Yang’s iris illusion: External contour causes length-assimilation illusions

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Abstract: The Delboeuf illusion and the Ebbinghaus illusion (also known as the Titchener illusion) demonstrate that an external contour can lead to size-assimilation and size-contrast perception. This paper explores a novel illusion, revealing that neighboring external contours can also lead to a distortion in length perception. The illusion was originally discovered from a face stimulus (Experiment 1) in which a face was depicted alongside its mirror image so as to make the four irises absolutely equidistant. The distance between the middle two irises was underestimated in Asian faces, but overestimated in Caucasian faces. The illusion was also maintained when the facial stimuli were replaced by line drawings of eyes (Experiment 2). However, the illusion vanished when the irises were presented alone. Further scrutiny of the differences in facial characteristics between Asian and Caucasian faces reveals that the illusion might be elicited by the relative position of the eye shapes. This hypothesis was confirmed in Experiment 3, in which the distances between the eye shapes and the irises were manipulated.

Key words: illusion, face perception, eyes illusion, iris illusion.

Vision is an important faculty which allows human beings to perceive, interpret, and interact with the external world. People incline to believe in the information conveyed by vision, even though subjectively perceived reality does not always reflect objective physical reality. Hundreds of interesting illusions have been discovered, demonstrating that visual perception may be distorted by the arrangement or presentation of visual stimuli. Among these many illusions, the best-known associated with length and size distortions are probably the Müller-Lyer (Müller-Lyer, 1889) and the Delboeuf illusions (Delboeuf, 1865, 1892; Nicolas, 1995; Oyama & Goto, 2007; for a review see Goto, Uchiyama, Imai, Takahashi, Hanari, Nakamura, & Kobari, 2007).

As shown in Figure 1a, the line with outward-pointing arrowheads at the ends (upper) is strongly perceived as longer than the one with inward-pointing arrowheads at the ends (bottom), despite the two lines being absolutely equal in length. The Müller-Lyer illusion has been widely replicated in various modified versions. However, an interesting contrast to it has been found, revealing that the distortion of

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width does not conform to that of length (Dengler, 1972; Griggs, 1974; Waite & Massaro, 1970). As shown in Figure 1b, in which the lines between the arrowheads are replaced by rectangles, the rectangle connected to the outward-pointing arrowheads at the ends (upper) is perceived as longer, but also narrower than that connected to the inward-pointing arrowheads at the ends (bottom). In other words, the perceptions of length and of width are distorted in different directions: the length dimension is perceptually enlarged, whereas the width dimension is perceptually shrunk.

In the Delboeuf illusion, however, the distortion of the visual experience occurs in the evaluation of stimulus size. A size-assimilation illusion was illustrated in Figure 1c, the concentric outer circle on the left side is perceived as smaller than the concentric inner circle on the right side, even though the two circles are equal in size. The perceived size of the circle assimilates toward the size of the neighboring circle. However, an interesting contrary effect of the illusion was demonstrated when the enlargement of the external circle exceeds certain extent (about 5–6 times larger than the internal circles). At the moment, the Delboeuf illusion gradually switches from size-assimilation illusion to size-contrast illusion. As shown in Figure 1d, the concentric inner circle on the
left side is now perceived as larger than the concentric inner circle on the right side. This phenomenon indicates that the Delboeuf illusion represents a dynamic integration between assimilation and contrast (for a detail review see Goto et al., 2007; Oyama, Torii, & Mochizuki, 2005). The Ebbinghaus illusion (Ebbinghaus, 1893, 1902; see Wundt, 1898), also known as the Titchener Illusion (Titchener, 1901), however, demonstrates a different kind of size distortion: mainly a size-contrast illusion. As shown in Figure 1e, the inner circle on the left side is perceived as smaller than the inner circle on the right side, despite the two circles being equal in size.

The neighboring objects elicit not only length and size distortion, but also shape distortion. Lee and Freire (1999) found that changing the arrangement of the facial features within a face can elicit a shape distortion of the external face contour. The illusion remains existent when the face configuration is replaced by a “T” word. As illustrated in Figure 1f, the left oval is perceived as elongated, taller, and narrower than the right oval despite the two ovals are entirely identical. The Müller-Lyer illusion, Delboeuf illusion, Ebbinghaus illusion, and the shape illusion collectively suggest that human beings perceive the external stimuli in a relative rather than an absolute manner. A length-assimilation, size-contrast, size-assimilation, or shape-distortion effects can be elicited by nearby items. Moreover, different kind of distortion mechanisms are mutual interactive.

In this research, we explore a novel illusion which demonstrates that an external contour similar to the outer circle in the Delboeuf illusion can not only lead to a size-contrast, size-assimilation, or shape-distortion effect, but may also result in a distance-assimilation effect as revealed in the Müller-Lyer illusion. Three experiments were constructed to explore the novel illusion, denominated as Iris Illusion.

**Experiment 1**

**Method**

**Participants.** Nineteen Swiss undergraduate students (17 female; mean age 21.6 years) from the University of Zurich and sixteen Taiwanese staff (12 female; mean age 35.7 years) from Hsauenching Elementary school in Taipei county participated in Experiment 1.

**Materials.** Sixty-four full-color photographs of faces balanced in race and gender (16 Swiss females, 16 Swiss males, 16 Taiwanese females, and 16 Taiwanese males) were picked at random from a face database assembled by VICOREG (Visual Cognition Research Group at the University of Zürich, Switzerland). Two kinds of stimuli, referred to as *face stimuli* and *iris stimuli*, were generated from the 64 selected faces. The *face stimuli* involved mirror-images of the original faces that were presented alongside the original faces. The resulting four eyes from left to right were denoted as #1, #2, #3, and #4, respectively, as illustrated in Figure 2. Eyes #1 and #2 belong to the left-hand face, and eyes #3 and #4 belong to the right-hand face. The distance between Irises #1 and #2 is equal to the distance between Irises #3 and #4 since the faces were mirrored images of each other. Meanwhile, the two faces were carefully merged so as to make the distance between Irises #2 and #3 equal to the distance between Irises #1 and #2, and between Irises #3 and #4. In other words, the four irises are exactly equidistant (see Figure 2a). The manipulation was applied to the 64 faces. The iris stimuli involved the same procedure, except that all facial content but the irises was deleted (see Figure 2b). The stimuli were standardized to 1024 x 768 pixels at 300 dpi resolution.

**Procedure.** The experiment was a five-factor mixed design with stimulus type (face or iris), face race (Caucasian/Scottish or Asian/Taiwanese), face gender (male or female), and orientation (upright or inverted) as within-subject factors, and participants (Caucasian/Scottish or Asian/Taiwanese) as between-subject factors.

Each stimulus (face stimuli and iris stimuli) was presented on a 17” CRT monitor, once with upright and once with inverted orientation, resulting in 256 trials. The *face/iris stimuli* were presented on the screen without time limit. The
viewing distance was about 50 cm. A forced choice paradigm was adopted. Participants were instructed that the distance between irises #1 and #2 was equal to the distance between irises #3 and #4 because the two faces were mirror-images of each other. However, the distance between irises #2 and #3 varied in the stimuli; it could be shorter, longer, or equal to the distance between irises #1 and #2 or between irises #3 and #4. Participants were required to judge whether the distance between irises #2 and #3 was longer, shorter, or equal to the distance between irises #1 and #2 or between irises #3 and #4, and pressed one of the corresponding keys, labeled as “Shorter”, “Equal”, and “Longer”. Eight practice trials balanced in stimulus type, orientation, race, and gender were provided prior to the formal trials for participants. The practice trials were not analyzed.

Results

Percentage. The average probability of the three different perceptions, i.e. shorter, equal, and longer, was calculated for each participant in each condition. Throughout the whole research, the data were subjected to five-factor ANOVAs with stimulus type, face race, face gender, and orientation as within-subject factors and participant race as a between-subject factor. Separate ANOVAs were carried out for the judgments of shorter, equal, and longer because these three assessments are dependent on each other.

1 Judgment of shorter. Figure 3 illustrates the mean probability and standard errors for the judgment of shorter in different conditions. The judgment of shorter is an incorrect assessment which implies that the perception of the distance was underestimated. Repeated measure ANOVA on average probability was conducted to examine the frequency of the visual distortion. The ANOVA on average probability for short judgment revealed main effects of stimulus type, $F_{1,33} = 67.536$, $MSE = 14.658$, $p < .001$; face race, $F_{1,33} = 224.322$, $MSE = 5.591$, $p < .001$; and face gender ($F_{1,33} = 9.812$, $MSE = .131$, $p < .004$. The ANOVA also revealed a significant interaction between stimulus type and face race, $F_{1,33} = 10.541$, $MSE = 4.701$, $p < .001$, and between stimulus type and face gender, $F_{1,33} = 31.611$, $MSE = .419$, $p < .001$. Simple main effect analysis revealed that the difference of the probability for short judgment between Caucasian face and Asian face was significant for face stimulus ($p < .001$) but not for iris stimulus ($p = .209$), and the difference of the probability between

![Figure 2](a) The composite Asian and Caucasian faces. The distances between any neighboring two irises are the same (Experiment 1 and 2). (b) The counterpart iris image of Figure 2 (Experiment 1). (c) The counterpart line-drawing image of Figure 2 (Experiment 2). The distance between the two white dots is the intercanthal distance, see discussion session.

female face and male face was also significant for face stimulus ($p < .001$) but not for iris stimulus ($P = .109$).

As can be seen from Figure 3, participants consistently assess the distance between irises #2 and #3 as shorter in face stimulus, but not in iris stimulus. The results confirm the existence of the new optical illusion. The perception of the distance between irises #2 and #3 is perceptually distorted. However, the extent of the distance distortion is different between the faces of different races. The illusion is stronger in viewing Asian faces than Caucasian faces. In addition, the illusion is stronger in viewing female faces than male faces. However, the illusion is demonstrated comparably across participants from different ethnic groups, since the participant factor revealed neither a main effect nor interactions with other factors.

Figure 3  The mean probability and standard errors for the judgment of shorter.

Figure 4  The mean probability and standard errors for the judgment of equal.

2 Judgment of equal. Figure 4 illustrates the mean probability and standard errors for the judgment of equal in different conditions. The judgment of equal is a correct assessment. The ANOVA on average probability for equal judgment revealed main effects of stimulus type, $F_{1,33} = 99.237$, $MSE = 19.153$, $p < .001$, and face race, $F_{1,33} = 113.590$, $MSE = 2.275$, $p < .001$. The ANOVA also revealed significant interaction between stimulus type and face race, $F_{1,33} = 66.463$, $MSE = 2.249$, $p < .001$, and between stimulus type and face gender, $F_{1,33} = 10.094$, $MSE = 1.82$, $p < .003$. Simple main effect analysis revealed that the difference of the probability between Caucasian face and Asian face and between female face and male face were significant for face stimulus ($ps < .001$) but not for iris stimulus ($F's < 1$). There was no main effect of
participant group (Caucasian vs. Asian) and no interaction between participant group and other factors.

As can be seen from Figure 4, participants correctly assessed the distance between the irises #2 and #3 as equal in iris stimulus but not in face stimulus. The assessment of the distance remained intact in iris stimulus. The presentation of isolated irises did not lead to a distortion in distance perception.

Judgment of longer. Figure 5 illustrates the mean probability and standard errors for the judgment of longer in different conditions. The judgment of longer is also an incorrect assessment, because the distances are in fact equal. The judgment of longer implies that the perception of the distance was overestimated. Repeated measure ANOVA on average probability was conducted to examine the frequency of the visual distortion. The ANOVA on average probability for longer judgment revealed a main effect of face race, $F_{1,33} = 36.576, MSE = .743, p < .001$, and significant interactions between stimulus type and face race, $F_{1,33} = 18.623, MSE = .447, p < .001$, and between stimulus type and orientation, $F_{1,33} = 8.689, MSE = .068, p < .006$. Simple main effect analysis revealed that difference of the probability between Caucasian face and Asian face was significant for face stimulus ($p < .001$) but not for iris stimulus ($P = .076$); and the difference of the probability between upright face and inverted face was significant for face stimulus ($p < .008$) but not for iris stimulus ($F < 1$).

As can be observed from Figure 5, an opposite effect of Iris Illusion was found when participants were required to assess the distance in Caucasian faces. Participants tended to assess the distance as longer in Caucasian faces. The opposite effect of the illusion was demonstrated to the same extent on participants from the two different ethnic groups. However, the opposite effect of the illusion did not occur when participants were required to assess the distance in Asian faces.

Discussion
Overall, the results of Experiment 1 confirm the existence of the new illusion. Positioning an image of a face alongside its mirrored image can elicit a distortion in distance perception. Participants underestimated the distance between irises #2 and #3. The illusion emerged only when the irises were imbedded in the facial context, not when the irises were presented alone. The magnitude of the illusion seems to be stronger in Asian faces than in Caucasian faces. Interestingly, an opposite effect of the illusion was observed on some Caucasian faces, revealing that the distance was assessed as longer instead of shorter in these Caucasian faces. The illusion was independent of the orientation of the face stimulus and the races of participants.

Experiment 2
Although the new illusion demonstrated in Experiment 1 was observed originally from

![Figure 5](image-url)  The mean probability and standard errors for the judgment of longer.

face stimulus, the illusion seems to be dissociated from the influence of face perception, which is vulnerable to cross-race recognition and inversion. Instead, the illusion seems to be related to the geometrical attributes of the regions around the eyes. Experiment 2 aims to explore whether the illusion is elicited merely by the shape of eyes.

**Method**

**Participants.** Fifteen undergraduate Swiss students (14 Female; mean age 22.7 years) from the University of Zurich and sixteen Taiwanese staff (13 Female; mean age 37.2 years) from Hsauncheing Elementary school in Taipei county participated in Experiment 2.

**Materials.** Two kinds of stimulus were used in Experiment 2. The **iris stimulus** was identical to that used in Experiment 1, as displayed in Figures 2b and 3b. However, the **face stimuli** were replaced by another set of stimuli termed **line drawing eye stimuli**. The **line drawing stimuli** were generated from the face stimulus used in Experiment 1. The contours (shapes) of the eyes of each face stimulus were depicted via PhotoImpact 10 and the irises remained inside the eye shapes as illustrated in Figure 2c.

**Procedure.** The design and procedure of Experiment 2 were identical to those of Experiment 1.

**Results**

**Percentage.** The method of analysis in Experiment 2 is identical to that used in Experiment 1. Separate ANOVAs were carried out for the judgments of shorter, equal, and longer because these three assessments are dependent on each other.

1 **Judgment of shorter.** The judgment of shorter implies that participants tended to underestimate the distance. The ANOVA on average probability for shorter judgment revealed main effects of stimulus type, $F_{1,29} = 194.231$, $MSE = 17.914$, $p < .001$; and face race, $F_{1,29} = 182.197$, $MSE = 4.019$, $p < .001$. The ANOVA also revealed a significant interaction between stimulus type and face race, $F_{1,29} = 223.853$, $MSE = 3.758$, $p < .001$. Simple main effect analysis revealed that the difference of the probability between Caucasian face and Asian face was significant for **line drawing stimulus** ($p < .001$) but not for **iris stimulus** ($F < 1$). Experiment 2 revealed the similar pattern as in Experiment 1. Participants judged the distance between irises #2 and #3 as shorter than that between irises #1 and #2 or between irises #3 and #4 when assessing line drawing stimulus but not when assessing iris stimulus. The illusion was stronger when participants assessed Asian faces than when they assessed Caucasian faces. However, in contrast to Experiment 1, the effect of face gender vanished in **line drawing stimulus**. The results of Experiment 2 indicated that the distance distortion can also be elicited by merely presenting the line drawing of the eye shapes.

2 **Judgment of equal.** The judgment of equal is the only correct response. The ANOVA revealed main effects of stimulus type, $F_{1,29} = 105.039$, $MSE = 13.747$, $p < .001$, and face race, $F_{1,29} = 56.824$, $MSE = 1.736$, $p < .001$. The ANOVA also revealed a significant interaction between stimulus type and face race, $F_{1,29} = 56.294$, $MSE = 1.536$, $p < .001$. Simple main effect analysis revealed that the difference of the probability between Caucasian face and Asian face was significant for **line drawing stimulus** ($p < .001$) but not for **iris stimulus** ($F < 1$). Identical to the results of Experiment 1, participants correctly assessed the distance between irises #2 and #3 as equal when only the irises were presented. The probability of correct assessment reduced when the irises were presented with line drawing of eye shapes. The reduction of correct assessment of the distance in **line drawing stimuli** conforms to the existence of the illusion.

3 **Judgment of longer.** The judgment of longer implies an overestimation of the distance perception. The ANOVA on average
probability revealed main effects of face race, $F_{1,29} = 33.937, MSE = .472, p < .001$ and a significant interaction between stimulus type and face race, $F_{1,29} = 35.716, MSE = .489, p < .001$. Simple main effect analysis revealed that the difference of the probability between Caucasian face and Asian face was significant for line drawing eye stimulus ($p < .001$) but not for iris stimulus ($F < 1$).

The distance between irises #2 and #3 was judged as longer more often in Caucasian line drawing stimulus than in Asian line drawing stimulus. Similar to the results of Experiment 1, participants from the two different ethnic groups also demonstrated an opposite effect of the illusion when assessing the distance in Caucasian line-drawing stimulus.

**Discussion**

Overall, the results of Experiment 2 replicate the results of Experiment 1, revealing that depiction of mere line drawings of the facial eyes can also elicit the illusion to the same extent as full face stimulus. The pattern of the illusion in Experiment 2 was almost identical to Experiment 1, except that the gender effect and its interaction with other factors disappeared in the judgment of shorter in Experiment 2.

Although in Experiment 1, female face stimuli seem to elicit stronger illusion than male face stimuli, the influence from the gender of the face stimuli was weak. The influence from face gender vanishes when line drawings stimulus were adopted in Experiment 2. Consequently, the emergence of gender effect must be due to gender related properties of the photographic images such as the shape of nose, mouth and other features, texture, or make-up.

On the contrary, the shape of the eyes and the distance between the eyes might be the critical contributor associated with the new illusion. Moreover, the opposite effect demonstrated in Asian vs. Caucasian faces could be due to the racial difference in the eye regions of the faces. A recent anthropometric analysis reported by Kunjur, Sabesan, and Ilankovan (2006) demonstrated that Chinese men and women had wider intercanthal distances, the distance between the two small white dots in Figure 2, than Indian and white men and women. To examine this facial geometrical difference between Asian and Caucasian faces, we measured the intercanthal distances and the widest part of the face for all the 64 faces used in this research, and calculated the relative proportion (intercanthal distances/face width). The proportion in Asian faces ($M = .256$) is significant higher than that in Caucasian faces ($M = .23$), $t(62) = 5.110, p < .001$. This anthropometric analysis not only confirms the findings of Kunjur et al. (2006) but also provides an important cue for exploring the origin of the new illusion.

To manifest the difference between the line drawings of eye shapes that elicit the opposite effect of the illusion, we morphed the top three line drawings images which elicited the strongest illusion in divergent effects (longer vs. shorter). Selecting only the top three faces which elicit the strongest illusion would be easier to detect the facial characteristics which elicit the illusion. The three line drawings images which induced the strongest “longer” illusion (enlarged effect) and the strongest “shorter” illusion (shrinking effect) were morphed by FantaMorph software separately. Figure 6 illustrates the results of the morphing for the two opposite effect. The original sizes of the eyes were adjusted to equalize the distances between the irises of the two outputs for comparison. As can be seen in Figure 6a, the eye shapes #1 and #2, and eye shapes #3 and #4 seem to be close to each other in the image which elicits the longer illusion. As a result, eye shapes #2 and #3 seem to be apart in Figure 6a. By contrast, in Figure 6b, the eye shapes #1 and #2, and eye shapes #3 and #4 seem to be apart from each other in the image which elicits the shorter illusion. As a result, eye shapes #2 and #3 seem to be close in Figure 6b. Accordingly, the difference of the facial characteristic might be a critical factor for the emergence of the illusion. In light of these findings, we designed Experiment 3 to examine whether the illusion was elicited by the relative position of eye shapes and irises.
**Experiment 3**

The results of Experiment 1 and 2, and the finding of the face morphing, imply that the opposite illusion demonstrated in Experiment 1 and 2 might be elicited by the intercanthal distances of the faces and the relative position of the eye shapes and the irises inside the eyes. Figure 7 provides an extreme example of Iris Illusion. In “none eye shapes”, the distance between irises #2 and #3 are perceived as equal to the distance between irises #1 and #2, and between irises #3 and #4. This pattern was confirmed in Experiment 1 and 2 that no illusion occurs when only the irises were presented in the stimulus. In “Asian eye shapes”, the distance between irises #2 and #3 are perceived as shorter than the distance between irises #1 and #2 or between irises #3 and #4, which in again confirmed in Experiment 1 and 2 when Asian faces were judged. Meanwhile, in “Caucasian eye shapes”, the distance between irises #2 and #3 are perceived as longer than the distance between irises #1 and #2, or between irises #3 and #4, which in also found in Experiment 1 and 2 when some Caucasian faces were judged.

Experiment 3 aims to examine this hypothesis by manipulating the intercanthal distances of the faces and the relative position of the eye shapes and irises. We created four irises and four eye shapes, and manipulated the inward or outward movement of the eye shapes. We predict that if the opposite effect of the illusion is elicited by the relative position of the eye shapes and the irises, the distance between irises #2 and #3 should be overestimated when the paired eye shapes (eye shapes #1 vs. #2, and eye shapes #3 vs. #4) are moved inwards, similar to the

![Figure 6](image)

**Figure 6** The outputs of the morphing for longer and shorter illusions. The input of the morphing contains the top three line drawings of eyes shape which elicit the strongest longer effect for (a), and the strongest shorter effect for (b).

![Figure 7](image)

**Figure 7** Caricature illustration of Yang’s Iris Illusion. (a). No illusion (b). Illusion for shorter perception in Asian faces (c). Illusion for longer perception in Caucasian faces (d). Illustration of Giovanelli illusion.

Caucasian eye shapes in Figure 6. By contrast, the distance between irises #2 and #3 should be underestimated when the paired eye shapes are moved outwards, similar to the Asian eye shapes in Figure 6. In order to prevent the possible disturbance caused by the same correct answer throughout the whole experiment, the distance between the irises were also manipulated. Participants would sometimes have to respond “longer” and sometimes “shorter”. This procedure helps to keep the participants engaged in the task and remain motivated.

Method

Participants. Only Caucasian participants were recruited in Experiment 3 because Experiment 1 and 2 revealed that the illusion was demonstrated equally among participants from different ethnic groups. Eighteen students (11 Female; mean age 24.45 years) from the University of Zurich participated in the experiment.

Materials. Two factors were manipulated in the experiment: iris distance and eye shape movement, as shown in the columns and rows in Figure 8. Twelve stimuli were created by the combination of these two factors.

The factor of iris distance contained three levels: equal, longer, and shorter. In the equal condition, four irises were created and the distances between any neighboring two irises were equal, as illustrated in the Equal column in Figure 8. In the longer condition, the distance between irises #2 and #3 was moved apart for
10 pixels (one eye for 5 pixels) as illustrated in the “Longer” column in Figure 8. The separation of 10 pixels was about 0.3 cm on the 17” monitor, subtending about 0.34 degree from a viewing distance of 50 cm. In shorter condition, the distance between irises #2 and #3 was moved closer for 10 pixels (one eye for 5 pixels) as illustrated in the “Shorter” column in Figure 8.

The factor of eye shape movement contained four levels: None, Neutral, Outward, and Inward as illustrated in the left most panel in Figure 8. There were no eye shapes in the “None” eye shapes condition. In the “Neutral” eye shapes condition, two pairs of line-drawing eye shapes were created such that the four irises in equal condition will locate in the middle of the eye shape, as shown in Figure 8–e. In the “Outward” eye shapes condition, the eye shapes #1 and #3 were moved leftwards for 8 pixels, and the eye shapes #2 and #4 were moved rightwards for 8 pixels. The additional separation of 16 pixels between eye shapes #1 and #2 and between eye shapes #3 and #4 were was about 0.5 cm on the 17” monitor, subtending about 0.57 degree from a viewing distance of 50 cm. This condition was created to mimic the facial characteristics of Asian faces. In the “Inward” eye shapes condition, the eye shapes #1 and #3 were moved rightwards for 8 pixels, and eye shapes #2 and #4 were moved leftwards for 8 pixels. This condition was created to mimic the facial characteristics of Caucasian faces. The movement of the eye shapes was exactly in opposite direction between the “Outward” and “Inward” eye shapes conditions.

The three levels in the factor of irises distance were applied to the four manipulations in the factor of eye shape movement. As a result, twelve combinations between manipulation of iris distance and eye-shape movement were generated as illustrated from Figure 8a to Figure 8l.

Procedure. The 12 conditions were repeated 18 times, resulting in 216 trials. The 216 trials were presented randomly on a 17” CRT monitor without time limit. The viewing distance is about 50 cm. Participants were informed that the distance between irises #1 and #2 was equal to the distance between irises #3 and #4. However, the distance between irises #2 and #3 was either increased, decreased, or remained unchanged. They were instructed to judge whether the distance between iris #2 and #3 was shorter, equal, or longer compared to the distance between iris #1 and #2 or between iris #3 and #4. Participants were required to press one of the three corresponding keys labeled as “Longer”, “Shorter” and “Equal” for their assessment. After participants responded, a mask (colorful random dot image) was shown on the screen for 1000 milliseconds and the next trial appeared immediately after the end of the mask stimulus. Twelve practice trials containing each condition were provided prior to the formal experiment for the participants to familiarize themselves with the procedure. The responses in the practice trials were not included in the analysis.

Results
The overall probabilities for the longer, shorter, and equal responses were 27%, 27%, and 46%, respectively. The probability was not equivalent among the three possible choices, even though the whole trials were distributed equivalently between the three choices. Participants revealed a higher tendency to assess the distance as equal rather than longer or shorter. The conservative response strategy might be due to the subtle discrepancy between the distances. Therefore, the chance level of the selections among the three choices (shorter, equal, and longer) should be adjusted to take into account the biased response strategy. The overall probability for the three choices which could appropriately reflect participants’ response strategy served as a better baseline and was therefore set as chance level for further comparison. The difference between the chance level and the observed probability in different condition was examined by Two Sample Proportion z-test.

The results are shown in Figure 8. The asterisks denote the conditions in which the observed probability is significantly higher than the chance level, indicating a bias towards the distance perception. The relative statistics of the conditions where the observed probability

Table 1  The statistics of the conditions where the observed probability is significantly higher than the chance level

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</tbody>
</table>

aProbability difference refers to the difference between observed probability and chance level.

is significantly higher than the chance level is also shown in Table 1. The major findings are reported as follows in order of the manipulation in the factor of irises distance.

**Equal distance.** As shown in the middle column in Figure 8, participants correctly judged the distance between irises #2 and #3 as equal to the distance between irises #1 and #2 or between irises #3 and #4 when the eye shapes were removed, i.e. in None eye shapes condition (Figure 8b), or when the irises were positioned in the center of eye shapes, i.e. in Neutral eye shapes condition (Figure 8e). However, the perception was distorted in different directions depending on whether the eye shapes were moved outward or inward. Participants tended to underestimate the distance when the eye shapes were moved outward, and frequently misjudged the equal distance as shorter, as illustrated in Figure 8h. By contrast, they tended to overestimate the distance and frequently misjudged the equal distance as longer when the eye shapes were moved inward, as illustrated in Figure 8k.

**Longer distance.** As shown in the second left column in Figure 8, similar to the equal distance condition, the perception was unbiased when the eye shapes were removed, i.e. in None eye shapes condition (Figure 8a), or when the irises were positioned in the center of the eye shapes, i.e. in Neutral eye shapes condition (Figure 8d). Participants correctly judged the distance between irises #2 and #3 as longer than the distance between irises #1 and #2, or between irises #3 and #4. However, they tended to underestimate the distance and significantly misjudged the longer distance as equal when the eye shapes were moved outward, as shown in Figure 8g. By contrast, they tended to overestimate the distance and enhanced the longer perception when the eye shapes were moved inward as shown in Figure 8j.

**Shorter distance.** Repeatedly, the perception was intact in the None-eye shapes (Figure 8c) or in Neutral-eye shapes (Figure 8f) conditions. Participants correctly judged the distance as shorter in these two conditions. However, the shorter perception was enhanced when the eye shapes were moved outward, as shown in Figure 8i. By contrast, the shorter distance was overestimated and misjudged as equal when the eye shapes were moved inward, as shown in Figure 8l.

**Discussion**
The results of Experiment 3 were in accordance with the findings of Experiment 1 and 2, revealing that the external contour can elicit distance-
assimilation illusion when participants are required to assess the distances between the objects enclosed by the contour. The opposite effects of the illusion demonstrated in Experiments 1 and 2 were successfully replicated by moving the eye shapes inward or outward. These results confirm the hypothesis that the illusion was elicited mainly by the external contour and the position of irises enclosed in the eyes. Moreover, moving the external contour in different directions can generate contrary effects of the illusion. The distances between irises #2 and #3 were underestimated when the eye shapes were moved outwards. However, the distance between irises #2 and #3 was overestimated when the eye shapes were moved inwards. Apparently, the perceived iris positions assimilate toward the centers of the eye shape positions and lead to the distance distortion.

**General discussion**

The Müller-Lyer, Delboeuf, Ebbinghaus, and shape illusions demonstrate that neighboring external contours or inner object can lead to either length-assimilation, size-assimilation, size-contrast, or shape-distortion illusions. This paper explores a novel illusion, Iris Illusion, demonstrating that moving the neighboring external contours can lead to a distance-assimilation. Moreover, the distance-assimilation illusion can be elicited in different manners (overestimation vs. underestimation of the distance) depending on the direction of the movement.

The most striking and remarkable aspect regarding the illusion is the opposite effect demonstrated in Iris Illusion. However, as for why moving the eye shapes inward or outward in reference to the enclosed irises can induce the opposite effect of inter-irises distance perception may still need to be clarified. Gregory (1963, 1968) proposed a notion of “misapplied size constancy scaling” to explain the distance-contrast effect demonstrated in the Müller-Lyer illusion (Figure 1a). He argued that the occurrence of the Müller-Lyer illusion was due to the inappropriate registration of depth cues. The shafts inside the arrowheads were unconsciously registered as being of different depths. The size constancy scaling mechanism in our vision automatically takes into account the different depths, and so interpreted the distance differently. This proposition, however, cannot be applied to explain the Iris illusion, because the curvatures of the eye shapes are in identical directions in both Caucasian and Asian faces. Moreover, the illusion occurs in plane, without any involvement of depth registration. Obviously, Gregory’s concept cannot appropriately account for the emergence of the illusion.

Giovanelli (Giovanelli, 1966; Giovanelli & Sinico, 2005) ever introduced an illusion which seems to be similar to the Iris Illusion. As illustrated in Figure 7d, Giovanelli found that the dot inside the circle seems to shift in position away from the center of the circle. Giovanelli illusion is fundamentally a position-contrast illusion as the dot tends to deviate to the opposite direction. However, a very interesting contrary effect is demonstrated between Giovanelli illusion and Iris Illusion. As shown in Figure 7d, the Giovanelli illusion is replicated 4 times and arranged similarly to the spatial pattern of Iris Illusion. According to the prediction of Giovannelli illusion, the dots #1 and #3 would tend to shift away to the left side, whereas the dots #2 and #4 would tend to shift away to the right side. In this manner, dots #2 and #3 would be perceived to move closer to each other, while dots #1 vs. #2 and dots #3 vs. #4 would be perceived to move apart from each other. Accordingly, it would be reasonable to predict that humans would perceive the distance between dots #2 and #3 (move closer) to be shorter than the distance between dots #1 and #2 or between dots #3 and #4 (move apart). However, contrary to the expectation of Giovannelli illusion, an entirely opposite effect was demonstrated in Iris Illusion. Results of experiments 1 to 3 in current research clearly show that participants tend to perceive the distance between irises #2 and #3 to be longer than the distance between irises #1 and #2 or between irises #3 and #4 as illustrated in Figure 7c. Participants perceive the irises to shift to the
congruent direction as the movement of the eye contour instead of to the opposite direction as expected by Giovanelli illusion. Apparently, an effect of position-assimilation occurs and hence it leads to a distortion in distance judgment. The position-contrast assumption as predicted by Giovanelli illusion cannot apply to Iris Illusion.

In the three experiments of this research, participants were required to judge the distance between two dots and compare the virtual distances between any two dots. Apparently, participants might make their distance judgment based on the position of the dots. It is then plausible to consider Iris Illusion as a position-distortion illusion. However, we regard Iris Illusion as a distance-distortion illusion based on the following four reasons. First, although participants were required to judge the distance represented by two end-points without a solid line connecting each other, optical illusions, such as for example the Müller-Lyer illusion are described as a distance distortion illusion even if no connecting line is used between the stimuli (DeLucia & Hochberg, 1991; Gillam, 1998; Goldstein, 2007). Second, the participants in our experiments were instructed to judge the distance between two dots and not the position of the dots during the tests (participants were not required to evaluate whether the dots shift leftwards or rightwards). Regarding Iris Illusion as a distance-distortion illusion would more realistically reflect the mental perception of the participants’ judgment during the test. Third, in real live, when the instruction “estimate the distance between A and B” is used, there is often no connecting line between the two points A and B (e.g. estimate the distance between two football players on a soccer field or the distance between two trees in the wood, etc.). Fourth, Schwaninger, Ryf, and Hofer (2003) applied the method of adjustment and found that participants tend to overestimate the distance between eye and mouth for 39% and the inter-eye distance for 11% although no connecting line was on the faces to be judged. Nevertheless, Iris Illusion is, nevertheless, highly related to a position-distortion illusion. It might be reasonable to say that the distance-distortion is based on the position-distortion. However, it would be confounding to define Iris Illusion as a position-distortion illusion as the position itself was not directly evaluated.

In sum, the results of the experiments show that the external contour which can elicit size-assimilation distortion in Delboeuf illusion can also lead to distance-assimilation distortion. The perceived positions of the inner objects assimilate toward the centers of the external shape positions, something like a Müller-Lyer illusion. The illusion implies that human perception depends on the mechanism which automatically integrates the attended information with the irrelevant neighboring information. Apparently, humans cannot free themselves from the influence of peripheral information when intentionally attending to a central target. This research presents an initial finding of Iris Illusion and more effort should be devoted to clarify the mechanism of the Iris Illusion in order to better understand the perceptual mechanism underlying the illusion. The finding of the illusion is not only interesting for visual perception research but also enlightening in other domains when a visual effect of enlargement or shrinkage in distance is demanded, such as the design of clothing, advertisements, art works, buildings, etc.

References


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