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BRIEF REPORT

Inducing the Use of Right Eye Enhances Face-Sex Categorization Performance

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Face recognition ability varies tremendously among neurologically typical individuals. What causes these differences is still largely unknown. Here, we first used a data-driven experimental technique—bubbles—to measure the use of local facial information in 140 neurotypical individuals during a face-sex categorization task. We discovered that the use of the eye and eyebrow area located on the right side of the face image from the observer's viewpoint correlates positively with performance, whereas the use of the left-eye and eyebrow area correlates negatively with performance. We then tested if performance could be altered by inducing participants to use either the right- or the left-eye area. One hundred of these participants thus underwent a 1-hr session of a novel implicit training procedure aimed at inducing the use of specific facial information. Afterward, participants repeated the bubbles face-sex categorization task to assess the changes in use of information and its effect on performance. Participants that underwent right-eye induction used this facial region more than they initially did and, as expected, improved their performance more than the participants who underwent the left-eye induction. This is the first clear evidence of a causal link between the use of specific face information and face recognition ability: Use of right-eye region not only predicts but causes better face-sex categorization.

Keywords: individual differences, face recognition, visual representation, face recognition ability, lateralization

A major achievement of the human visual system is its ability to decipher information about an individual's identity, gender, and emotional state from a face stimulus with impressive efficiency and speed (e.g., Jeffreys, 1996). But not all humans are equally competent at face recognition. Indeed, face recognition ability varies tremendously among neurologically typical individuals (e.g., Duchaine & Nakayama, 2006; Russell, Duchaine, & Nakayama, 2009).

Research in cognitive neuroscience and psychology has only begun to unveil the perceptual mechanisms responsible for these individual differences. Observers that process faces "holistically" tend to better identify them (DeGutis, Wilmer, Mercado, & Cohan, 2013; Wang, Li, Fang, Tian, & Liu, 2012; but see Konar, Bennett, & Sekuler, 2010). Moreover, face identification ability correlates with narrower tuning to horizontal information (Pachai, Sekuler, & Bennett, 2013; see also Duncan et al., 2017), and with the use of eye information (Royer et al., 2018; Tardif et al., in press). These findings, however, fall short of establishing a causal link between perceptual mechanisms and face recognition ability. It may be, for example, that the use of horizontal information and face recognition ability are not directly linked but have a common cause.

A few studies attempted to go beyond such correlations (Brunsdon, Coltheart, Nickels, & Joy, 2006; DeGutis, Bentin, Robertson, & D'Esposito, 2007; DeGutis, Cohan, & Nakayama, 2014; Schmalzl, Palermo, Green, Brunsdon, & Coltheart, 2008). In the most thorough, DeGutis and colleagues (2014) trained 24 developmental prosopagnosics—individuals showing great difficulty recognizing faces despite not having sustained any brain injuries—to identify faces that varied along a combination of eye-to-eyebrow and nose-to-mouth spacing cues. Participants exhibited a modest improvement on a measure of front-view face discrimination. Unfortunately, the training procedure used by DeGutis and colleagues (2014) was rather tedious (~8 hr in a 3-week period) and unspecific—it remains unknown, for example, which interattribute distances, if any, are responsible for the improvement. Finally, it remains to be shown that this procedure can improve, even modestly, the performance of individuals with average face recognition abilities.

Here, using a data-driven experimental technique (bubbles; see Gosselin & Schyns, 2001) and a large sample size, we first revealed the use of facial information of skilled and unskilled face-sex recog-

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nizers. We chose this facial judgment because it is one of the most biologically and socially relevant and it has been neglected in past work on face-recognition ability. We discovered that the use of the eye and eyebrow located on the right side of the face image from the observer's viewpoint is linked to better individual performance, whereas the use of the left eye and eyebrow is linked to worse performance. Then, with these performance correlates as priors, we attempted to induce specific information usage in a single 1-hr session of a novel implicit training procedure. Finally, participants repeated the bubbles face-sex discrimination task to assess the changes in use of information and its effect on performance. We show that right eye and eyebrow usage not only correlates with but also causes better face-sex discrimination.

Method

Participants

A total of 140 participants (45 men; age range = 18–30 years old) with normal or corrected-to-normal vision completed the preinduction bubbles face-sex discrimination task. The first 40 participants (10 men; age range = 18–30 years old) were recruited as a part of the correlational portion of this study—before the training portion of the study was even planned. These participants completed the preinduction phase only. We then recruited an extra 100 participants for the induction portion of the study. These participants (35 men; age range = 18–30 years old) thus completed the same preinduction task, followed by the induction and postinduction bubbles face-sex discrimination tasks. The experimental protocol was approved by the ethics board of the Université de Montréal and the study was conducted in accordance with the approved guidelines. Informed consent was obtained from each participant and monetary compensation was given to all participants.

Pre- and Post-Induction Stimuli

The 300 color face images (150 men) from Dupuis-Roy, Fortin, Fiset, and Gosselin (2009) were used to generate the stimuli. These face images were scaled, rotated, and translated so that the position of the eyes, the nose, and the mouth coincided as much as possible while preserving relative distances between them. Average interpupil distance was 0.49 degrees of visual angle. Face images were randomly reflected over their vertical midline (mirror-reversed) on half the trials to control for possible information asymmetries such as cast shadows resulting from different lighting conditions (e.g., Vinette, Gosselin, & Schyns, 2004). Stimuli for the pre- and post-induction bubbles face-sex discrimination tasks were created by superimposing an opaque gray mask punctured by randomly located Gaussian windows with a standard deviation of 2.13 min of arc, or "bubbles," on randomly selected face images (Gosselin & Schyns, 2001; Figure 1a). Stimuli subtended 3.08 degrees × 3.08 degrees of visual angle (256 pixels × 256 pixels).

Induction Stimuli

The induction phase consisted in inducing the use of either the left or the right eye and eyebrow area by eliminating the sex information in the nontarget eye and eyebrow area. Specifically, the stimuli for the induction phase of the bubbles face-sex discrimination task were identical to the pre- and post-induction bubbles face-sex discrimination ones, except that the nontarget eye areas in the face images (e.g., the left eye and eyebrow for right-eye area induction group) were replaced by an androgynous eye area, cropped from the average of all face images (see Figure 1b). The nontarget eye areas were disks with a diameter of 0.96 degrees of visual angle centered either on coordinates $x_{\text{left eye}} = -0.53$ and $y_{\text{left eye}} = 0.29$ degrees of visual angle relative to the center of the face images, or on coordinates $x_{\text{right eye}} = 0.53$ and $y_{\text{right eye}} = 0.29$ (see Figure 1b). The choice to induce the use of one of the two eye and eyebrow areas had three main motivations. First, previous studies have shown that the eye and eyebrow areas of the face are the most important cues for the discrimination of sex from faces (e.g., Dupuis-Roy, Faghel-Soubeyrand, & Gosselin, 2018; Dupuis-Roy et al., 2009; Gosselin & Schyns, 2001; Russell, 2003; Schyns, Bonnar, & Gosselin, 2002). We thus reasoned that participants would only learn to use the only remaining eye area containing face-sex information (i.e., the target eye). Second, preliminary observations from the first 40 participants suggested that right-eye-and-eyebrow area usage from the observer's perspective was correlated to higher performance while left-eye-and-eyebrow area usage was correlated to lower performance. Third, both eye regions convey exactly the same amount of face-sex discrimination information because faces were mirror-reversed on half the trials. Thus, any observed difference between the induction groups—differences in information usage and performance—can be ascribed to the experimental manipulation.

Note that during the induction phase, the purpose of the bubbles procedure was not to reveal the use of information. Instead, we employed the bubbles procedure during the induction phase to maintain accuracy constant at 75% correct throughout the entire experiment, to make the experimental manipulation more difficult to notice (a comparison between the two eyes was not always possible due to the random sampling), and to give an impression of continuity between experimental phases in the hope that participants would remain unaware of the nontarget eye area manipulation.

Apparatus

The experimental program ran on Mac Pro computers in the MATLAB environment (The Mathworks, Natick, MA), using functions from the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997). Stimuli were shown on 27-in. ASUS VG278H LCD monitors (1,600 × 900 pixels at 60Hz). Participants performed the experiment in a dimly lit room. Chin rests were used to maintain viewing distance at 90 cm.

Procedure

In the preinduction phase, 140 participants completed three 100-trial blocks of a bubbles face-sex discrimination task. In the induction phase, the last 100 tested participants also completed five 100-trial blocks of induction bubbles face-sex discrimination task. During this induction phase, participants were randomly assigned to either the left-eye ($n = 50$) or the right-eye induction group ($n = 50$). In the postinduction phase, these 100 participants underwent three additional 100-trial blocks of bubbles face-sex

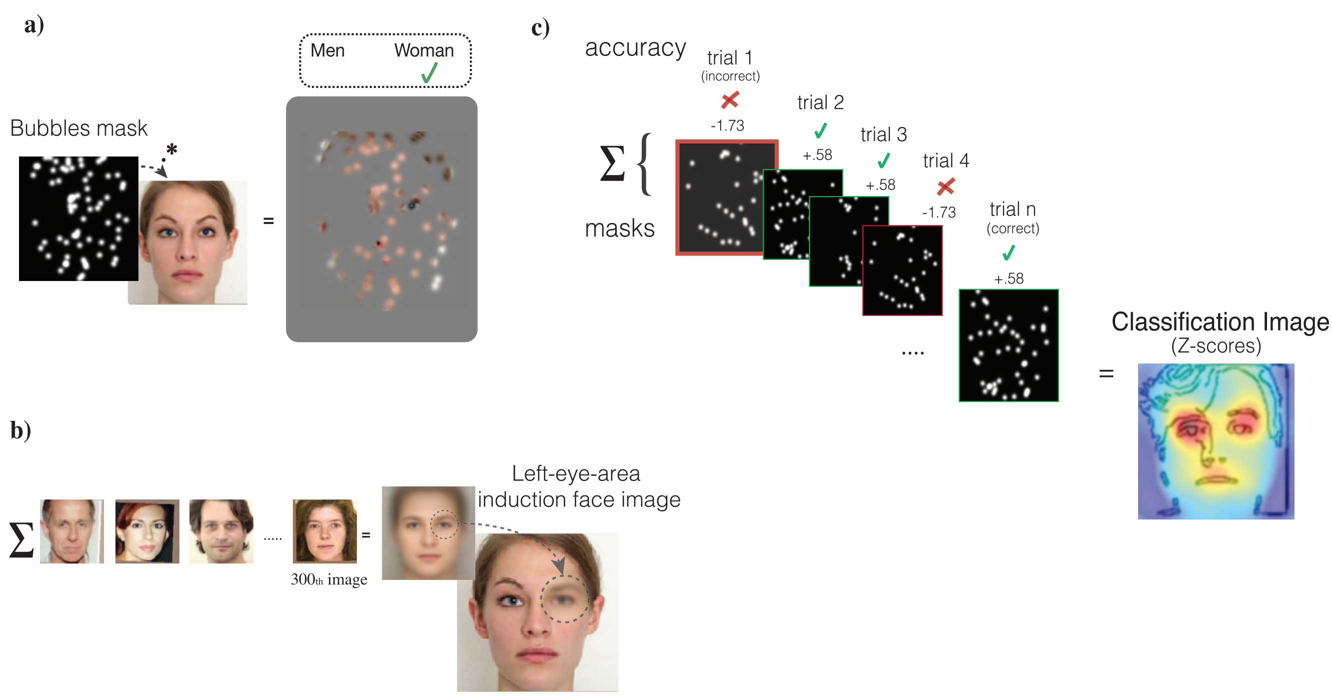

Figure 1. Creation of stimuli and classification image computation. (a) An opaque mask punctured by randomly positioned bubbles was superimposed on a face image to create the face stimulus for each trial. (b) During the induction phase, the nontarget eye area (here the right-eye area for a left-eye-area-induction stimulus) was replaced by the corresponding facial area from an androgynous face obtained by averaging all our face images. (c) To reveal use of facial information, a classification image (CI) is computed by summing bubble masks weighted by corresponding accuracies transformed in *z* scores. From "Uncovering gender discrimination cues in a realistic setting," by N. Dupuis-Roy, I. Fortin, D. Fiset, and F. Gosselin, 2009, *Journal of Vision, 9,* p. 2. Copyright 2009 by the Association for Research in Vision and Ophthalmology. See the online article for the color version of this figure.

discrimination task similar to the ones they did before the induction. Participants could take a short break between blocks. The experiment was followed by a debriefing session, during which we probed participants about their awareness of the nontarget eye area manipulation during the induction phase. The preinduction, induction, postinduction, and debriefing phases were conducted on a single day and lasted a total of approximately 2 hr.

Every trial comprised the following sequence of events: a black fixation cross centered on a uniform mid-gray field shown for 750 ms, followed immediately by a uniform mid-gray field shown for 250 ms, and followed immediately by a stimulus presented until a response was made by the participant (see the bubbles stimuli). Participants were asked to indicate the sex of the partly revealed face by pressing on the appropriate keyboard key as rapidly and as accurately as possible. Response keys were counterbalanced across participants. No feedback was provided to participants about their responses. The quantity of revealed face information (i.e., the number of bubbles) necessary to maintain an accuracy of 75% was adjusted on a trial-by-trial basis with the QUEST algorithm (Watson & Pelli, 1983).

Results

Average Use of Information

A group-average analysis (N = 140) replicated previous results showing that the eyes and eyebrows and, to a lesser extent, the mouth are the most important facial cues for face-sex discrimination (e.g., Dupuis-Roy et al., 2009; 2018; Gosselin & Schyns, 2001; Russell, 2003; Schyns et al., 2002). For each individual, we computed the sum of bubble masks weighted by accuracies transformed in *z* scores (see Figure 1c). The 256-pixel × 256-pixel plane yielded by this operation is called a classification image (CI). High CI values indicate facial areas positively correlated with accurate face-sex categorization. We then summed all individual CIs across 140 individuals and convolved the resulting average CI with a Gaussian kernel of 12 pixels of standard deviation. To estimate the mean and the standard deviation of the distribution of the null hypothesis (i.e., no correlation between accuracies and sampled stimulus information), we repeated this procedure on randomly permutated accuracies. The mean and standard deviation of this random CI were used to calculate the *z* scores of the average CI (Chauvin, Worsley, Schyns, Arguin, & Gosselin, 2005). To determine the face information significantly correlated with accuracy, we applied the cluster test to the average CI. The cluster test is based on the probability that, above an arbitrary threshold, a cluster of size K (or more) pixels has occurred by chance (Friston, Worsley, Frackowiak, Mazziotta, & Evans, 1994). The statistical threshold provided by this test corrects for multiple comparisons while taking the spatial correlation inherent to smooth classification images into account (for more details, see Chauvin et al., 2005). Statistically significant clusters are outlined in black on Figure 2a (search region = 11,429 pixels; arbitrary *z*-score

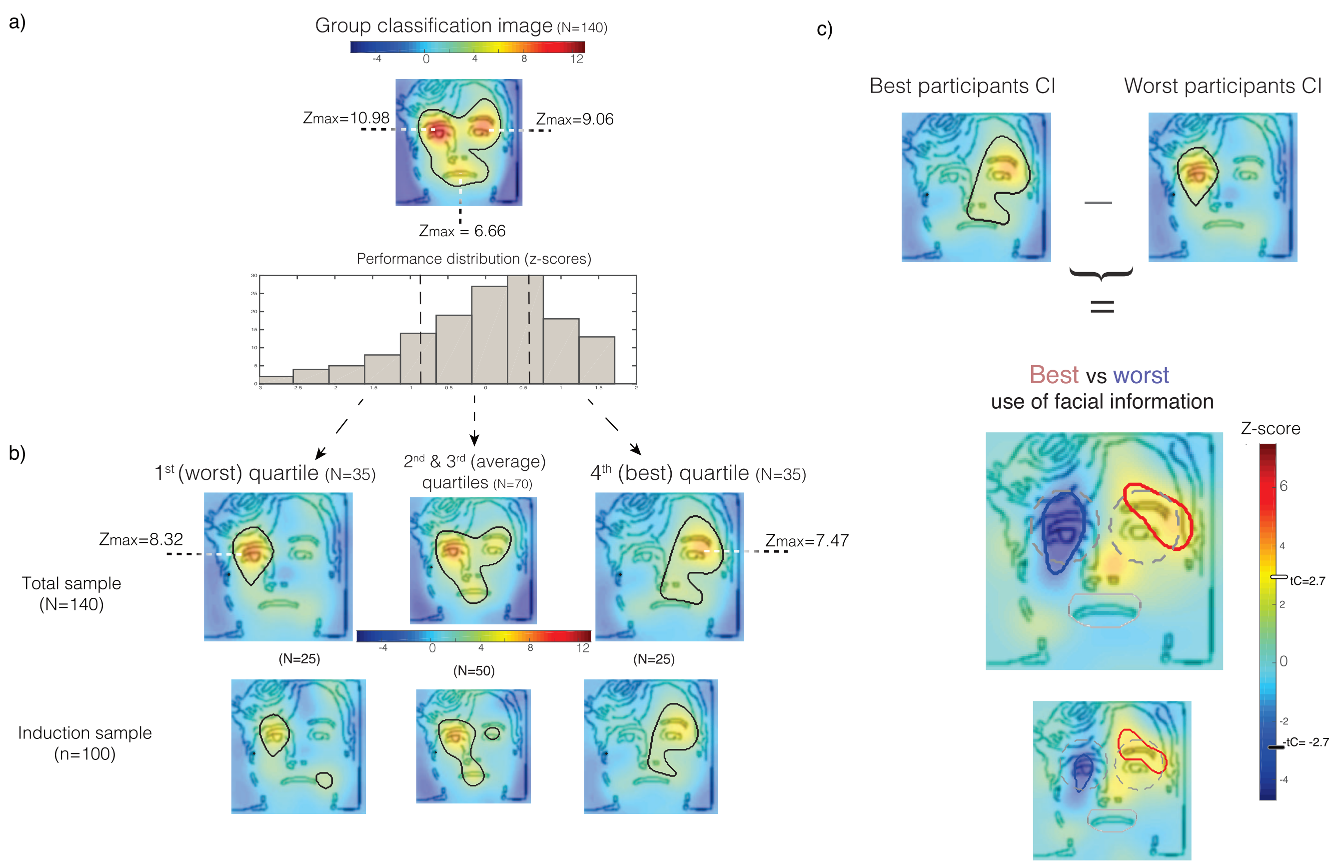

Figure 2. (a) Average use of information. Background face outline added to help interpretation. Colored blobs outlined in black represent face areas significantly associated with accurate face-sex discrimination. (b) Use of information as a function of sex-discrimination ability quartiles. These analyses were performed both on all participants that completed the preinduction bubbles task (N = 140; see upper row) and for the subset of these participants that completed the preinduction, induction, and postinduction bubbles tasks (n = 100; see lower row). (c) Contrast between the use of information of best (fourth quartile) and worst (first quartile) participants. Colored blobs outlined in red and blue, respectively, represent face areas significantly associated with accurate face-sex discrimination for skilled and unskilled face-sex recognition.

threshold = 3, cluster size statistical threshold = 91 pixels, $p < .05$).

As in previous bubbles (e.g., Dupuis-Roy et al., 2009, 2018; Gosselin & Schyns, 2001; Ince et al., 2016), eye-tracking (Butler et al., 2005), and chimeric faces studies (Butler et al., 2005; Innes, Burt, Birch, & Hausmann, 2016), there appeared to be a slight bias for the use of the left-eye region from the observer's perspective compared with the right-eye region (see Figure 2a). We showed that this bias is statistically significant by averaging z scores in two regions of interest (ROI)—the right-eye and the left-eye anatomically defined ROIs—for each individual unsmoothed CI and compared average ROI scores with a two-tailed paired t test ($M_{\text{left-eye ROI}} = 0.034$, $SD_{\text{left-eye ROI}} = 0.051$; $M_{\text{right-eye ROI}} = -0.023$, $SD_{\text{right-eye ROI}} = 0.047$; $t[139] = 1.978$, $p = .050$, Cohen's $d = 0.167$). Right- and left-eye ROIs were identical to the nontarget eye area described above in the Induction Stimuli section. In other words, they were disks of 0.96 degrees of visual angle of diameter centered either on coordinates $x_{\text{left-eye ROI}} = -0.53$ and $y_{\text{left-eye ROI}} = 0.29$ degrees of visual angle relative to the center of the face images, or on coordinates $x_{\text{right-eye ROI}} = 0.53$ and $y_{\text{right-eye ROI}} = 0.29$ (also see Figures 2 and 3). Note that these results cannot be explained by information asymmetries between the right- and left-eye areas because face stimuli were mirror-reversed with a probability of 0.5 on every trial.

Face-Sex Categorization Ability Measure

We used the number of bubbles necessary to maintain performance at an accuracy of 75% correct adjusted with the QUEST algorithm (Watson & Pelli, 1983) as our individual index of face-sex discrimination performance. This average number of bubbles threshold for the three 100-trial preinduction bubbles face-sex discrimination task ranged from a low of 23 to a high of 89 across participants (for the 140 participants that completed the preinduction phase: M = 46.51, SD = 14.01, Mdn = 43.74; for the 100 participants that completed the preinduction, induction, and postinduction phases: M = 46.83, SD = 14.77, Mdn = 43.62). Royer and colleagues (2015; see also Royer et al., 2018; Tardif et al., in press) showed that this number-of-bubbles threshold is strongly

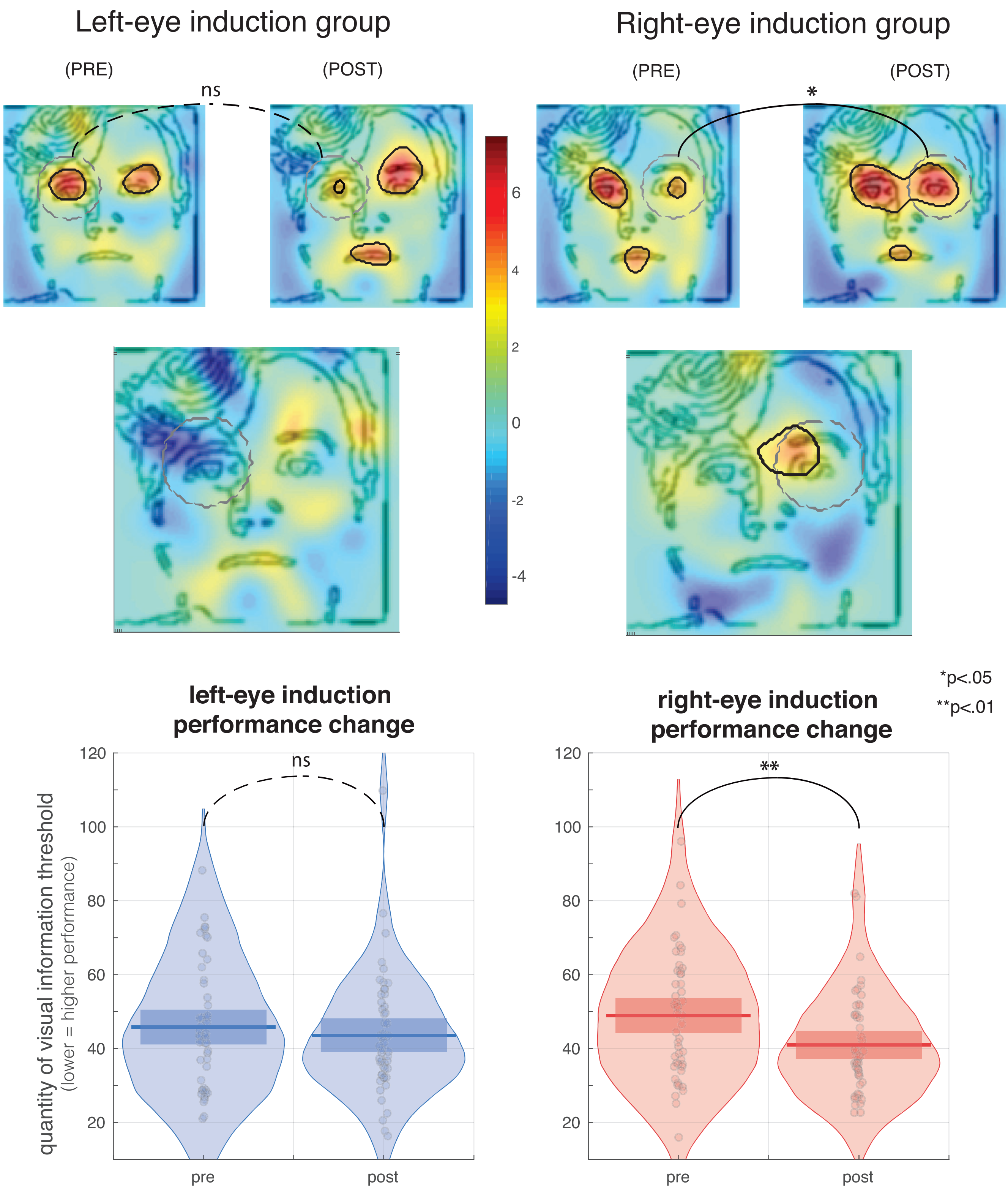

Figure 3. Impact of the implicit induction procedure on the use of facial information. The right-eye induction group post- versus preinduction contrast CI contains a statistically significant blob (second row, outlined with a black line), which falls 74.65% within the target eye area (second row, delimited by gray dashed line).

correlated with three commonly used face recognition ability tests ($r = -.79$ with the mean of the Cambridge Face Memory Test+, the Cambridge Face Perception Test, and the Glasgow Face Matching Test–Short version), even after controlling for general visual and cognitive processing ability ($r_{partial} = -.72$ after having factored out the mean of the Horse Memory Test; Duchaine & Nakayama, 2005, the Cambridge Car Memory Test; Dennett et al., 2012, and the Cambridge Hair Memory Test; Garrido et al., 2009).

Sims and Pelli (1987) advice to use the standard deviation of the posterior probability density function of the threshold outputted by the QUEST algorithm to assess the quality of the threshold estimate—the number of bubbles necessary to maintain performance at an accuracy of 75% correct in our case. Importantly, these standard deviations were comparable in the left-eye and right-eye induction groups in the pre- and post-induction phases ($M_{\text{right-induction/preinduction}} = 10.836$, $SD_{\text{right-induction/preinduction}} = 0.302$; $M_{\text{right-induction/postinduction}} = 10.863$, $SD_{\text{right-induction/postinduction}} = 0.278$; $M_{\text{left-induction/preinduction}} = 10.810$, $SD_{\text{left-induction/preinduction}} = 0.242$; $M_{\text{left-induction/postinduction}} = 10.902$, $SD_{\text{left-induction/postinduction}} = 0.336$; $F_{\text{interaction}}[1,196] = 0.620$, $p = .431$; $F_{\text{subject group}}[1,196] = 0.020$, $p = .883$; $F_{\text{task}}[1,196] = 2.100$, $p = .149$); and the quality of the threshold estimates did not correlate with the thresholds themselves (for the 140 participants that completed the preinduction phase: $r = -.046$, $p = .590$; for the 100 participants that completed the preinduction, induction, and postinduction phases: $r = -.789$, $p = .435$).

Correlation Between Face-Sex Categorization Ability and Use of Information

Next, we examined the facial information used by best and worst face-sex recognizers both for all participants that completed the preinduction phase ($N = 140$) and for the subset of these participants that completed the preinduction, induction, and postinduction phases ($n = 100$). As a first approximation, we summed the CIs of the participants in the first performance quartile (i.e., the worst 35 participants for $N = 140$, and the worst 25 participants for $n = 100$), smoothed them with a Gaussian kernel of 12 pixels of standard deviation, transformed them in z scores and applied a cluster test (search region = 11,429 pixels, arbitrary z-score threshold = 3, cluster size statistical threshold = 91 pixels, $p < .05$). We did the same with the CIs of the participants in the last performance quartile (i.e., the best 35 participants for $N = 140$, and the best 25 participants for $n = 100$) and in the two middle performance quartiles (70 average participants for $N = 140$, and 50 participants for $n = 100$; Figure 2b). Statistically significant regions from these CIs revealed that the worst participants rely mostly on the left-eye-and-eyebrow region, whereas the best participants rely mostly on the right-eye-and-eyebrow region. To confirm these results, we computed the difference between the CI of the best participants and the CI of the worst participants and applied another cluster test (search region = 11,429 pixels, arbitrary z score threshold = 2.7, cluster size statistical threshold = 277 pixels, $p < .05$). The resulting CI, shown in Figure 2c, indicates that the best participants use the right eye and eyebrow significantly more than the worst participants, and that the worst participants use the left eye and eyebrow significantly more than the best participants. Finally, we computed, for each participant, the difference between the average z scores located in the left- and right-eye-and-eyebrow ROIs and then compared these difference scores between the best and worst subject groups with a two-tailed unpaired t test. This revealed a large effect of performance on individual use of facial information (for $N = 140$: Cohen's $d = 0.961$, $M_{\text{best}} = 0.676$, $SD = 1.165$; $M_{\text{worst}} = -0.601$, $SD = 1.475$, $t[68] = 4.020$, $p = 1.48 \times 10^{-4}$; for $n = 100$: Cohen's $d = 0.884$, $M_{\text{best}} = 0.684$, $SD = 1.238$; $M_{\text{worst}} = -0.563$, $SD = 1.565$, $t[48] = 3.125$, $p = .003$).

As grouping participants may conceal important statistical information, we conducted another, more fine-grained analysis. We computed simple linear regressions between the individual mean z scores within three anatomically defined ROIs and performance. The right- and left-eye-and-eyebrow ROIs have already been described. The final ROI—the mouth area—is shown in Figure 2c. It was included in this analysis because, as we have already mentioned, the mouth is known to be an important facial feature for sex discrimination. The use of the right-eye-and-eyebrow area was positively correlated with performance (for $N = 140$: $r = .260$, $p = .003$; and for $n = 100$: $r = .270$, $p = .007$); the use of the left-eye-and-eyebrow area was negatively correlated with performance (for $N = 140$: $r = -.244$, $p = .001$, $r^2 = .0595$; and for $n = 100$: $r = -.29$, $p = .004$, $r^2 = .084$), and the use of the mouth area did not correlate with performance (for $N = 140$: $r = -.073$, $p > .4$; and for $n = 100$: $r = -.100$, $p > .3$). A multiple linear regression model between the use of information within the left- and right-eye-and-eyebrow ROIs and the performance explained 10% and 12% of the performance variance, respectively: for $N = 140$ ($r^2 = .101$), $F(3, 129) = 4.849$, $p = .003$, and for $n = 100$, $F(3, 92) = 4.120$, $r^2 = .119$, $p = .009$.

To summarize, these correlational analyses revealed a systematic link between face-sex discrimination performance and the use of the right- and left-eye areas both for all participants that completed the preinduction phase ($N = 140$) and for the subset of these participants that completed the preinduction, induction, and postinduction phases ($n = 100$). Next, we tried to determine if this link is causal in the latter group of participants.

Pre- and Post-Induction Comparison

In the induction phase, we attempted to induce the use of either the left- or the right-eye-and-eyebrow area by eliminating the sex information in the nontarget eye and eyebrow area in two groups of 50 randomly selected individuals among the subset of 100 participants that completed the preinduction, induction, and postinduction phases. The debriefing sessions suggest that participants were unaware of the manipulation of the nontarget eye and eyebrow information during the induction phase. No participant reported any discontinuity in the experiment, or said that he or she saw any changes in the eyes when asked explicitly about this.

To test crudely whether we successfully induced the use of the target eye regions, we first contrasted the post- and preinduction CIs in each induction group. We subtracted the pre- and post-induction CIs for both subject groups and applied cluster tests to the contrast CIs (search region = 11,429 pixels, arbitrary z-score threshold = 2.7, cluster size statistical threshold = 277 pixels, $p < .05$; see Figure 3). In the contrast CI of the right-eye induction group, the only statistically significant blob fell 74.65% within the target eye area (see Figure 3, white dashed line). In the contrast CI of the left-eye induction group, however, no pixel attained statistical significance. We confirmed more rigorously both results by contrasting the mean z score within the target eye and eyebrow

ROI for each group: a two-way mixed analysis of variance with target-eye usage as dependent variable and induction group (left-eye and right-eye induction) and experimental tasks (preinduction and postinduction) as independent variable revealed a significant interaction, $F(1, 98) = 6.210$, $p = .014$; $\eta^2 = .060$. Post hoc comparisons showed that participants from the right-eye induction group did in fact increase significantly their use of the right-eye area (one-tailed paired-samples t test, $M_{\text{preinduction}} = 0.302$, $SD_{\text{preinduction}} = 0.774$; $M_{\text{postinduction}} = 0.621$, $SD_{\text{postinduction}} = 0.679$; $t[49] = 2.016$, $p = .025$, Cohen's $d = 0.285$) but participants from the left-eye induction group did not increase significantly their use of the left-eye area between the pre- and postinduction phases (one-tailed paired t test, $M_{\text{preinduction}} = 0.529$, $SD_{\text{preinduction}} = 0.774$; $M_{\text{postinduction}} = 0.279$, $SD_{\text{postinduction}} = 0.887$; $t[49] = -1.520$, $p = .933$).

Next we verified if this change in the use of facial information in the right-induction participants did result in better individual performance. As predicted, participants from the right-eye induction group fared significantly better during the post- compared with preinduction phase ($M_{\text{preinduction}} = 48.940$, $SD_{\text{preinduction}} = 16.770$; $M_{\text{postinduction}} = 40.970$, $SD_{\text{postinduction}} = 13.430$; one-tailed paired t test, $t[49] = 3.412$, $p = 6.5 \times 10^{-3}$, Cohen's $d = 0.480$); participants from the left-eye induction group, on the other hand, did not perform significantly worse in the post- than in the preinduction phases ($M_{\text{preinduction}} = 45.820$, $SD_{\text{preinduction}} = 16.650$; $M_{\text{postinduction}} = 43.600$, $SD_{\text{postinduction}} = 16.220$; one-tailed paired t test, $t[49] = 1.010$, $p = .840$). Finally, we compared the performance improvement of each group that is, the difference between the number of bubbles threshold in the post- and preinduction phases: As expected, the participants of the right-eye induction group ($M = -7.970$, $SD = 16.500$) improved significantly more than those of the left-eye induction group ($M = -2.210$, $SD = 15.450$; one-tailed independent t test, $t[98] = 1.800$, $p = .037$, Cohen's $d = 0.360$).

Discussion

We revealed, for the first time, that the use of specific facial information not only correlates but also causes better face-sex categorization in neurotypical individuals. We began by measuring the default use of local facial information during a face-sex discrimination task using bubbles (Gosselin & Schyns, 2001). This data-driven approach revealed that the use of the right-eye-and-eyebrow area from the observer's perspective is positively correlated with performance, whereas the use of the left-eye-and-eyebrow area is negatively correlated with performance. Next, we attempted to induce implicitly participants to increase their use of either the left- or the right-eye area by eliminating the sex cues in the nontarget eye region. The 1-hr induction procedure was successful for the right-eye induction participants but not for the left-eye induction ones. The training of the left-eye induction group, which we conjectured would result in a performance decrease, might have failed because it was in competition with perceptual learning—a performance increase which is caused by practice, even in the absence of external feedback (e.g., Guggenmos, Wilbertz, Hebart, & Sterzer, 2016). It may also have been overly optimistic to hope for a statistically significant gain in the use of the left-eye area given the bias for its use observed in our participants during the preinduction phase (see also Butler et al., 2005; Dupuis-Roy et al., 2018; Ince et al., 2016; Innes et al., 2016). In any case, the successful induction of the use of the right-eye area was accompanied, as expected, by a significant performance improvement in the right-eye induction participants, and by a significantly greater performance improvement in the right-eye induction participants than in the left-eye induction participants. This is the first clear demonstration of a causal link between the use of specific face information and face recognition performance.

Why would the use of the right eye and eyebrow cause better recognition performance? Face processing tends to be lateralized in the right brain hemisphere of healthy individuals. This right-hemisphere advantage has been shown to favor the use of the left half of the face, and is believed to underlie the general-population bias for left eye (Yovel, Tambini, & Brandman, 2008). Our right-eye induction participants showed clearly this left-eye area bias prior to training, which suggests that they processed faces primarily with their right brain hemispheres. They did not stop using this left-eye-and-eyebrow information after training; rather they started using the right-eye-and-eyebrow information more. We believe thus that the enhanced performance in the right-eye induction participants reflects a greater recruitment of bilateral face-specific brain regions. Recent findings have indeed linked such bilateral brain activity in the fusiform gyri and occipital face areas (Huang et al., 2014) as well as stronger interhemispheric connectivity (Geiger, O'Gorman Tuura, & Klaver, 2016) to greater face recognition ability.

The failure of previous face recognition training studies has been attributed to the high heritability of face recognition ability (Wilmer, 2017). DeGutis et al. (2014), for example, required three weeks to train their participants and produced modest effects on individual recognition ability. The fact that we managed to increase individual performance following a mere 1-hr training session suggests, on the contrary, that this ability is quite malleable. Although crucial questions regarding, for example, real-world and task generalization, and resistance to extinction remain unanswered, our induction procedure shows promise as a mean for individuals specifically impaired in face recognition (e.g., developmental prosopagnosics; Duchaine & Nakayama, 2006) and professionals relying on strong face processing (e.g., police officers, security agents, customs officials) to improve their abilities.

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