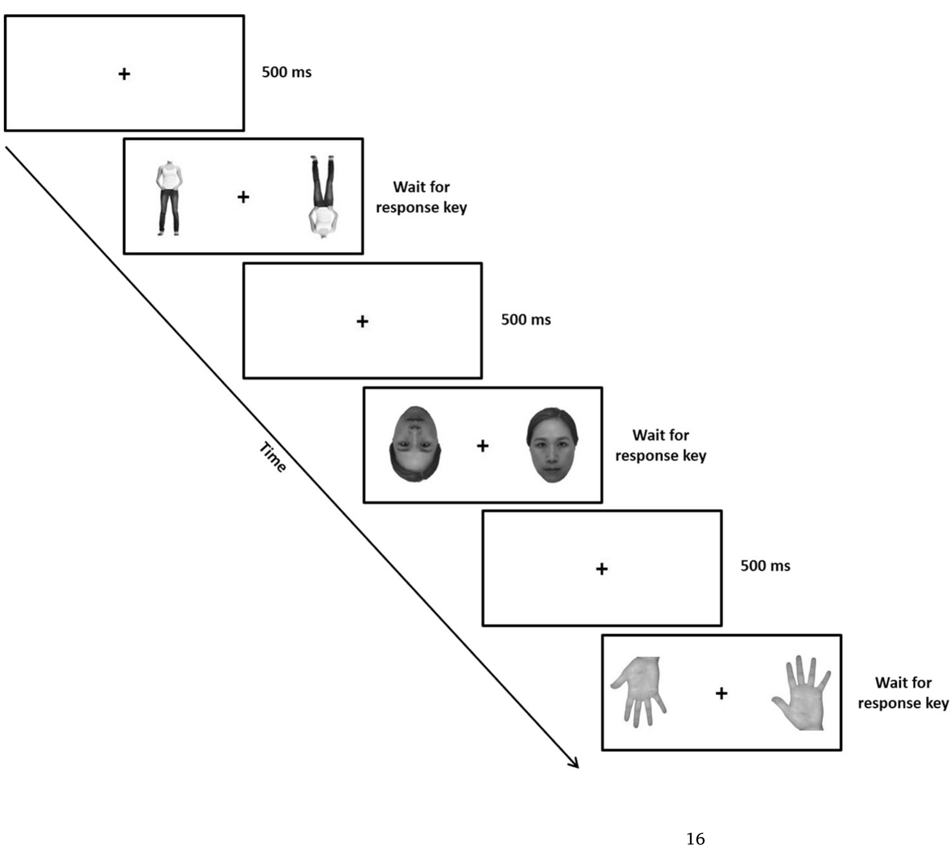

Fig. 1. Schematic showing 3 typical trials from Experiments 1a and 1b. A fixation cross was presented centrally for 500 ms, followed by two images of the same object, face, body, or hand. One image was always inverted, while the other was always upright. One image was always a standard size, while the size of the other image could vary (see text for details). The participant judged which of the two stimuli appeared physically larger by pressing a left or right button, which also triggered the next trial.

index fingers of their left and right hands respectively. Participants were instructed to fixate on the central cross, and to judge which of two stimuli presented on either side of the cross appeared to be physically larger. Stimulus presentation and data collection were controlled by an E-Prime script (Psychology Software Tools, Sharpsburg, PA).

There were 8 blocks of 80 trials each, resulting in 640 trials in total. Each block consisted of stimuli from a single stimulus category. Blocks 1–4 and 5–8 each consisted of one repetition of each of the four categories, in random order. Each trial began with a fixation cross appearing on the centre of the screen (Fig. 1). After 500 ms, the same image stimulus was presented 480 pixels (18.5° visual angle) on either side of the central fixation cross. Both images were identical except that one was always upright while the other was always inverted (i.e., rotated 180° in picture plane), and they could differ in size. On half the trials the upright stimulus was the comparison stimulus, while on the remaining trials the inverted stimulus was the comparison. One of the two images occupied a space 400 square pixels (standard size), while the other image maximally occupied a square space measuring either 380, 390, 400, 410, or 420 pixels per side, (14.7, 15.0, 15.4, 15.8, 16.2° visual angle, respectively), corresponding to a −5, −2.5, 0, 2.5, or +5% change in the linear dimensions of the standard, respectively. The left and right placement of the stimuli was counterbalanced across trials. Participants were instructed to look at the fixation cross throughout. Participants made self-paced judgements regarding which of the two stimuli appeared to be physically larger by pressing either the 'q' key on the keyboard with their left index finger if the stimulus to the left of fixation appeared larger, or the 'p' key with their right index finger if the stimulus to the right of fixation appeared larger. Participants could rest after each block and commence the next block when ready. Prior to the experiment proper, participants completed a practice block of 6 trials. The total duration of the experiment was approximately 25 min.

2.1.5. Analysis

For each participant, psychometric curves were fitted for all conditions (i.e. a separate curve for the object, face, body and hand conditions). The proportion of responses for which the *upright* stimulus (object, face, body, hand) was judged larger was modelled as a function of the difference in size between the upright and inverted stimuli by fitting a cumulative Gaussian curve using maximum likelihood estimation with the Palamedes toolbox (Prins & Kingdon, 2009; http://www.palamedestoolbox.org/download.html) in MATLAB (Mathworks, Natick, MA). The point of subjective equality (PSE, i.e., the mean of the best-fitting Gaussian), slope (i.e., the inverse of the standard deviation), and goodness of fit (R^2) were calculated for each curve. The PSE estimates the difference in size between the upright and inverted stimuli (quantified as the difference in linear dimensions as a percentage of standard size) for which the participant perceived them as being the same size. Thus, if there is no perceptual bias, stimuli should be perceived as the same when they actually are the same, and PSEs should on average equal '0'. Positive PSEs indicate that participants judged the inverted stimulus to be larger than the upright counterpart, while negative PSEs indicate the opposite. Data for participants below the preset threshold ($R^2 < 0.2$) for any condition (object, face, body, hand) were removed, resulting in a final sample size for Experiment 1a of 124 people.

2.1.6. Results

Results are shown in the left panels of Figs. 2 and 3. The mean R^2 was 0.854 (SD = 0.169; range 0.214–1), indicating good overall fit to the data. We first compared PSEs in each condition to 0 to test for overall biases. PSEs for faces were significantly > 0 (*M*: 3.28%), $t(123) = 9.57$, $p < 0.0001$, Cohen's $d = 0.86$, indicating a bias to perceive upright faces as smaller than inverted faces. This provides a clear replication of the basic illusion reported by Araragi et al. (2012). For bodies, there was a significant effect in the opposite direction (*M*: −2.34%), $t(123) = -3.79$, $p < 0.0001$, $d = 0.34$, with upright bodies perceived as bigger than inverted bodies. No overall illusion was found for hands (*M*: −0.24%), $t(123) = -0.51$, *n.s.*, $d = 0.05$, nor objects (*M*: 0.30%), $t(123) = 1.52$, *n.s.*, $d = 0.14$.

To compare the illusion across conditions, an analysis of variance (ANOVA) was conducted on PSEs, revealing a significant difference across conditions, $F(3, 369) = 28.53$, $p < 0.0001$, $\eta_p^2 = 0.19$. The Holm–Bonferroni method was used to counteract multiple comparisons and to control for Familywise error rate. PSEs for the Body condition differed significantly from PSEs for the Face, Object, and Hand conditions (all $p < 0.014$). Similarly, PSEs for the Face condition differed significantly from PSEs for the Object and Hand conditions (all $p < 0.0001$). There was no difference between the Hand and Object conditions; $t(123) = 1.02$; $p = 0.31$ (Table 1).

An ANOVA on slopes revealed a significant difference across conditions, $F(3, 369) = 11.93$, $p < 0.0001$, $\eta_p^2 = 0.09$, indicating that the precision of judgments differed across the different stimulus categories (Table 1). All follow-up comparisons (*t*-tests) between the four conditions were significant when corrected for multiple comparisons using the Bonferroni-Holm step-down test, except for hand versus object ($p = 0.64$).

2.1.7. Discussion

Experiment 1a clearly replicated the finding of Araragi et al. (2012) showing that upright faces are perceived as smaller than inverted faces. Unexpectedly, however, participants perceived upright bodies to be *larger* than their inverted counterparts, thereby demonstrating a novel reverse illusion for bodies relative to faces. Also, Experiment 1a demonstrated that hands and objects do not show any size illusion.

3. Experiment 1b

Experiment 1a was performed in an undergraduate class setting, with all participants tested simultaneously. This is clearly non-optimal for collecting psychophysical data, as evidenced by the comparatively large rate of participant exclusion and variability (see Supplementary material). Thus, the aim of Experiment 1b was to replicate the pattern of results observed in Experiment 1a under controlled laboratory conditions. Additionally, we used an extended stimulus set which incorporated a broader range of stimulus sizes to allow better estimation of psychometric functions.

3.1. Method

3.1.1. Participants

Twenty participants were recruited. Data for one participant whose R^2 was under 0.2 for one condition was removed from the dataset. The data for the remaining 19 participants (mean age 31.0 years, SD = 9.0; 2 left-handed by self-report; 14 female) were included in the final analysis. All participants had normal or corrected-to-normal vision.

3.1.2. Stimuli

Stimuli were similar to Experiment 1a but used an expanded range of exemplars of each category and sizes. The stimulus set (32 stimuli) consisted of greyscale images of 8 frontal view headless bodies (4 male and 4 female) and 8 faces (4 male and 4 female), 8 hands (4 male and 4 female) and 8 inanimate everyday objects. Images were resized to 7 different sizes measuring 364, 376, 388, 400, 412, 424, 436 square pixels, (subtending 14.1, 14.5, 15.0, 15.4, 15.9, 16.3 and 16.8° visual angles, respectively), which correspond respectively to −9, −6, −3, 0, +3, +6, and + 9% change in linear dimensions relative to the standard (400 square pixels). In addition to the 4 objects adopted in Experiment 1a, the stimulus set further included a camera, kettle, pail, and due to experimenter error, a basketball. Due to its round shape, a basketball does not have a canonical or upright orientation and should not have been included in the stimulus set. All results reported below are with

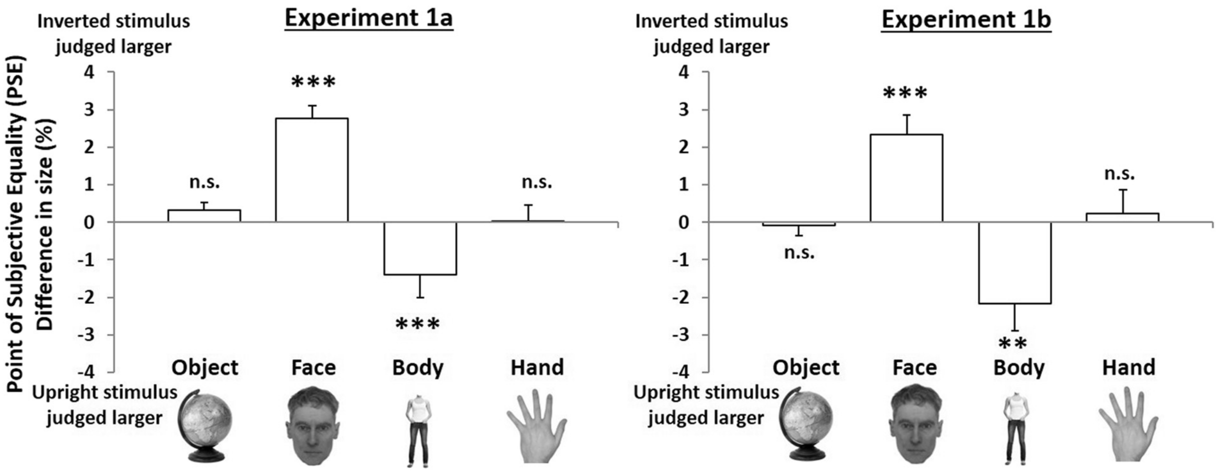

Fig. 2. Mean PSEs for each of the stimulus categories (Object, Face, Body, and Hand) for Experiment 1a (N = 124; left panel) and Experiment 1b (N = 19; right panel). Positive PSE values indicate that the *inverted* stimulus was judged larger than the same-sized upright stimulus, negative values indicate the opposite. Error bars give the standard error of the mean (± SEM). Note: ** indicates p value < 0.001; and *** indicates p value < 0.0001.

the basketball stimulus removed. Significant results did not change when the analysis was performed with or without the basketball.

3.1.3. Procedure

Participants were seated one at a time, in a quiet, dimly-lit testing room facing a computer monitor at a distance of approximately 40 cm. There were 8 blocks of 112 trials each, resulting in 896 trials in total. Participants completed a short practice block of 6 trials before commencing. In all other respects, the procedure and design were identical to Experiment 1a.

3.1.4. Results

Results are shown in the right panels of Figs. 2 and 3. Data analysis and psychometric curve fitting followed the same procedures as for Experiment 1a. The mean R^2 was 0.930 (SD = 0.094; range 0.322–1.0), indicating good overall fit. Overall, results were similar to Experiment 1a. Analysis of PSEs (compared to 0) revealed a significant bias to

Table 1
The mean percentage (SD = standard deviation) of standard size PSE (point of subjective equality) for each of the 4 experimental stimulus categories (object, face, body, and hand) for Experiments 1a (N = 124) and 1b (N = 19). Positive PSE values indicate that the *upright* stimulus was judged larger than the same-sized inverted stimulus, while negative PSE values indicate the reverse. Bold font indicates significance at $p < 0.05$.

		Experiment 1a		Experiment 1b	
		Mean	SD	Mean	SD
PSE	Object	0.32	2.21	−0.10	1.12
	Face	**2.76**	3.81	**2.34**	2.26
	Body	**−1.39**	6.87	**−2.16**	3.13
	Hand	0.04	5.12	0.23	2.72
Slope	Object	0.04	0.01	0.05	0.01
	Face	0.05	0.01	0.06	0.02
	Body	0.03	0.01	0.03	0.01
	Hand	0.03	0.01	0.04	0.01

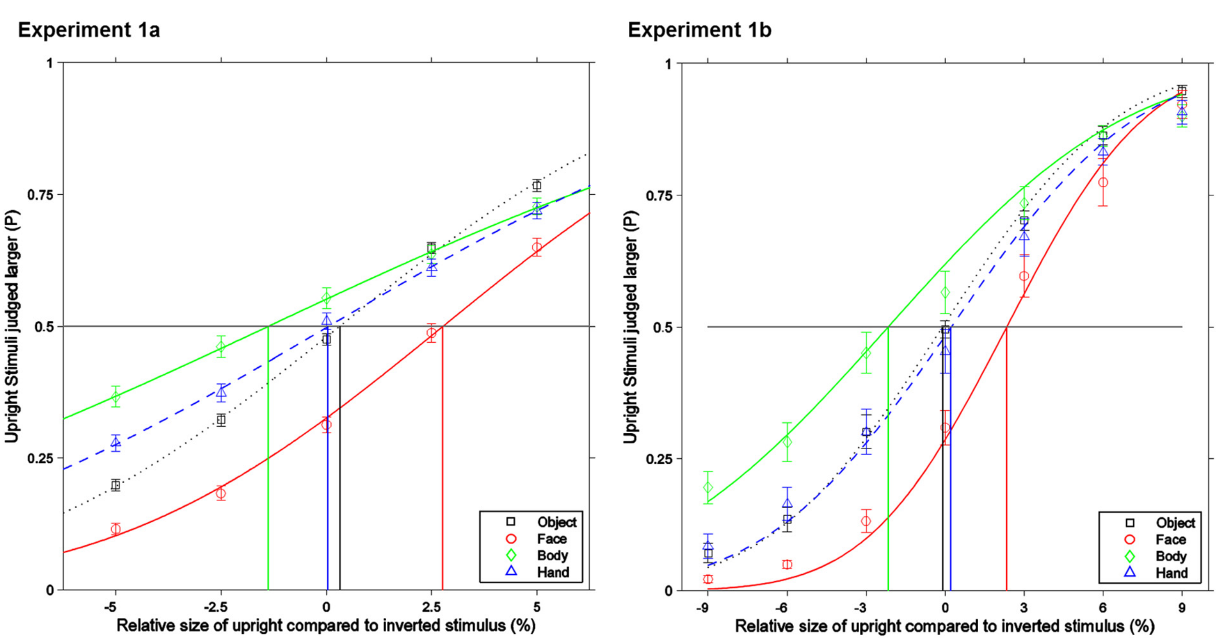

Fig. 3. Mean probability of trials where the *upright* stimulus (body, face, hand, and object) was judged larger than the same-sized inverted stimulus for Experiment 1a (N = 124; left panel) and Experiment 1b (N = 19; right panel). A comparison size of 0% (horizontal axis) indicates that the size of the upright and inverted stimuli was objectively equal. Size of standard image (400 pixels^2) = 0% on the X ordinate. Error bars give standard error of the mean (± SEM).

perceive upright faces as smaller than inverted faces (*M*: 2.34%), $t(18) = 4.52$, $p < 0.0001$, $d = 1.04$, providing further replication of the main result of Araragi and colleagues (Araragi et al., 2012). Also as in Experiment 1a, there was a significant effect in the opposite direction for bodies (*M*: −2.16%), $t(18) = -3.01$, $p = 0.007$; $d = 0.69$, with upright bodies perceived as bigger than inverted bodies. There were again no significant perceptual biases for either hands (*M*: 0.23%), $t(18) = 0.36$, $p = 0.723$; $d = 0.08$, or objects (*M*: −0.10%), $t(18) = -0.38$, $p = 0.711$; $d = 0.09$.

As in Experiment 1a, an ANOVA conducted on PSEs, revealed a significant difference across conditions, $F(3, 54) = 10.24$; $p < 0.0001$; $\eta_p^2 = 0.36$. The Holm–Bonferroni method confirmed that PSEs for the Body condition differed significantly from PSEs for the Face, Object and Hand conditions (Table 1). Further, PSEs for the Face condition differed significantly from PSEs for the Object condition. However, the comparison between the Face and Hand conditions just failed to survive correction for multiple comparisons (non-significant; $p = 0.03$).

3.1.5. Discussion

Experiment 1b performed in a controlled laboratory setting, replicated the results of Experiment 1a performed in an in-class group setting. Both experiments clearly replicated the finding that faces are judged to be larger when inverted than upright (Araragi et al., 2012). Further, both studies found that human bodies showed a reverse size illusion, being perceived as larger when upright than inverted. There were no size illusions as a function of orientation for hand or object stimuli.

4. Experiment 2

Because the human face has a unique morphology, often comprising a large contrast between face and darker hair, it could be argued that a high contrast between face and hair drove the size illusion. The size underestimation of upright faces (Araragi et al., 2012) may therefore be due to differences in perceived depth between upright and inverted faces. When the contrast polarity of photographic images is reversed, the effects of illumination are also reversed: shadow areas such as the nostrils, become bright rather than dark, whereas directly illuminated regions are now dark instead of bright (Fig. 4). Photographic negation disrupts observers' ability to use shading cues to infer facial structure and to discern patterns of pigmentation and colouration. Faces of negative contrast polarity are less recognisable than faces of positive polarity (Bruce & Langton, 1994; Bruce & Young, 1998; Galper, 1970; Galper & Hochberg, 1971; Kemp, Pike, White, & Musselman, 1996; Nederhouser, Yue, Mangini, & Biederman, 2007; Russell, Sinha, Biederman, & Nederhouser, 2006). If the illusion relies on contrast, then the illusion should reverse for negative images of faces. In contrast, if the visual system depends only on the geometric properties of faces, then the size illusion should remain even for negative images.

A further concern about the results from Experiments 1a and b is that the opposite effects seen for faces and for bodies could reflect an artefact of some low-level property of the stimuli (Tanca, Grossberg, & Pinna, 2010) which differs between faces and bodies. One such potential cue is luminance. The face stimuli in Experiments 1a and 1b tended to have hair which was darker than their skin. The bodies, in contrast, tended to have trousers in darker colours than shirts. Thus, a perceptual bias for objects to be perceived as bigger when they are lighter towards the top and darker towards the bottom could potentially account for the opposite results we find for faces and bodies (Tanca et al., 2010). If this were the case, then reversing the contrast polarity of the stimuli by using negative photographic stimuli should flip the effects for faces and bodies. In contrast, contour and configuration of body and face stimuli are preserved in negative images, which preserve all the geometric properties and spatial frequencies, of their positive counterpart images, but have the crucial difference that contrast luminance is reduced. If the effects we report above arise from the distribution of luminance across the image, then they should reverse for negative images, which will reverse these distributions. If the illusions arise from category-specific perceptual mechanisms, then they should remain even for negative images.

4.1. Methods

4.1.1. Participants

Twenty people participated. Data from one participant was excluded because R^2 was less than the pre-set threshold (i.e. 0.2) for one condition. Of the remaining nineteen participants (12 females), the mean age was 31.8 (SD = 13.7) years and 2 were left-handed. All had normal or corrected to normal vision.

4.1.2. Stimuli

The eight body and eight face stimuli from Experiment 1b were used to create reversed (negative) polarity stimuli, using Photoshop software (Adobe, San Jose, CA). As in Experiment 1b, images were saved to seven different sizes (measuring 364, to 436 square pixels; −9, to +9% change relative to the standard 400-square pixel size.

4.1.3. Design

Trials consisted of either negative or positive polarity contrast stimuli, never both within the same trial. The positive and negative polarity contrast trials of faces and bodies were presented randomly within the same block (Figs. 1 and 4). There were 8 blocks of 112 trials each, resulting in a total of 896 trials. All other procedures were identical to Experiment 1b.

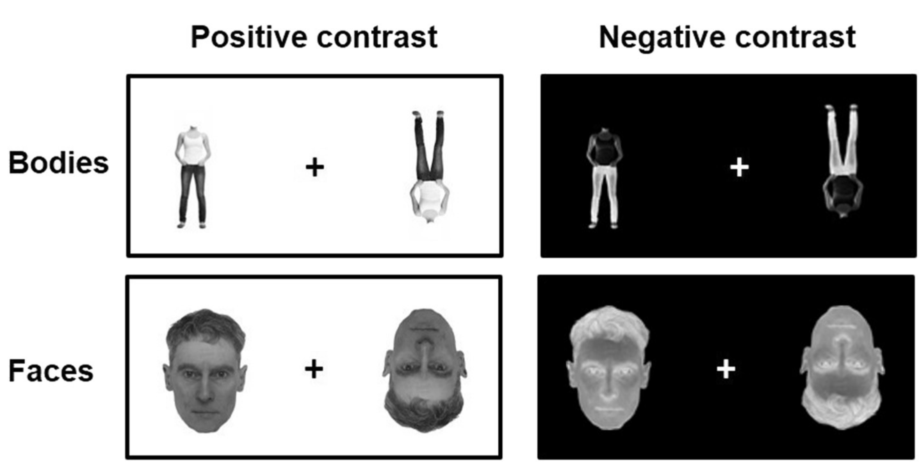

Fig. 4. Schematic of stimuli from Experiment 2, showing examples of positive and negative polarity contrast trials. Only face and body stimuli were used.

4.1.4. Results

Mean R^2 was 0.914 (SD = 0.095; range 0.570–0.996), indicating good fit to the data. Analysis of PSEs indicated that upright faces were perceived as smaller than inverted faces for both positive (*M*: 3.25%), $t(18) = 6.86$, $p < 0.0001$, $d = 1.57$, and negative (*M*: 2.67%), $t(18) = 6.77$, $p < 0.0001$, $d = 1.55$, polarity. For bodies, there were effects in the same direction as the previous experiments, but these did not reach significance for either positive (*M*: −1.43%), $t(18) = -1.17$, $p = 0.310$, $d = 0.27$, or negative polarity (*M*: −1.22%), $t(18) = -1.04$, $p = 0.259$, $d = 0.24$.

To examine the effects of contrast, we ran a 2 × 2 ANOVA with factors category (face, body) and polarity (positive, negative). There was a significant main effect of category, $F(1, 18) = 14.59$; $p = 0.001$; $\eta_p^2 = 0.41$. Critically, however, there was no main effect of polarity, $F(1, 18) = 0.42$; $p = 0.523$; $\eta_p^2 = 0.02$, nor an interaction, $F(1, 18) = 1.01$; $p = 0.328$; $\eta_p^2 = 0.05$.

4.1.5. Cross-experiment meta-analysis

Both Experiment 1a and Experiment 1b found a size underestimation of upright faces relative to inverted faces, and a size underestimation for upright bodies relative to inverted bodies. However, in Experiment 2, only the size underestimation for faces reached significance; the effect for bodies was in the same direction, but failed to reach significance. Visual inspection of the data revealed that two participants showed an unexpected strong positive PSE (> 7.77) for the body, accounting for the non-significant body overestimation effect observed in Experiment 2 (see Supplementary Materials, Fig. S1). In order to integrate the evidence from all three studies, a meta-analysis (Cumming, 2014; http://www.latrobe.edu.au/psychology/research/research-areas/cognitive-and-developmental-psychology/esci/2001-to-2010) (N = 162) was performed on the PSEs using ESCI software (Fig. 7; Exploratory Software for Confidence Intervals; http://erin.sfn.org/resources/2012/04/16/exploratory-software-for-confidence-intervals-comma-esci). A random-effects model was selected to account for heterogeneity among the results from all experiments (Berkey, Hoaglin, Mosteller, & Colditz, 1995; Thompson & Higgins, 2002).

The meta-analysed PSE effect for Faces was 2.73% [$t(162) = 11.50$; $p < 0.0001$′; $I^2 = 0\%$], providing a clear replication of the illusion reported by Araragi et al. (2012) for faces to be perceived as smaller when upright. The overall PSE for Bodies was −1.67% [$t(162) = -3.82$; $p < 0.0001$; $I^2 = 0\%$], providing strong overall evidence for an opposite illusion for bodies. There was no overall evidence from the 3 experiments for any illusion at all for either Hands [0.13%, $t(143) = 0.30$; $p = 0.765$] or Objects [0.09%, $t(143) = 0.47$; $p = 0.639$]. There was little evidence of heterogeneity between experiments for each condition (Q statistic all < 1.3, all $p > 0.26$; with a corresponding I^2 statistic, all < 19%).

5. General discussion

We tested whether the size underestimation of upright faces effect (Araragi et al., 2012) is specific to faces, or generalizes to other stimuli with canonical orientations, such as human bodies, body parts like hands, and non-body objects. Consistent with the report of Araragi and colleagues, there were clear effects of inversion on size for faces in all experiments, with faces judged to be larger when inverted than upright. This effect was not apparent for any of the other three categories of stimuli, suggesting a high level of specificity to faces. Interestingly, and contrary to our initial predictions, human bodies showed a novel *reverse* size illusion with upright bodies judged as larger than the same body inverted. No size illusion (in either direction) was apparent for hands or for objects. Furthermore, Experiment 2 showed that the magnitude of the size illusion for faces and bodies is unaffected when negative photographic stimuli were used, demonstrating that the opposite illusions for faces and bodies are not an artefact of luminance differences across categories (e.g., hair being darker than the rest of a face). In Experiment 2, the reverse size illusion for bodies failed to reach significance. Critically, negative contrast stimuli preserve configural information, thereby suggesting that the visual system driving the illusion depends on geometric properties.

5.1. Configural processing and the size illusion

Featural information refers to the properties of the individual parts of a face, while configural information refers to the metric distances between the individual parts and the relative spatial arrangements or configurations of these parts. When a face is inverted, featural and configural information are decoupled (Barton, Keenan, & Bass, 2001; Carey & Diamond, 1977; Farah et al., 1995; Leder & Bruce, 2000) as has been demonstrated in several face inversion illusions (Thompson, 1980, 2010; Thompson & Wilson, 2012). Studying illusions that rely on inversion effects offers an insight into body and face processing, as well as the strength of holistic coding and the processes underlying the various illusions. Examples of illusions thought to incorporate holistic processing are the composite illusion (Young et al., 2013), the part-whole illusion (Tanaka & Farah, 1993), and the “fat face thin” illusion (Thompson, 2010). Holistic processing is also evident in the inverted face size illusion (Araragi et al., 2012; this study), which demonstrates that inverting the face affects perceived size of the whole face. These illusions occur for the upright but not for the inverted stimulus (Thompson, 2010). Configural, or higher-order face information (Diamond & Carey, 1986) is disrupted when inverted faces are processed (Leder & Bruce, 2000; Searcy & Bartlett, 1996).

Araragi et al. (2012) found evidence for a size underestimation of upright faces which operates for cartoon faces, and photographic faces. One possible explanation of the results from Experiments 1a and b was that the opposite illusory effects seen for faces and for bodies reflect luminance differences between both stimulus types. A perceptual bias for objects which are darker towards the bottom e.g. the inverted faces used here, to be perceived as bigger could potentially account for the opposite results we find for faces and bodies. However, reversing the contrast polarity of the stimuli using negative photographic stimuli in Exp. 2 did not flip the effects for faces and bodies. Thus, luminance cues do not drive the opposite illusory effects. Our results clearly show that the size illusion is not disrupted when faces are observed in negative contrast polarity (Figs. 5–7), suggesting that the visual mechanisms driving the illusion depend on the geometric properties of the stimuli,

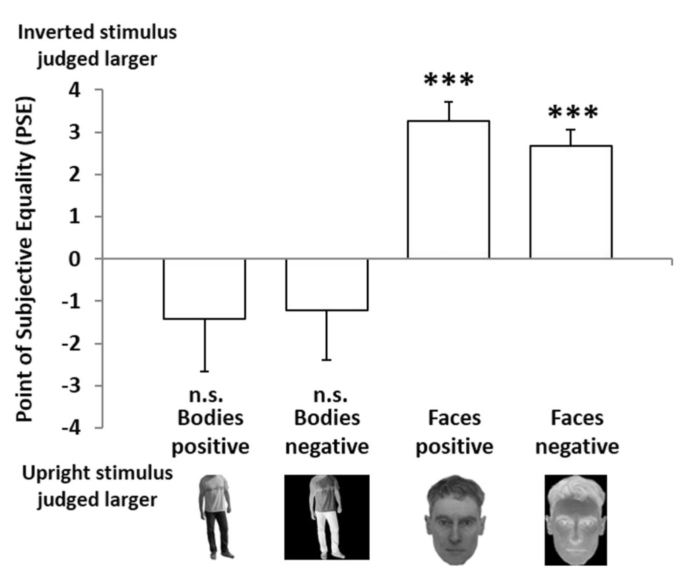

Fig. 5. PSEs from Experiment 2. Positive values indicate that the inverted stimulus was judged larger than the same-sized upright stimulus. Error bars give the standard error of the mean (± SEM). Note: *** indicates p value < 0.0001.

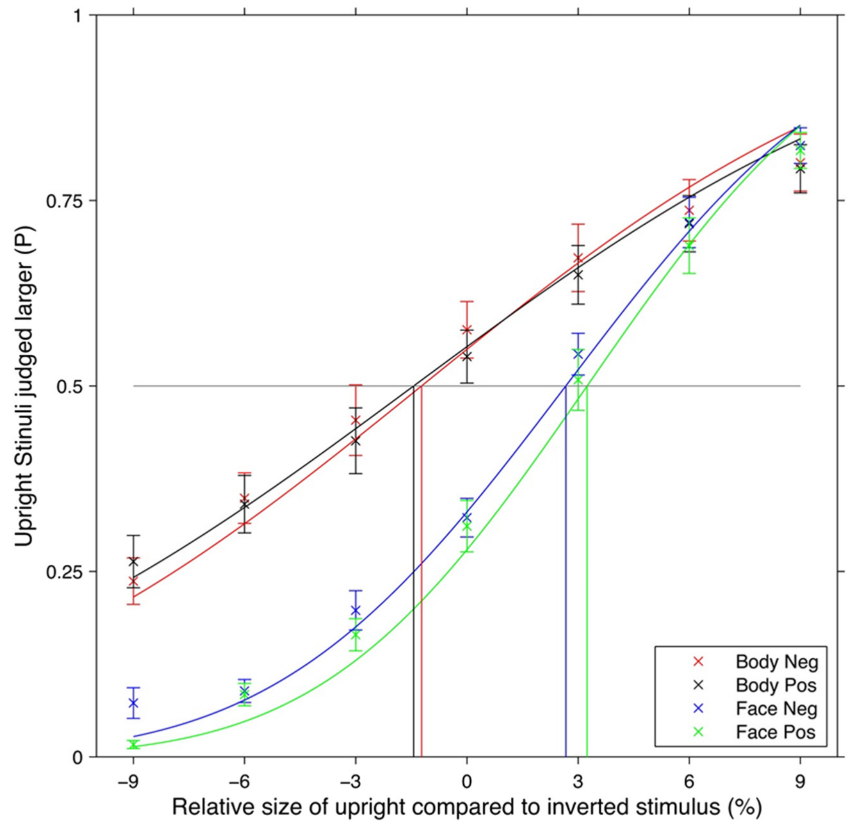

Fig. 6. Results from Experiment 2. Mean proportion of upright stimuli perceived as larger than the same stimulus inverted. Size of standard image = 0%. Error bars give standard error of the mean (± SEM).

rather than relying on image properties such as the contrast between light (e.g. a pale face) and dark (e.g. black hair). These results therefore raise an interesting dissociation with previous studies which have shown that *recognition* for faces of reversed ('negative') contrast polarity is impaired (Bruce & Young, 1998; Galper, 1970; Kemp et al., 1996) and familiar faces are more difficult to recognise when viewed as photographic negatives (Galper, 1970). It may be that when faces (and other classes of object) (e.g., Yin, 1969) are presented in negative polarity, the disruptive effect on recognition results from misinterpretation of shadow cues to the 3D structure of a face (e.g., Kemp et al., 1996), whereas the perceived size of the body and face images depends on an over-reliance on featural rather than configural processing.

5.2. Can configural processing explain the reverse size illusion for bodies?

Our finding of a reverse illusion for bodies provides behavioural evidence that bodies and faces are processed differently, at least in part. Our results further suggest that the processing of human bodies appears to be clearly dissociable from object processing and are consistent with previously reported face and object perception data which indicated that human bodies might be processed differently from faces, hands and objects and by different selective mechanisms (Hole, George, & Dunsmore, 1999; Johnston, Hill, & Carman, 2013; Lewis & Johnston, 1997). It seems that inversion has specific effects on body processing, similar to that of the face, processing, but possibly via a distinct mechanism. Body forms might not be processed holistically as integrated representations (Maurer et al., 2002). Recent studies suggest that human faces and human body forms are unique stimulus classes.

Neuroimaging studies using fMRI have revealed distinct, but partly overlapping, brain areas for face and body perception (Kanwisher & Yovel, 2006; Peelen & Downing, 2005; Schwarzlose, Baker, & Kanwisher, 2005). Faces and human body forms appear to be processed in adjacent and overlapping but distinct networks within the fusiform gyrus (Peelen & Downing, 2005; Schwarzlose et al., 2005). The fusiform face area (FFA; Barton, 2003) and the occipital face area (OFA; Rossion et al., 2003; Sorger, Goebel, Schiltz, & Rossion, 2007) are two occipitotemporal regions selectively activated by visual presentation of human faces. FFA is implicated more with configural processing of faces (Benuzzi et al., 2007; Rossion et al., 2000; Tong, Nakayama, Moscovitch, Weinrib, & Kanwisher, 2000), while OFA is thought to be involved in processing of face parts (Yovel & Kanwisher, 2005). Visual processing of non-facial body parts selectively activates bilateral occipitotemporal regions called extrastriate body area (EBA; Downing, Jiang, Shuman, & Kanwisher, 2001). EBA responds to viewing static and dynamic displays of the human body and its single parts, but not faces and objects (Peelen & Downing, 2007). A second body selective area - the fusiform body area (FBA) responds selectively to whole bodies and body parts (Peelen & Downing, 2005; Schwarzlose et al., 2005). FFA and EBA spatially and anatomically overlap to varying degrees in most observers, though neuroimaging techniques such as multivariate pattern analysis, as well as high-resolution fMRI, can distinguish between these two functionally defined regions (Peelen & Downing, 2005, 2007; Schwarzlose et al., 2005). FBA responds more to whole bodies than to single body parts (Taylor, Wiggett, & Downing, 2007), while EBA processes non-facial body parts (Taylor et al., 2007; Urgesi, Calvo-Merino, Haggard, & Aglioti, 2007). Thus, distinct brain areas appear to be involved in the perception of faces and bodies, and their parts. The present results showing opposite size illusions for body and for face stimuli are consistent with the notion that human body forms and human faces are processed as unique stimulus classes.

The reason for the size overestimation of upright bodies remains unclear. Our results provide no clear evidence for a configural processing mechanism involved in human body form perception, at least for body shapes without heads, which might be related to a lack of configural processing of these stimuli. This behavioural evidence corresponds with previous neuroimaging data (Kanwisher & Yovel, 2006;

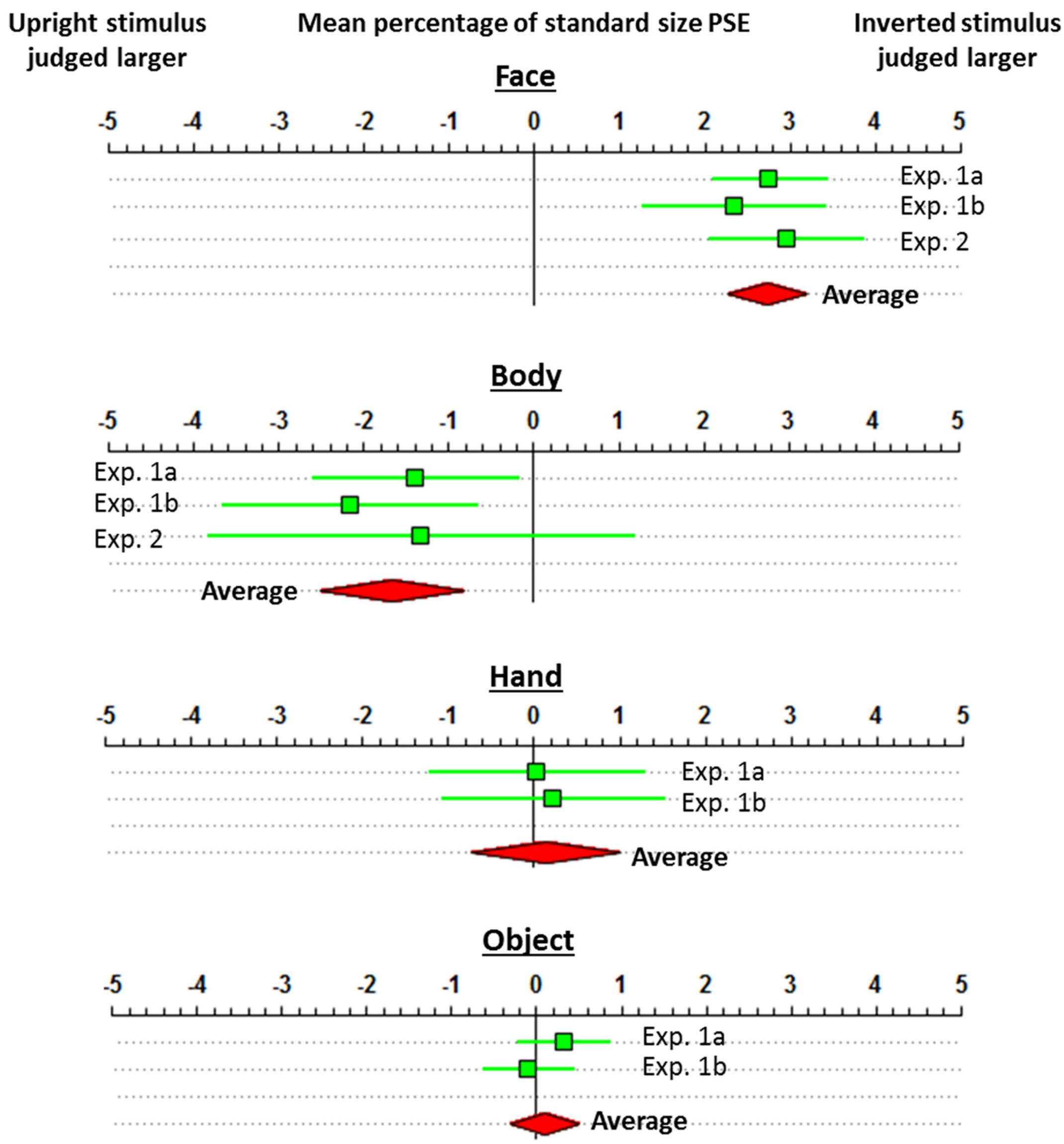

Fig. 7. Forest plots for Face, Body, Hand and Object conditions in the meta-analysis of all 3 experiments pooled together.

Peelen & Downing, 2005; Schwarzlose et al., 2005) which suggested that human bodies, like faces, are processed in specialized distinct, though possibly overlapping cortical areas. There is however, as yet considerable uncertainty as to whether faces and bodies are processed by the same neuronal mechanisms (domain general hypothesis), or by dissociable mechanisms (face specificity hypothesis) (Kanwisher & Yovel, 2006; Tarr & Cheng, 2003). Body shapes and faces might share some initial processing mechanisms (e.g. first-order relational and structural information), but later stages might process both stimulus classes differentially. The presence of the head may also be critical for the processing of the human body. A possible explanation for the size overestimation of upright bodies is that body stimuli are only processed as bodies when presented in the upright orientation, and the missing head is perceptually 'added' by the cognitive system resulting in an enlarged percept (Citti & Sarti, 2006; Moore, Yantis, & Vaughan, 1998). According to this account, an inverted body is processed by the brain as an object and its veridical size is thereby more readily accounted. The presence of a head clearly alters perceptual and neural processing. Upright human bodies without heads largely overlap with the typical representation for a complete human body shape, whereas inverted human body shapes without heads, on the other hand, clearly do not. The 'body inversion effect' (i.e. disproportionate recognition for inverted bodies relative to other objects) is abolished for headless bodies but not when other body parts, such as arms or a leg, are removed (Minnebusch et al., 2009). Bodies without heads elicit longer electrophysiological N170 latencies compared to human bodies with heads (Minnebusch et al., 2009). Interestingly, configural processing possibly from the spacing of the features seems to have a (diminishing) effect on the perceived size of the face. Therefore, information obtained and their consequent influence on the perception of the size of a face should be absent when the face is inverted. However, when a face is inverted, holistic processing is disrupted so that only featural processing can be used to judge size.

In the visual cortex, receptive field (RF) size progressively increases at successively higher levels in the processing hierarchy (Kravitz, Saleem, Baker, Ungerleider, & Mishkin, 2013; Smith, Singh, Williams, & Greenlee, 2001; Zeki, 1978). RFs are smallest in V1, larger in V4, and larger still in cytoarchitectonic areas TE (anterior inferior temporal cortex) and TEO (posterior inferior temporal cortex) respectively. Upright faces activate separate higher-level visual areas than inverted faces (Haxby, Hoffman, & Gobbini, 2000; Pitcher, Garrido, Walsh, & Duchaine, 2008; Yovel & Kanwisher, 2005), and may involve neuronal populations with larger receptive fields than those involved in processing the same face inverted. Such neural activity could give rise to a conscious percept of a ‘smaller’ upright face (Zeki, 1998). A reversal of this ‘RF size and stimulus orientation’ relationship for bodies, i.e. *smaller* RF size for upright bodies and *larger* RF size for inverted bodies, could provide a possible neural mechanism and explanation for the reverse body illusion. Clarifying this issue would increase our understanding of how humans recognise other humans.

According to theories of vision, the visual system may use neurons with differing receptive field sizes to create a series of neural representations of the same stimulus on different scales (Blakemore & Campbell, 1969; Campbell & Robson, 1968; Pantle & Sekuler, 1968), thereby providing the brain with a neural representation of a face from a number of scales simultaneously, and enabling the visual system to solve problems of scale intractable using single scaled representations only. A small population of face-selective neurons in the superior temporal sulcus (STS) of the monkey have been identified which show size constancy, i.e., the absolute size of a face is determined by the magnitude of the neuronal response, independently of the distance of the face (Rolls & Baylis, 1986). Such neurons could contribute to a face recognition system by ensuring that only objects within a specific absolute size range are classified as faces.

Future neuroimaging research could unlock whether an inverted face illusorily experienced as larger, activates a greater retinotopic map in visual cortex than an identical upright face that projects the same visual angle on the retina. The retinotopic representation of a visual stimulus can change in accordance with its *perceived* angular size (S. O. Murray, Boyaci, & Kersten, 2006). Measuring whether an inverted stimulus shows a different spatial extent of visuo-cortical activation while occupying the same retinal area as its upright counterpart, remains a vital question for future research; and could inform us which stages of the retinotopic representation in the human visual system are affected by the size illusion scaling process. The answer would elucidate face and body processing neural mechanisms in the human brain. It seems the goal of the visual system is not to precisely measure the size of a face or body image projected onto the retina, but rather to identify the source of the image so that one can interact with it appropriately.

5.3. Absence of a size illusion for human hands

Interestingly, in Experiments 1a and 1b, upright and inverted hands, were judged to be identical in size. In a previous EEG study (Yovel, Pelc, & Lubetzky, 2010), a significant BIE was found when hands were removed from a body form. Indeed neuroimaging results have provided evidence for a distinct representation for the hand in left extrastriate visual cortex (Bracci, Ietswaart, Peelen, & Cavina-Pratesi, 2010); (see also Susilo, Yang, Potter, Robbins, & Duchaine, 2015). Hand selective areas have been observed in humans in right ventral visual cortex, left STS and right inferior parietal cortex (C. Gross, Bender, & Rocha-Miranda, 1969; C. G. Gross, 2008; McCarthy, Puce, Belger, & Allison, 1999). Considering the important role played by hands in our daily lives e.g. during feeding and grooming behaviours and communication, the hand, similar to the face and body, ought to be “special” too (Bracci et al., 2010), and yet elicits no size illusion.

A possible limitation of this study is that in everyday life, human body shapes are usually perceived with heads. Bodies without heads might be unnatural stimuli, which may lead to different processing strategies. Inverted human body shapes without heads might not match the typical representation of bodies. Recent research has shown that bodies with and without heads can be processed differently (Minnebusch et al., 2009). Bodies with heads might activate both face and body sensitive areas, whereas bodies without heads may be processed by the brain as non-biological unnatural stimuli (Minnebusch et al., 2009; Minnebusch et al., 2010; Reed et al., 2003; Reed et al., 2006). The head is a critical feature of the body and absence of the head may alter how the body is perceived, at least during recognition tasks.

In conclusion, we replicated (Experiments 1a and 1b) and extended (Experiment 2) the intriguing size illusion effect previously reported by Araragi et al. (2012), where an upside down face is perceived as larger than the same face stimulus upright. Additionally, we found evidence for a novel reverse illusion for human body forms and report the absence of any illusion for body parts (i.e., human hands) and non-body objects. The illusion is not altered when faces are presented with negative polarity contrast (Exp 2), suggesting that face illusions may be driven by low level perceptual processes (Coren & Enns, 1993). Intriguingly, when taken together the current results indicate that the face, body and hands produce an illusion, a reverse illusion and no illusion respectively, suggesting that all body-parts are processed differentially by the brain. One possibility is that selective representations exist for bodies, faces and hands, and the mechanism underlying the size illusions operates at the level of these separate representations, rather than the whole. Our findings offer an intriguing insight into body and face perception and offer prospects for future research. Clearly the goal of the visual system is not to measure the precise size of the image of a human projected onto the retina, but rather perhaps to determine how one should socially interact with it.

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