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Evidence for a size underestimation of upright faces

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Abstract. We quantitatively examined the difference in perceived size between upright and inverted faces using the method of constant stimuli. The stimuli included eight face images modified from two cartoon faces produced by Kitaoka (2007, http://www.psy.ritsumei.ac.jp/~akitaoka/kao-e.html and 2008, *Cognitive Psychology* **5** 177–185) and six photographic faces, including a photographic face used by Thompson (2010, http://illusioncontest.neuralcorrelate.com/2010/the-fat-face-thin-fft-illusion/). Experiment 1 showed that an upright face and outline were perceived to be significantly smaller than an inverted face and outline, respectively. Moreover, the amount of the size underestimation in the face stimulus condition was significantly larger than that in the outline stimulus condition. Experiment 2 showed that an upright face was perceived to be significantly smaller than 90° and 270° rotated faces, whereas an inverted face was not perceived to be significantly larger than a 90° or 270° rotated face. Experiment 3 showed that upright faces were perceived to be significantly smaller than upright and inverted outlines, whereas inverted faces were not perceived to be significantly larger than upright or inverted outlines. Experiments 4 and 5 showed that upright photographic faces were also perceived to be significantly smaller than inverted photographic faces. These results provide quantitative evidence for a size underestimation of upright faces.

Keywords: size illusion, face perception, upright faces, underestimation, face inversion effect

1 Introduction

The face inversion effect, or facial inversion effect, refers to a phenomenon that the recognition of inverted faces is more difficult than that of upright faces. Moreover, the inversion effect for faces is larger than those for other objects (Rakover and Teucher 1997; Valentine 1988). For example, previous studies, using paired-associate and forced-choice recognition tasks, respectively, have reported that, in adults, the learning and memory for upright faces were better than those for inverted faces (Goldstein 1965; Yin 1969).

The "Thatcher illusion" (Thompson 1980) is a famous face illusion, and would be one type of the face inversion effect. That is, an upright face with inverted eyes and mouth is typically perceived to be more grotesque than an inverted face in which the eyes and the mouth are upright. The phenomenon suggests that the facial expression of upright faces is easier to be distinguished than that of inverted faces.

Recently, a size illusion was proposed for the face inversion effect. Kitaoka (2007, 2008, 2010), using cartoon face stimuli, as shown in figure 1, reported a phenomenon that inverted faces were perceived to be larger than upright faces. Kitaoka (2007) referred to this phenomenon as the "upside-down face overestimation illusion", since he assumed that upright faces were the baseline. However, the illusion has not yet been supported by experimental data, and, in particular, there remains a question whether the illusion was based on the size overestimation of inverted faces compared to the actual (veridical) size and/or the size underestimation of upright faces compared to the actual size. For convenience, we hereafter refer to this phenomenon as "size underestimation of upright faces" (ie "size underestimation

Figure 1. Kitaoka (2010) demonstrated that inverted faces were perceived to be larger than upright faces, using two cartoon face stimuli.

of upright faces compared to inverted faces" and/or "size underestimation of upright faces compared to the actual size").[1]

Thompson (2010), using a photographic face stimulus, reported that "the upside-down version looks much thinner,—altogether a longer shaped face than the upright version". He referred to this phenomenon as "the fat face thin (fft) illusion". Although Thompson did not describe the difference in perceived size between upright and inverted faces, his report suggested that upright faces were not perceived to be smaller than inverted faces. The suggestion of Thompson's report might seem to contradict the size underestimation of upright faces. On the other hand, to our knowledge, experimental data in support of the fft illusion have not yet been published.

We quantitatively examined the size underestimation of upright faces, using the method of constant stimuli. In the present study, two stimuli (eg an upright face and an inverted face) were simultaneously presented to directly compare a whole size of one face or outline with that of another face or outline. Experiment 1 examined the difference in perceived size between upright and inverted faces or outlines of the face, using a cartoon stimulus. Experiment 2 examined, using a cartoon stimulus, whether the size underestimation of upright faces was based on the size underestimation of upright faces compared to inverted faces and/or the size overestimation of inverted faces compared to upright faces. Experiment 3, using two cartoon stimuli, examined whether the size underestimation of upright faces was based on the size

[1] This is based on the results of experiment 3 in the present study; upright faces were perceived to be significantly smaller than upright and inverted outlines, whereas inverted faces were not perceived to be significantly larger than upright or inverted outlines.

underestimation of upright faces compared to the actual (ie veridical) size and/or the size overestimation of inverted faces compared to the actual size. Experiments 4 and 5 examined, using six photographic stimuli, the size underestimation of upright faces.

2 Experiment 1

The purpose of experiment 1 was to quantitatively examine, using a cartoon face stimulus, the difference in perceived size between upright and inverted faces and the difference in perceived size between upright and inverted outlines of the face.

2.1 *Methods*

2.1.1 *Observers*. Eight adults[(2)] participated as observers. They had normal or corrected-to-normal visual acuity and were unaware of the purpose of the experiment. Written consent was obtained from all of them.

2.1.2 *Apparatus*. The stimuli were presented on a 19-inch CRT monitor (Trinitron GDM-F400, Sony). A computer (Vostro 430a, Dell) was used to control the presentation of the stimuli and to record responses that the observers made by pressing assigned keys. The observers' heads were held in position with a forehead- and chin-rest.

2.1.3 *Stimuli*. Figure 2 shows typical examples of stimuli used in experiment 1. A pair of faces or outlines of the face was presented on opposite sides of a fixation point.[(3)] The face stimulus was a modification of the cartoon female face (figure 1) produced by Kitaoka (2007), which was converted to a grey-scale image. There were two stimulus types: face and the outline. There were two stimulus orientations: upright and inverted. There were four test stimuli and the test–comparison stimulus combinations were upright face–inverted face (UF–IF), inverted face—upright face (IF–UF), upright outline–inverted outline (UO–IO), and inverted outline–upright outline (IO–UO). The test stimulus subtended 2.3 deg (ie length or height) × 2.8 deg (ie width) of visual angle. Hereafter, the length or width of the test stimulus is referred to as the "standard size" (ie 1.0). The size of the comparison stimulus was 0.94, 0.97, 1.00, 1.03,

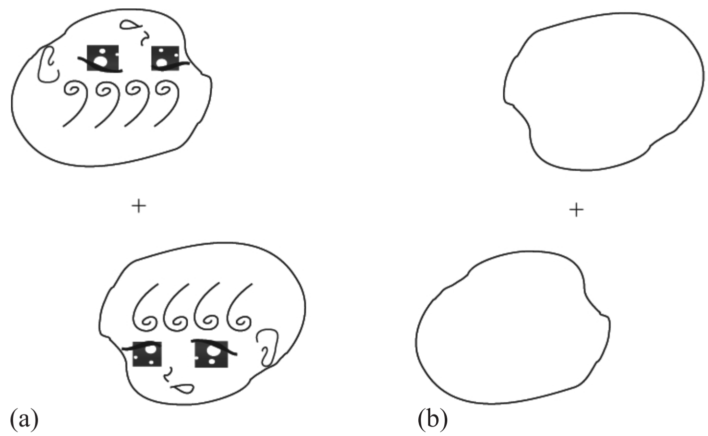


Figure 2. Stimuli of experiment 1. Two typical examples of cartoon face and outline stimuli in different size conditions. The crosses indicate the fixation point. (a) In the face stimulus condition, an upright face and an inverted face were presented. (b) In the outline stimulus condition, an upright outline and an inverted outline were presented.

(2) In the present study, adults were defined as being over 18 years old.

(3) We requested the observers to continue to steadily fixate on the fixation point and to simultaneously view two stimuli, since the fixation point and the instructions prevent artifacts, such as the difference in distance between the sight line and each face or outline due to the location of the sight line, from changing perceived sizes of stimuli.

or 1.06 times physically larger than the standard size [ie the length and width of the comparison stimulus were 0.94, 0.97, 1.00, 1.03, or 1.06 times physically longer than the length and width of the standard size (ie the test stimulus), respectively]. The stimuli were presented at the upper left and lower right positions as shown in figure 2a or the upper right and lower left positions as shown in figure 2b relative to the fixation point. The distance between the centre of the test or comparison stimulus and the fixation point was 1.7 deg. The location of the comparison stimulus was slightly changed (ie jittered) in each trial. The test and comparison stimuli were presented in a white circular background with a diameter of 12.5 deg. The luminance of the white background inside the circular background was 77.6 cd m^{-2}. The stimuli were presented until the observers responded by pressing assigned keys.

2.1.4 *Procedures*. The observers viewed the stimuli in a darkened room using binocular vision. The viewing distance was 114.6 cm.

The observers were requested to continue to steadily fixate on the fixation point, to simultaneously view two face or outline stimuli, and to report whether a face or outline presented in the upper or lower position (referred to as "test stimulus") was perceived to be larger or smaller than that in the lower or upper position (referred to as "comparison stimulus"). Moreover, the observers were requested to judge the size based on the perceived size of the whole face or outline, not based on any other factors. Further, the observers were requested to respond on the basis of the initial perception of the sizes, even if the perceived sizes changed with further viewing. Assigned keys corresponding to "larger" or "smaller" were counterbalanced between the observers to avoid a simple keypress response bias.

Each observer completed three experimental sessions (three repetitions) consisting of two blocks (two test positions) of 120 trials (4 test stimuli × 5 comparison stimulus sizes × 6 repetitions). Before each block, each observer performed 5 practice trials to get accustomed to the task in each test position. The order of the blocks in each session and the trials in each block was randomised for each observer.

2.2 *Data analysis*

Figure 3a shows the means of the probabilities that test stimuli were perceived to be larger than comparison stimuli in experiment 1. The data were fitted with a cumulative normal distribution function. "The perceived size of the test stimulus" (hereafter "perceived size") for each observer was estimated by deriving a psychometric function from the data of each observer and calculating each point corresponding to a probability of 0.5. The unit of analysis was based on the mean averaged over the positions of the test stimuli and upright or inverted stimuli, since those conditions were counterbalanced.

2.3 *Results and discussion*

The results of experiment 1 quantitatively showed that the size underestimation of upright faces occurred. Figure 3b shows the means of the perceived sizes of the test stimuli in experiment 1. In the UF–IF and IF–UF combinations, *t*-tests showed that the perceived sizes were significantly smaller and larger than the standard size (1.0), respectively ($t_7 = 6.78$, $p < 0.01$; $t_7 = 12.18$, $p < 0.01$). The results indicated the size underestimation of upright faces compared to inverted faces and/or the size overestimation of inverted faces compared to upright faces. In addition, a *t*-test showed that the absolute value of the perceived size in the face stimulus condition[4] was significantly smaller than the standard size ($t_7 = 9.81$, $p < 0.01$).

[4] The absolute value of the perceived size in the face or outline stimulus condition was calculated as the mean averaged over "the perceived size in the UF–IF or UO–IO combination" and "the reciprocal of the perceived size in the IF–UF or IO–UO combination".

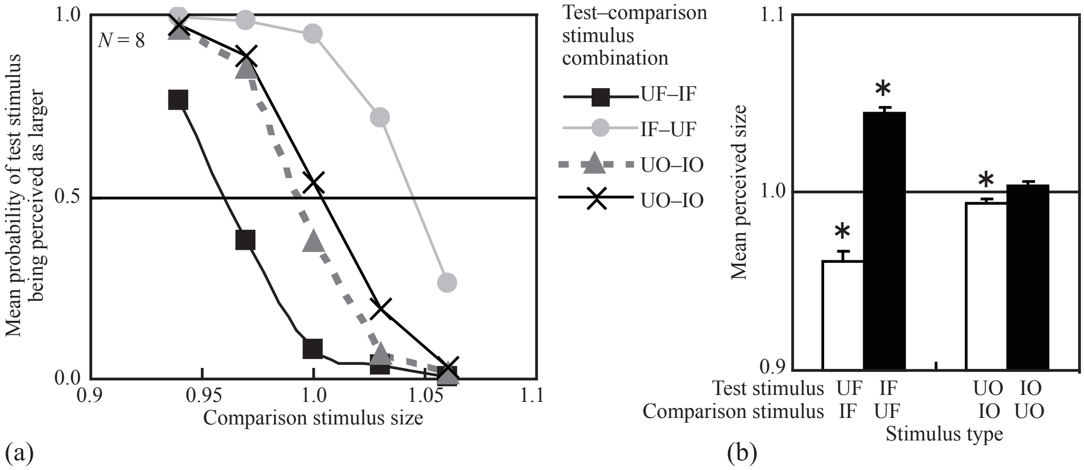


Figure 3. Results of experiment 1. (a) The means of the probabilities that test stimuli were perceived to be larger than comparison stimuli (ie the test stimulus being perceived as larger) as a function of the comparison stimulus size separately for each test–comparison stimulus combination. (b) The means and standard errors of the perceived sizes of test stimuli as a function of the stimulus type, separately for each test orientation. Asterisks (*) indicate that each perceived size was significantly larger or smaller than the standard size (ie 1.0). UF and IF indicate upright and inverted faces, respectively. UO and IO indicate upright and inverted outlines, respectively.

The results of experiment 1 partially showed that a size underestimation of upright outlines occurred. In the UO–IO combination, a t-test showed that the perceived size was significantly smaller than the standard size ($t_7 = 2.75, p < 0.05$). On the other hand, in the IO–UO combination, a t-test showed that the perceived size was not significantly larger than the standard size ($t_7 = 1.29$, $p > 0.05$). A t-test showed that the absolute value of the perceived size in the outline stimulus condition was significantly smaller than the standard size ($t_7 = 2.40, p < 0.05$).

Face processing largely affects the size underestimation of upright faces. The results showed the existence of size underestimation not only of upright faces but also of upright outlines. Therefore, it is possible that the size underestimation of upright faces is not based on face processing. Alternatively, the phenomenon might be based on the difference in shape between upright and inverted outlines of the face. However, a t-test showed that the absolute value of the perceived size in the face stimulus condition was significantly smaller than that in the outline stimulus condition ($t_7 = 14.57, p < 0.01$). The statistical results indicated that the amount of the size underestimation of upright faces was larger than that of upright outlines. Therefore, face processing largely affects the size underestimation of upright faces, although the difference in shape between upright and inverted outlines might affect the phenomenon.

3 Experiment 2

The purpose of experiment 2 was to quantitatively examine, using a cartoon face stimulus, whether the difference in perceived size between upright and inverted faces was based on the size underestimation of upright faces compared to inverted faces and/or the size overestimation of inverted faces compared to upright faces. In experiment 2, we operationally defined perceived sizes of 90° and/or 270° rotated faces as a baseline, and compared the perceived size of an upright or inverted face with that of a 90° or 270° rotated face.

3.1 *Methods*

The methods used in experiment 2 were identical to those used in experiment 1, except for the following points. As shown in figure 4, there were four stimulus orientations; upright (U), inverted (I), 90° rotated from the upright (90), and 270° rotated from the upright (270).

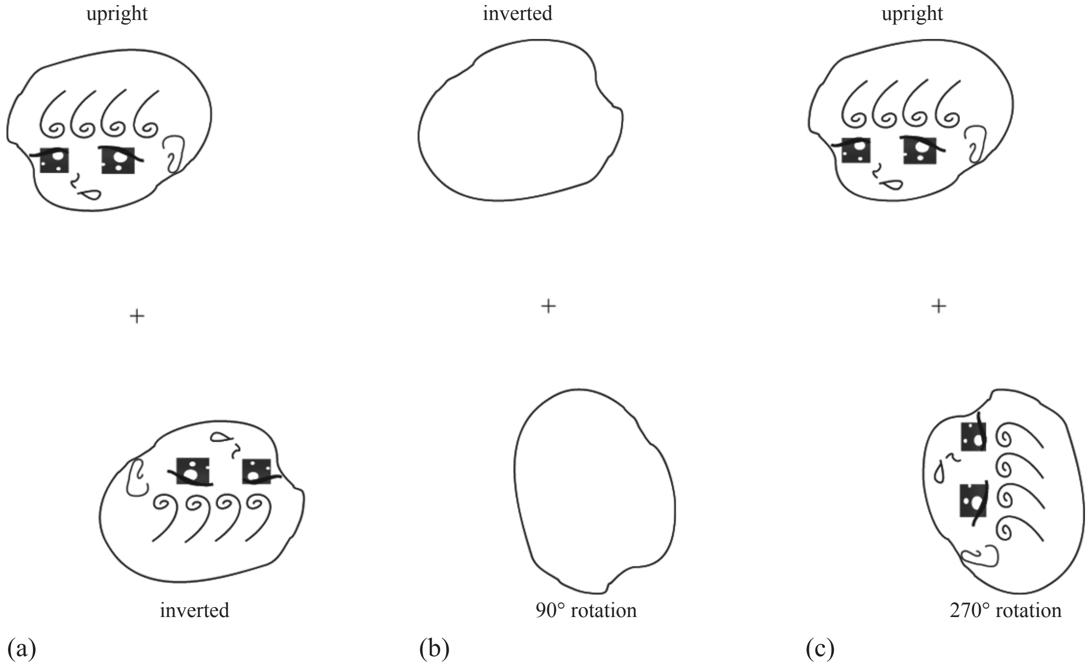


Figure 4. Stimuli of experiment 2. Three typical examples of the face and outline stimuli in same size conditions. Two faces or two outlines in each column were presented in each trial. The crosses indicate the fixation point. (a) Stimuli in the UF–IF combination. (b) Stimuli in the IO–90O combination. (c) Stimuli in the UF–270F combination.

The test–comparison stimulus combinations were UF–IF, IF–UF, UF–90F, UF–270F, IF–90F, IF–270F, UO–IO, IO–UO, UO–90O, UO–270O, IO–90O, and IO–270O,[(5)] as shown in figure 5. The distance between the centre of the test or comparison stimulus and the fixation point was 2.6 deg.

Each observer completed three experimental sessions (three repetitions) consisting of two blocks (two test positions) of 360 trials (4 test stimuli × 3 comparison stimuli [180° (ie upright or inverted) +90° +270°] × 5 comparison stimulus sizes × 6 repetitions). Before each block, each observer performed 10 practice trials to get accustomed to the task in each test position.

3.2 *Results and discussion*

The results of experiment 2 support the existence of the size underestimation of upright faces, and do not support the existence of the size underestimation of upright outlines. Figure 5 shows the means of the perceived sizes of the test stimuli in experiment 2. In the UF–IF and IF–UF combinations, *t*-tests showed that the perceived sizes were significantly smaller and larger than the standard size, respectively ($t_7 = 2.75$, $p < 0.05$; $t_7 = 2.89$, $p < 0.05$). Moreover, a *t*-test showed that the absolute value of the perceived size in the face stimulus condition was significantly smaller than the standard size ($t_7 = 4.37$, $p < 0.01$). On the other hand, in the UO–IO and IO–UO combinations, *t*-tests showed that the perceived sizes were not significantly smaller and larger than the standard size, respectively ($t_7 = 0.44$, $p > 0.05$; $t_7 = 0.91$, $p > 0.05$). Moreover, a *t*-test showed that the absolute value of the perceived size in the outline stimulus condition was not significantly smaller than the standard size ($t_7 = 1.41$, $p > 0.05$).

These results in the UF–90F, UF–270F, IF–90F, and IF–270F combinations showed that the difference in perceived size between upright and inverted faces was based on the size underestimation of upright faces compared to inverted faces rather than the size

[(5)] UF, IF, 90F, and 270F indicate upright, inverted, 90° rotated, and 270° rotated faces, respectively. UO, IO, 90O, and 270O indicate upright, inverted, 90° rotated, and 270° rotated outlines, respectively.

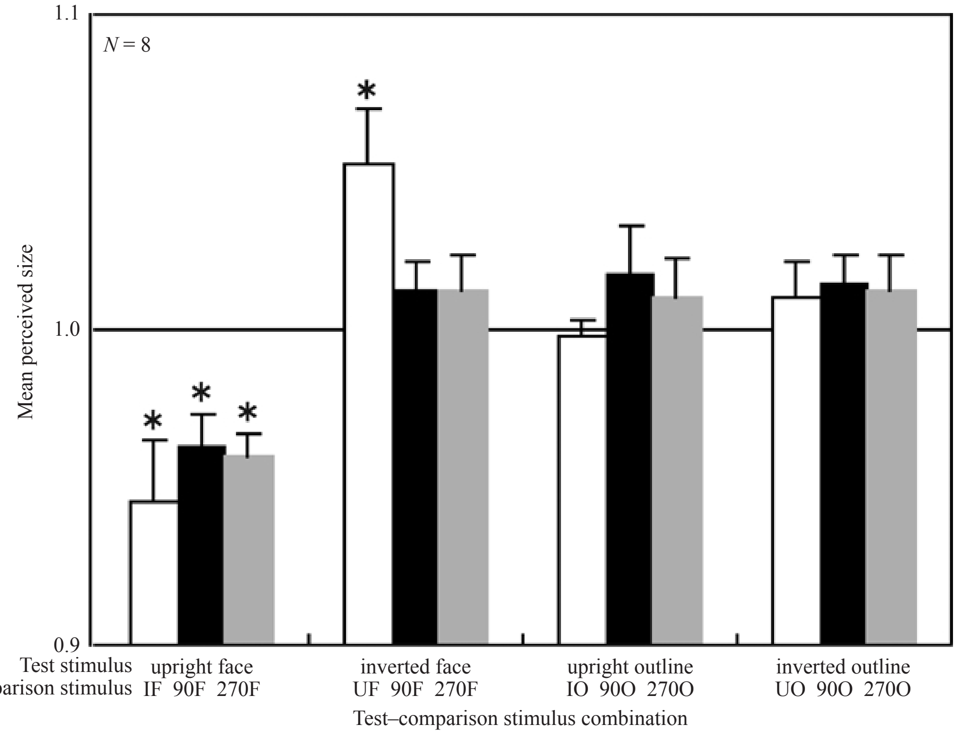


Figure 5. Results of experiment 2. The means and standard errors of the perceived sizes of the test stimuli as a function of the test stimulus separately for each comparison stimulus. Asterisks (*) indicate that each perceived size was significantly larger or smaller than the standard size.

overestimation of inverted faces compared to upright faces. In the UF–90F and UF–270F combinations, *t*-tests showed that the perceived size was significantly smaller than the standard size ($t_7 = 3.49$, $p < 0.05$; $t_7 = 6.00$, $p < 0.01$). On the other hand, in the IF–90F and IF–270F combinations, *t*-tests showed that the perceived size was not significantly larger than the standard size ($t_7 = 1.54$, $p > 0.05$; $t_7 = 1.17$, $p > 0.05$). In the UO–90O and UO–270O combinations, *t*-tests showed that the perceived size was not significantly smaller than the standard size ($t_7 = 1.10$, $p > 0.05$; $t_7 = 0.90$, $p > 0.05$). Further, in the IO–90O and IO–270O combinations, *t*-tests showed that the perceived size was not significantly larger than the standard size ($t_7 = 1.60$, $p > 0.05$; $t_7 = 1.06$, $p > 0.05$).

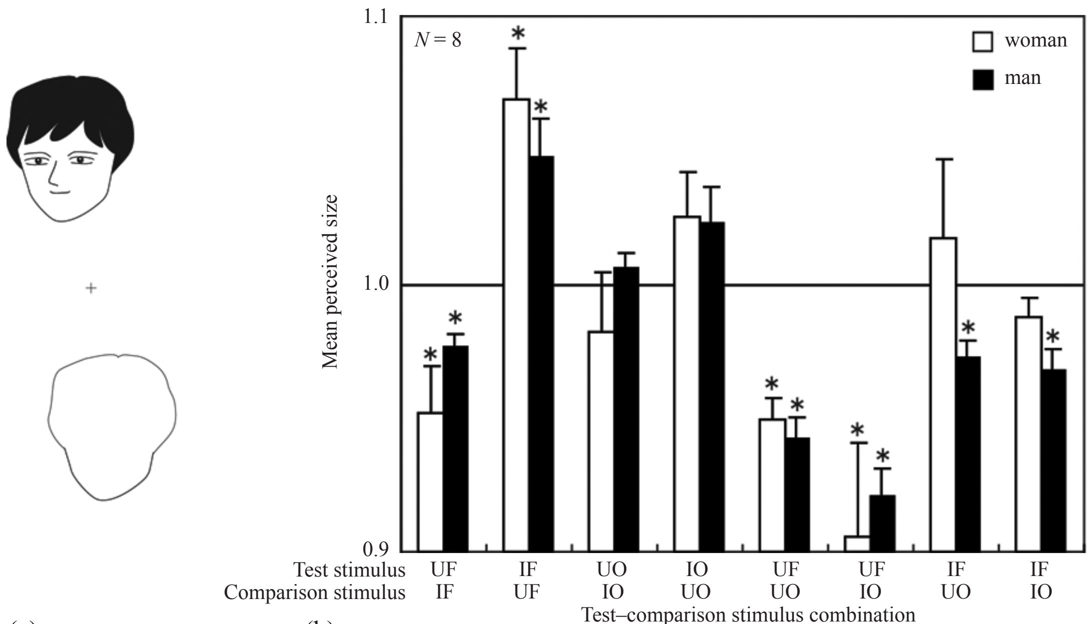
The results of experiment 2 do not support the size underestimation of upright outlines shown in experiment 1. In experiment 2, the results in the UO–IO and IO–UO combinations showed that the perceived sizes were not significantly smaller and larger than the standard size, respectively. Moreover, the absolute value of the perceived size in the outline stimulus condition was not significantly smaller than the standard size. The results of experiment 1 also showed that the amount of the size underestimation in the UO–IO combination was small, and that the perceived size in the IO–UO combination was not significantly larger than the standard size. On the other hand, the results of experiment 1 showed that the perceived size in the UO–IO combination was significantly smaller than the standard size, and that the absolute value of the perceived size in the outline condition was significantly smaller than the standard size. Although it is unclear why experiments 1 and 2 produced different results in the outline stimulus condition, the size underestimation of upright outlines does not appear to be a robust phenomenon (moreover, in experiment 3, the size underestimation of upright outlines did not occur).

4 Experiment 3

The purpose of experiment 3 was to quantitatively examine whether upright and inverted faces were perceived to be smaller and larger than the actual (ie veridical) size, respectively. Experiment 2, using a cartoon female face stimulus, showed that the size underestimation of upright faces compared to 90° and 270° rotated faces occurred, whereas the size overestimation of inverted faces compared to 90° or 270° rotated faces did not occur. On the other hand, it remains unclear whether upright faces are perceived to be smaller than the actual size and/or the other faces are perceived to be larger than the actual size. Therefore, in experiment 3, we operationally defined perceived sizes of upright and/or inverted outlines as the actual size,[6] and compared the perceived size of upright or inverted faces with that of upright or inverted outlines, using cartoon female and male face stimuli.

4.1 *Methods*

The methods used in experiment 3 were identical to those used in experiment 1, except for the following points. Seven of eight observers who participated in experiment 3 performed both female and male face conditions. One of the seven observers was the author TA, who might be aware of the purpose of experiment 3. There were two cartoon faces: a woman and a man. As shown in figure 6a, the male face was a modification of the cartoon face of the man produced by Kitaoka (2010), which was converted to a grey-scale image. In the male face stimulus, the test stimulus subtended 2.8 deg (ie length or height) × 2.3 deg (ie width) of visual angle. The test–comparison stimulus combinations were UF–IF, IF–UF, UO–IO, IO–UO, UF–UO, UF–IO, IF–UO, and IF–IO, as shown in figure 6b. The distance between the centre of the test or comparison stimulus and the fixation point was 2.6 deg.



(a) (b)

Figure 6. Stimuli and results of experiment 3. (a) A typical example of the male face stimulus in UF–UO combination and same size condition. A face and an outline were presented. The cross indicates the fixation point. (b) The means and standard errors of the perceived sizes of the test stimuli as a function of the test–comparison stimulus combination separately for each face. Asterisks (*) indicate that each perceived size was significantly larger or smaller than the standard size (ie 1.0).

[6] The results of experiments 2 and 3 showed that there was no significant difference in perceived size between upright and inverted outlines, although the results of experiment 1 showed that an upright outline was perceived to be significantly smaller than an inverted outline.

In each female or male face condition, an observer completed two experimental sessions (two repetitions) consisting of two blocks (two test positions) of 240 trials (8 combinations × 5 comparison stimulus sizes × 6 repetitions). Before each block, each observer performed 10 practice trials to get accustomed to the task in each test position. The order of female and male face conditions was randomised for each observer.

4.2 *Results and discussion*

The results of experiment 3 support the existence of the size underestimation of upright faces, and do not support the existence of the size overestimation of inverted faces. Figure 6b shows the means of the perceived sizes of the test stimuli in experiment 3. In the female and male face stimuli, upright faces were perceived to be significantly smaller than upright and inverted outlines. Four *t*-tests showed that the perceived sizes in the UF–UO and UF–IO combinations were significantly smaller than the standard sizes, respectively (woman: $t_7 = 6.57$, $p < 0.01$; $t_7 = 2.73$, $p < 0.05$; man: $t_7 = 6.69$, $p < 0.01$; $t_7 = 7.27$, $p < 0.01$). On the other hand, in the female face stimulus, *t*-tests showed that there was no significant difference between the perceived sizes and the standard size in the IF–UO and IF–IO combinations ($t_7 = 0.57$, $p > 0.05$; $t_7 = 1.66$, $p > 0.05$). Moreover, in the male face stimulus, *t*-tests showed that the perceived sizes in the IF–UO and IF–IO combinations were significantly smaller than the standard size ($t_7 = 4.27$, $p < 0.01$; $t_7 = 4.15$, $p < 0.01$).

The results showed that inverted faces were not perceived to be significantly larger than upright or inverted outlines. In the female face stimulus, there was no significant difference in perceived size between an inverted face and an upright or inverted outline, whereas, in the male face stimulus, an inverted face was perceived to be significantly smaller than upright and inverted outlines. Although the reason for the different results between the female and male faces is unclear, it might be due to the difference of aspect ratio "length–width" between the female and male face stimuli and/or a solid part of black hair of the male face stimulus. In the female face stimulus, the length (ie height) was shorter than the width, and there was not a solid part of black hair as shown in figure 4a. On the other hand, in the male face stimulus, the length was longer than the width, and there was a solid part of black hair as shown in figure 6a.

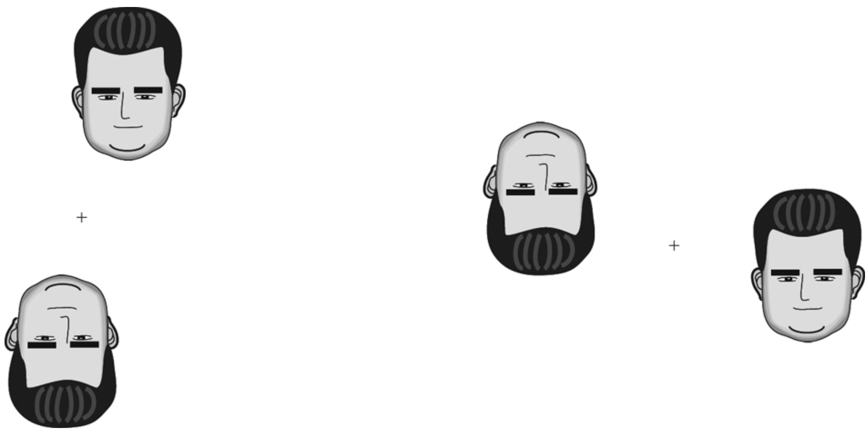
5 Experiment 4

The purpose of experiment 4 was to quantitatively examine the size underestimation of upright faces, using the Thompson's (2010) photographic face. He reported that an inverted face was perceived to be much thinner and longer than an upright face, using a photographic face stimulus, and referred to this phenomenon as the "fat face thin illusion" (fft illusion). Although he did not describe the difference in perceived size between upright and inverted faces, his report suggested that upright faces were not perceived to be smaller than inverted faces. We used not only vertical but also horizontal configurations in experiment 4, since Thompson's upright and inverted faces were (only) horizontally aligned (ie horizontal configuration).

5.1 *Methods*

The methods used in experiment 4 were identical to those used in experiment 1, except for the following points. The face stimulus was a modification of a photographic image of the man presented by Thompson (2010), which was converted to a grey-scale image. The luminance was 27.1 cd m^{-2}. The test stimulus subtended 3.1 deg (ie length or height) × 2.0 deg (ie width), respectively. The distance between the centre of the test or comparison stimulus and the fixation point was 2.6 deg. There were two test stimuli and the test–comparison stimulus combinations were UF–IF and IF–UF. There were two stimulus configurations: horizontal and vertical, as shown in figure 7. The observers were requested to report whether a face in the upper, lower, left, or right position was perceived to be larger or smaller than that in the lower, upper, right, or left position.

Each observer completed two experimental sessions (two configurations). An experimental session consisted of four blocks (2 test positions × 2 repetitions) of 60 trials (2 test stimuli × 5 comparison stimulus sizes × 6 repetitions). Before each block, each observer performed 10 practice trials to get accustomed to the task in each test position. The order of the sessions, the blocks in each session, and the trials in each block were randomised for each observer.



(a) (b)

Figure 7. Stimulus configurations of experiment 4. An upright face and an inverted face were presented in (a) vertical or (b) horizontal configuration. Note that the faces shown in the figure were not actually used in experiment 4, and the actual stimuli in experiment 4 were the photographic faces. The crosses indicate the fixation point.

5.2 *Results and discussioe*

The results of experiment 4, using a photographic face, showed that the size underestimation of upright faces occurred. Figure 8 shows the means of the perceived sizes of the test stimuli in experiment 4. In the vertical configuration, *t*-tests showed that the perceived sizes in the UF–IF and IF–UF combinations were significantly smaller and larger than the standard size, respectively ($t_7 = 3.30$, $p < 0.05$; $t_7 = 2.94$, $p < 0.05$). Similarly, in the horizontal configuration, *t*-tests showed that the perceived sizes in the UF–IF and IF–UF combinations were significantly smaller and larger than the standard size, respectively ($t_7 = 3.23$, $p < 0.05$; $t_7 = 4.34$, $p < 0.01$). In addition, two *t*-tests showed that there was no significant difference in perceived sizes in the UF–IF and IF–UF combinations between the horizontal and vertical configurations ($t_7 = 0.49$, $p > 0.05$; $t_7 = 1.41$, $p > 0.05$).

The results of experiment 4, using the Thompson's (2010) photographic face, showed the size underestimation of upright faces. Moreover, in both the horizontal and vertical configurations, the perceived sizes in the UF–IF and IF–UF combinations were significantly smaller and larger than the standard size, respectively. The difference between the present results and the suggestion of Thompson's report[7] might be due to an alignment effect related to the height of faces. As shown in figure 7, faces in the present horizontal configuration were presented to be vertically misaligned. On the other hand, in Thompson's (2010) horizontal configuration, two faces were presented to be vertically aligned. In the present experiment, the absence of an alignment effect of the height of faces might make clear the difference in

[7] In the present study, some observers reported that an inverted face was perceived to be longer and thinner than an upright face after the experimental trials in experiment 4. Their reports partly support Thompson's (2010) report.

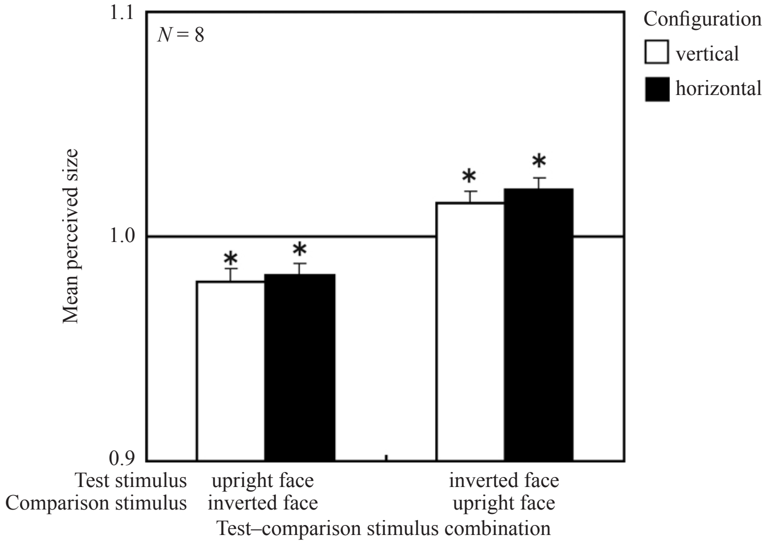


Figure 8. Results of experiment 4. The means and standard errors of the perceived sizes of the test stimuli as a function of the test–comparison stimulus combination separately for each configuration. Asterisks (*) indicate that each perceived size was significantly larger or smaller than the standard size.

perceived length (or height) between upright and inverted faces. On the other hand, another possible reason might be the difference in task between the present study and Thompson (2010). The present study measured the perceived size, whereas Thompson focused on the perceived shape. The difference thus might mean that the present study examined a size illusion of faces, whereas Thompson reported a shape illusion of a face.

6 Experiment 5

The purpose of experiment 5 was to quantitatively examine the size underestimation of upright faces using five photographic faces to test the generality of the phenomenon.

6.1 *Methods*

The methods used in experiment 5 were identical to those used in experiment 1, except for the following points. The face stimuli were modifications of five Japanese photographic faces (two women and three men) from the ATR Facial Expression Image Database (DB99; we received permission from ATR-Promotions to use these images), which were converted to grey-scale images. The test stimulus of face A (woman) subtended 3.0 deg (ie length or height) × 2.1 deg (ie width).[8] The test stimulus of face B (woman) subtended 3.0 deg × 2.1 deg. The test stimulus of face C (man) subtended 2.9 deg × 2.2 deg. The test stimulus of face D (man) subtended 3.0 deg × 2.1 deg. The test stimulus of face E (man) subtended 2.9 deg × 2.1 deg. The mean averaged over luminances of the five faces was 27.5 cd m^{-2} (SD = 0.7). The distance between the centre of the test or comparison stimulus and the fixation point was 2.6 deg. There were two test stimuli and the test–comparison stimulus combinations were UF–IF and IF–UF.

Each observer completed two experimental sessions (two test positions). An experimental session consisted of five blocks (five faces) of 120 trials (2 test stimuli × 5 comparison stimulus sizes × 12 repetitions). Before each block, each observer performed 20 practice trials to get accustomed to the task in each face and test position. The order of the sessions, the blocks in each session, and the trials in each block were randomised for each observer.

[8] In the present study, the ratio of length (ie height)/width of each face (ie head; all photographic faces have the hair portion as shown in figure 6a) was 0.84 (cartoon woman), 1.20 (cartoon man), 1.35 (face C), 1.36 (face E), 1.42 (face D), 1.43 (face A), 1.47 (face B), or 1.53 [Thompson's (2010) man].

6.2 *Results and discussion*

The results of experiment 5 showed that the size underestimation of upright faces occurred using five photographic faces. Figure 9 shows the means of the perceived sizes of the test stimuli in experiment 5. In the UF–IF combination, *t*-tests showed that the perceived size was significantly smaller than the standard size (face A: $t_7 = 4.43$, $p < 0.01$; face B: $t_7 = 5.62$, $p < 0.01$; face C: $t_7 = 4.91$, $p < 0.01$; face D: $t_7 = 4.28$, $p < 0.01$; face E: $t_7 = 5.10$, $p < 0.01$). In the IF–UF combination, *t*-tests showed that the perceived size was significantly larger than the standard size (face A: $t_7 = 4.84$, $p < 0.01$; face B: $t_7 = 4.80$, $p < 0.01$; face C: $t_7 = 4.18$, $p < 0.01$; face D: $t_7 = 4.33$, $p < 0.01$; face E: $t_7 = 7.10$, $p < 0.01$).

The present study showed the generality of the size underestimation of upright faces. Five experiments in the present study showed the size underestimation of upright faces not only in two cartoon faces (one woman and one man) but also in six photographic faces (two women and four men).

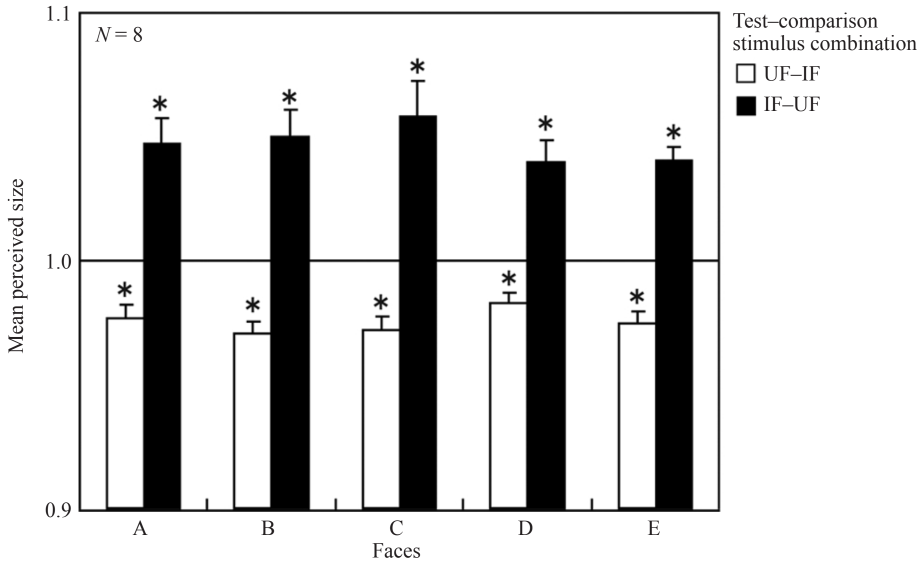


Figure 9. Results of experiment 5. The means and standard errors of the perceived sizes of the test stimuli as a function of the face separately for each test–comparison stimulus combination. Asterisks (*) indicate that each perceived size was significantly larger or smaller than the standard size.

7 General discussion

The present study confirmed the existence of the size underestimation of upright faces. Experiment 1 showed size underestimations of upright stimuli compared to inverted stimuli using both the face and outline stimuli. Moreover, the amount of the size underestimation in the face stimulus was significantly larger than that in the outline stimulus. Experiment 2 showed size underestimations of an upright face compared to 90° and 270° rotated faces, whereas a size overestimation of an inverted face compared to a 90° or 270° rotated face was not shown. Experiment 3 showed size underestimations of upright faces compared to upright and inverted outlines, whereas a size overestimation of inverted faces compared to upright or inverted outlines was not shown. Experiments 4 and 5 showed that the size underestimation of upright faces compared to inverted faces also occurred with six photographic faces. These results showed that the size underestimation of upright faces was based on the size underestimation of upright faces compared to the actual size, and suggested that face processing would affect the phenomenon.

The size underestimation of upright faces shown in the present study would be based on the perceived size of the face, and would not be based on the perceived shape of the face. In the present study, we did not control for the shape of the face (ie the shape of the outline of the face) in all faces, although we used upright and inverted faces and outlines. In addition, the observers were requested to base their size judgment on the perceived size of the whole face or outline, and not on any other factors. The results of experiments 2 and 3 showed that there was no significant difference in perceived size between upright and inverted outlines. Although the results of experiment 1 showed that an upright outline was perceived to be significantly smaller than an inverted outline, the results also showed that an inverted outline was not perceived to be significantly larger than an upright outline. Moreover, the amount of the size underestimation of an upright face was significantly larger than that of an upright outline. In addition, in experiment 3, the size underestimation of upright faces compared to upright outlines occurred, whereas the size overestimation of inverted faces compared to inverted outlines did not occur. Therefore, the size underestimation of upright faces would not be based on the difference in perceived shape (ie shape of the outline of the face) between upright and inverted faces.

The reason for the size underestimation of upright faces remains unclear, but the phenomenon is unlikely to be due to upper–lower visual field anisotropies. Previous studies have reported upper–lower visual field anisotropies. For example, He et al (1996) showed that the spatial resolution related to attention was lower in the upper visual field than in the lower visual field. Thus, in all experiments of the present study, the positions of the test stimuli and upright or inverted stimuli were counterbalanced between the upper and lower visual fields, and the statistical analyses were based on the means averaged over their conditions. Moreover, in experiment 4, the size underestimation of upright faces occurred in both the horizontal and vertical configurations.

One possible reason for the size underestimation of upright faces is a difference in perceived depth of the face (or head) between upright and inverted faces. Taya and Miura (2007) showed that the estimated width or length (ie height) of the cylinders decreased as the perceived depth of the cylinders increased. If upright faces were perceived to have more depth than inverted faces, the difference of the perceived depth might affect the size underestimation of upright faces. In the present study, it is unclear whether upright faces were perceived to have more depth than inverted faces. At least, we did not collect the observers' reports regarding the perceived depth of the face (or head) after the experimental trials. This issue should be examined in further studies.

The present study provides evidence for the size underestimation of upright faces. That is, upright faces were perceived to be smaller than inverted faces not only in two cartoon faces but also in six photographic faces. Moreover, the present results showed that the phenomenon was based on the size underestimation of upright faces compared to the actual (ie veridical) size and on face processing. On the other hand, the reason for the phenomenon is unclear. If the phenomenon is based on the difference in perceived depth of the face (or head) between upright and inverted faces, then the phenomenon would constitute one type of the face inversion effect. Further studies are required to clarify the reason for the phenomenon and to examine whether the phenomenon is based on the face inversion effect.

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