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Privileged Access to Awareness for Faces and Objects of Expertise

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Access to visual awareness for human faces is strongly influenced by spatial orientation: Under continuous flash suppression (CFS), upright faces break into awareness more quickly than inverted faces. This effect of inversion for faces is larger than for a wide range of other animate and inanimate objects. Here we asked whether this apparently specific sensitivity to upright faces reflects face-specific detection mechanisms or whether it reflects perceptual expertise more generally. We tested car experts who varied in their degree of car and face expertise and measured the time upright and inverted faces, cars, and chairs needed to overcome CFS and break into awareness. Results showed that greater car expertise was correlated with larger car inversion effects under CFS. A similar relation between better discrimination performance and larger CFS inversion effects was found for faces. CFS inversion effects are thus modulated by perceptual expertise for both faces and cars. These results demonstrate that inversion effects in conscious access are not unique to faces but similarly exist for other objects of expertise. More generally, we interpret these findings as suggesting that access to awareness and exemplar-level discrimination rely on partially shared perceptual mechanisms.

Keywords: visual awareness, perceptual expertise, face perception, interocular suppression, continuous flash suppression

At any given moment, only a small fraction of the sensory information from the environment is consciously experienced (Baars, 1997; Dennett, 2001). Because of capacity limitations, nonconscious representations of various aspects of sensory information are thought to compete for access to awareness (Koch, 2004). Although it is well established that even such nonconscious stimulus representations can influence behavior (Kouider & Dehaene, 2007), representations that eventually gain access to awareness have a special status. For example, according to the global workspace model, only conscious content is globally distributed to functionally specialized subsystems that engage in long-range interactions to optimally guide goal-directed behavior in nonautomatic, flexible and adaptive ways (Baars, 1988, 1997).

Breaking Continuous Flash Suppression (b-CFS)

What factors in the sensory input determine which stimulus representations are more potent competitors for access to this capacity-limited stage of conscious perception? For the visual modality, several recent studies have used a novel experimental paradigm called *breaking continuous flash suppression* (b-CFS; Jiang, Costello, & He, 2007; Stein, Hebart, & Sterzer, 2011a; see Figure 1a) to quantify potency to gain access to awareness. In this paradigm continuous flash suppression (CFS; Tsuchiya & Koch, 2005) is used to render a visual stimulus shown to one eye invisible for up to several seconds by flashing high-contrast, contour-rich CFS masks at about 10 Hz into the other eye. CFS represents a particularly strong variant of binocular rivalry, which is thought to result from reciprocal interactions between representations of the two stimuli shown to the two eyes at multiple sites of the visual system (Sterzer, Stein, Ludwig, Rothkirch, & Hesselmann, 2014; Tong, Meng, & Blake, 2006), thereby opening a window into the competitive dynamics underlying conscious perception. The CFS masks initially dominate perception until the stimulus shown to the other eye eventually overcomes suppression and breaks into awareness. In b-CFS, the time it takes observers to detect or localize the suppressed stimulus is taken as the measure of access to awareness.

Although it is well established that physical stimulus "strength," reflecting low-level stimulus characteristics such as luminance

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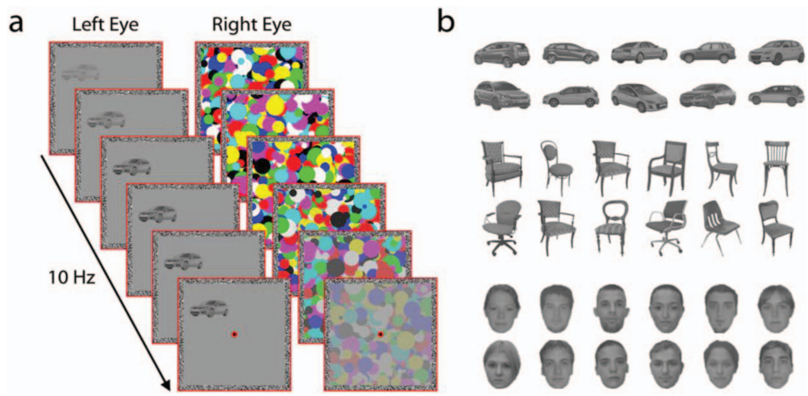

Figure 1. b-CFS procedure and target stimuli. (a) Illustration of a trial in the b-CFS experiment. An object was gradually introduced to one randomly selected eye while CFS masks flashing at 10 Hz were presented to the other eye. Participants localized as quickly and accurately as possible the quadrant in which an object or any part of the target became visible. (b) Example stimuli. Participants localized (upright and inverted) photographs of cars, chairs, and faces. See the online article for the color version of this figure.

contrast, is the main determinant of potency to gain access to awareness in b-CFS, more recent evidence demonstrates that also higher-level properties of visual stimuli, such as their structure, familiarity, or ecological relevance, can influence competition for visual awareness. When differences in lower level physical stimulus properties are equated, stimuli with greater familiarity, meaningfulness, or relevance break into awareness more quickly (reviewed by Gayet, Van der Stigchel, & Paffen, 2014). These b-CFS studies demonstrate that higher-level stimulus properties are being registered before suppression release, equipping more familiar, meaningful, or relevant stimuli with a competitive advantage in gaining access to the limited processing stage of conscious awareness.

Face-Specific Inversion Effects in b-CFS

A particularly robust and well-replicated finding is that suppression times for pictures of human faces are strongly modulated by the orientation in which they are displayed: Upright faces break into awareness more quickly than the same faces shown in inverted orientation, that is, rotated by 180 degrees (e.g., Jiang et al., 2007; Stein et al., 2011a; Yang, Zald, & Blake, 2007). Because upright and inverted faces are physically identical (i.e., they consist of the same pixels), this face inversion effect must be because of higher-level differences, most likely reflecting the visual system's sensitivity to the prototypical spatial configuration of facial parts (i.e., two eyes above nose above mouth; McKone, Kanwisher, & Duchaine, 2007), which is distorted in inverted faces. A similarly strong impact of stimulus inversion on access to awareness has been found for human bodies, while no comparable b-CFS inversion effects exist for a wide range of other familiar object categories, including monkey faces, animal bodies, and inanimate objects (Stein, Sterzer, & Peelen, 2012), or houses (Zhou, Zhang, Liu, Yang, & Qu, 2010). Thus, only human faces and bodies in their common upright configuration of parts are prioritized for access to conscious awareness. Although these previous b-CFS studies demonstrated that upright human faces and bodies are "special" in their potency to gain access to awareness, they did not address the underlying mechanism for this face- and body-specificity.

Putative Face-Specific Mechanisms

One possibility is that the disproportionately large inversion effects for faces and bodies reflect domain-specific perceptual mechanisms that are innate or develop early in life (Johnson, 2005; McKone et al., 2007). In newborns, a fast subcortical pathway involving the superior colliculus, the pulvinar, and the amygdala nuclei is thought to mediate orienting to face-like stimuli. While it had long been assumed that this pathway would serve no functional role in adult face perception, more recent findings indicate that the subcortical route supports initial face detection over the course of one's life (reviewed by Johnson, Senju, & Tomalski, 2015). Evidence for a role of the subcortical face detection pathway in adults comes primarily from studies tapping early, rapid visual processing by measuring fast saccadic responses (Nakano, Higashida, & Kitazawa, 2013; Tomalski, Csibra, & Johnson, 2009) or by recording subcortical neural activity to faces rendered invisible through interocular suppression (reviewed by Sterzer et al., 2014). Thus, it seems possible that the visual processes preceding and leading to suppression release in b-CFS involve subcortical pathway activity. Indeed, specific stimulus properties that modulate looking preferences in newborns (Farroni et al., 2005) have been found to have a similar influence on adults' awareness of upright relative to inverted faces in b-CFS (Stein, Peelen, & Sterzer, 2011b).

However, there is also evidence that awareness of faces is modulated by visual experience: Upright faces of friends are associated with shorter suppression times than upright faces of strangers (Gobbini et al., 2013), and the inversion effect in b-CFS is larger for the observer's own race and age group (Stein, End, & Sterzer, 2014). Although these findings show that access to awareness is influenced by experience, they are nevertheless compatible with experience-based tuning of perceptual mechanisms that are specific to faces.

Putative Expertise-Related Mechanisms

Alternatively, these face- and body-specific effects may at least partly be the result of our extensive experience in discriminating individual faces and bodies (Diamond & Carey, 1986; Gauthier & Tarr, 1997, 2002). A key prediction of the expertise account is that extensive experience in discriminating exemplars from object categories other than faces would result in "face-like" processing of objects from these categories (Gauthier & Logothetis, 2000). The disproportionally strong effect of inversion on recognition memory for faces relative to other object categories (e.g., Yin, 1969) is often regarded as evidence for face-specific configural processing, that is, strong spatial-relational integration of facial parts. Previous studies have confirmed the prediction of the expertise account using discrimination tasks, showing that expert-level discrimination of objects within a specific category such as cars is associated with larger inversion effects (Bruyer & Crispeels, 1992; Curby, Glazek, & Gauthier, 2009; Diamond & Carey, 1986; Gauthier, Skudlarski, Gore, & Anderson, 2000; Gauthier, Williams, Tarr, & Tanaka, 1998; Rossion, Gauthier, Goffaux, Tarr, & Crommelinck, 2002; Xu, Liu, & Kanwisher, 2005; but see Robbins & McKone, 2007). These findings show that extensive training in individual-level discrimination can result in enhanced configural processing of nonface objects in tasks in which observers have to identify individual exemplars, that is, when stimuli are consciously perceived and both training and test demand exemplar-level discrimination.

Recent evidence shows that perceptual expertise can influence performance even in tasks that do not require identification of exemplars. Experts have been found to be better at searching for targets from their category of expertise among distractor objects from other categories, both in difficult visual search in multielement displays (Hershler & Hochstein, 2009) and in photographs of cluttered real-world scenes (Reeder, Stein, & Peelen, 2015). While these studies demonstrate that objects of expertise are more efficiently discriminated from other objects, they do not address the question of whether objects of expertise are prioritized for access to awareness in the absence of such selection and categorization demands, as found for faces and bodies (Stein et al., 2012).

Evidence that some forms of real-world expertise—broadly construed as being exceptionally skilled in a certain domain (e.g., chess playing, high jumping, or typewriting)—can indeed influence the extent of unconscious processing comes from several recent masked priming studies. Expertise-related stimuli have been found to exert stronger priming effects in experts than in novices (Güldenpenning, Koester, Kunde, Weigelt, & Schack, 2011; Heinemann, Kiesel, Pohl, & Kunde, 2010; Kiesel, Kunde, Pohl, Berner, & Hoffmann, 2009). These studies convincingly demonstrate that some forms of real-world expertise can modulate initial, nonconscious visual processing. They did not, however, address whether expertise in exemplar-level object discrimination (of which face recognition is the prototypical example) can influence the visual processes that lead to conscious awareness.

The Present Study

To address this question, in the current study we measured the relationship between perceptual expertise with a nonface category (cars) and inversion effects for this category in b-CFS. To rule out potential confounds that can arise from comparing expert versus novices (e.g., differences in overall motivation or vigilance) we recruited only self-proclaimed car experts who varied in their perceptual performance on a sequential car matching task. Performance in this discrimination task provided an objective assessment of car expertise (e.g., Gauthier et al., 2000; McGugin, Gatenby, Gore, & Gauthier, 2012). If perceptual expertise were related to configural processing in access to awareness, we expected car discrimination performance to be positively correlated with car inversion effects in b-CFS. If, however, prioritized awareness of faces and bodies were mediated by perceptual mechanisms specifically tuned to detect conspecifics (Stein et al., 2011b, 2012), no such positive correlation would be expected for cars. Furthermore, if prioritized conscious access were mediated by perceptual expertise, one may also expect the advantage of upright over inverted faces in b-CFS to be positively correlated with individual face recognition abilities, which are highly variable (Bowles et al., 2009). Alternatively, if awareness of faces were governed by a distinct detection mechanism (Johnson, 2005; Stein et al., 2011b), no such positive correlation would be expected. In addition, we investigated whether configural processing in exemplar-level discrimination is related to configural processing at the transition to visual awareness. To test this, we correlated inversion effects from car and face discrimination tasks with car and face inversion effects in b-CFS. A positive correlation between inversion effects for the different categories would suggest that these tasks rely on partially shared perceptual mechanisms, with perceptual expertise enhancing configural processing at multiple levels of the processing hierarchy.

Method

Participants

All participants in the study were self-proclaimed car experts, recruited through postings to the University of Trento online subject pool and through flyers (distributed in libraries, university buildings, and car-related shops), stating that we were looking for car enthusiasts to take part in an experiment on visual perception of cars. Interested participants were tested if they labeled themselves as car experts, if they regarded themselves as better than most other people in discriminating between different cars, and if they said that they would regularly spend time on cars (e.g., auto shows) or read about cars or gather information on cars in some other way (e.g., through car magazines, the Internet, blogs, TV, and discussions with friends). That way all participants were recruited in the same way, avoiding selection biases (Reeder et al., 2015). Objectively assessed car expertise varied substantially across individuals in this group (see Results below).

Because of the limited availability of self-proclaimed car experts, we did not determine a fixed sample size but instead tried to test as many participants as possible over a period of approximately one year. In total, 32 self-proclaimed car experts took part in the study. After excluding two participants with extremely short overall suppression times (means of 0.88 and 1.04 seconds, respectively, both being below the cutoff according to the outlier labeling method by Hoaglin and Iglewicz (1987)), indicating that CFS was not working properly, the final sample consisted of 30 volunteers (3 women, 27 men, mean age 24.7 years, SD = 8.1 years). All participants reported normal or corrected-to-normal vision, were naïve as to the purpose of the experiment, and received a monetary compensation for their participation.

Apparatus and Stimuli

Discrimination experiment. During the discrimination experiment, observers viewed a 19-inch TFT monitor (1,280 × 1,024 pixels resolution, 60 Hz refresh rate) from a free viewing distance of approximately 57 cm. Stimulus presentation and response collection was controlled using "A Simple Framework" (Schwarzbach, 2011), a toolbox based on the Psychophysics Toolbox for Matlab (The MathWorks, Natick, MA). Stimuli were presented centrally on a white background. A central black fixation cross (0.9° × 0.9°) was continuously displayed.

Stimuli were 160 grayscale photographs of cars (8.8° × 8.8°) and faces (7.4° × 7.4°), respectively. High-resolution photographs of modern cars (no more than ~5 years out of production) commonly seen on European streets were retrieved from the Internet. A car expert (one of the authors) created 80 pairs of cars that he judged to be very difficult to distinguish as belonging to the same or different make or model based on perceptual similarities alone. There were 40 "same" pairs showing the same make and model that could appear in different positions and colors and could be from different years and series. Another 40 "different" pairs showed either same makes but different models (20 pairs) or different makes and models (20 pairs). In most car images, names or text and letters written on the side of the cars or on license plates were not visible. In a few images a brand logo appeared but the logo was never revealed on both cars in a pair. Face photographs were obtained from "The Database of Faces" created by the AT&T Laboratories Cambridge, United Kingdom (http://www.cl.cam.ac.uk/research/dtg/attarchive/facedatabase.html). Faces were fit to a standard oval shape by cropping around the forehead, cheeks, and chin, omitting the hair and ears. Faces were White or mixed-ethnicity, reflecting the major ethnicities of the participants of the current study. There were 40 same pairs showing two different images of the same person, and 40 different pairs showing different people matched by gender and hair color. For both cars and faces, inverted versions of the pairs were generated by rotating the images by 180 degrees.

b-CFS experiment. For the b-CFS experiment, observers viewed a 19-in CRT monitor (1,280 × 1,024 pixels resolution, 100 Hz refresh rate) dichoptically through a custom-built mirror stereoscope. The observer's head was stabilized by a chin-and-head rest at a viewing distance of approximately 50 cm. The mirrors of the stereoscope were adjusted for each observer to promote stable binocular fusion. The screen was black except for the uniform gray area in which the stimuli were presented. Two red frames (10.4° × 10.4°) were displayed side-by-side on the screen such that one frame was shown to each eye (distance between the centers of the two frames 21.6°). To further support binocular fusion, noise contours (width 0.5°) consisting of pixels with random intensities were presented within the red frames. In the center of each frame a red fixation dot (0.5° × 0.5°) with a black dot (0.2° × 0.2°) in its center was displayed (Figure 1a). Participants were asked to maintain stable fixation throughout the experiment. Visual stimuli were presented with Matlab using the Cogent 2000 toolbox functions (http://www.vislab.ucl.ac.uk/cogent.php).

Target stimuli were 40 photographs of cars (3.6° × 1.1–2.2°), faces (2.1–3.0° × 3.1°), and chairs (1.7–2.8° × 3.6°), respectively. Car targets were a subset of the photographs used in the discrimination experiment (but now presented in gray scale and with lower contrast), faces were photographs of young Whites selected from the "Center for Vital Longevity Face Database" (Minear & Park, 2004), and chairs were selected from the Internet. All stimuli were converted to gray scale and normalized for mean luminance and RMS contrast (see Figure 1b). Different contrast settings were used for different object categories to achieve approximately similar overall suppression times across categories (based on informal pilot testing). Note that because overall suppression times are influenced by various, partially unknown low-level stimulus characteristics (Gray, Adams, Hedger, Newton, & Garner, 2013; Meng, Cui, Zhou, Chen, & Ma, 2012; Stein, Seymour, Hebart, & Sterzer, 2014; Stein & Sterzer, 2012; Stein et al., 2012; Yang & Blake, 2012) we do not interpret differences in overall suppression times but only compare suppression times for physically identical stimuli presented in upright and inverted orientations. For all 120 target stimuli, inverted versions were created by rotating the images by 180 degrees.

To induce interocular suppression, we created high-contrast, contour-rich CFS masks (9.2° × 9.2°) consisting of randomly arranged white, black, and gray circles (diameter 0.4°–1.8°; see Figure 1a) using Matlab code available online (http://martin-hebart.de/code/make_mondrian_masks.m).

Procedure

Discrimination experiment. After the b-CFS experiment (see below), participants completed separate blocks of car and face sequential matching tasks. On each trial, a stimulus appeared for 1 s in the center of the screen, and after a fixation-only period of 500 ms a second stimulus remained on the screen until response. Participants responded by pressing the "1" key on the number pad if they believed the two stimuli depicted the same car model (car block) or the same person (face block) and the "2" key if they believed the two stimuli were different. They were instructed to respond as accurately as possible, without speed pressure.

Both the car and the face blocks contained 160 trials, in which each of the 80 stimulus pairs (40 same, 40 different) was shown twice, once in upright and once in inverted orientation. Upright and inverted trials were intermixed and trial order was randomized. All participants first completed the car discrimination block and then the face discrimination block.

b-CFS experiment. Before the discrimination experiments participants performed a standard b-CFS localization task: After a 700-ms period with no fixation dot and a 700-ms fixation period, CFS masks updated at 10 Hz were shown to one randomly selected eye, while a photograph of an object was gradually introduced to the other eye by increasing its contrast over the first second of each trial. Beginning one second after trial onset, the contrast of the CFS masks was linearly decreased to zero over 7.9 s. The object was presented until response, or for a maximum trial length of 10 s. Objects were presented in one of the quadrants of the fusion contour, centered at an eccentricity of 3.3°. Before the experiment, participants were informed about the presentation of upright and inverted cars, chairs, and faces, and they were asked to press one of four keys on a QWERTY keyboard corresponding to the four quadrants ("F" or "V" with their left hand and "J" or "N" with their right hand) to indicate as fast and accurately as possible in which quadrant an object or any part of an object emerged from suppression. No object recognition or discrimination was required for this task.

The b-CFS experiment consisted of 240 trials (separated by mandatory breaks after 80 and 160 trials) in which each combination of three target object categories, two target orientations, and 40 target exemplars per category occurred once. The eye to which the target object was presented was randomized such that half of the targets from each category were presented to one eye and the other half to the other eye, with the constraint that both the upright and the inverted versions of a specific target stimulus were presented to the same eye. Target locations were randomized with the constraint that for each of the six conditions (three target categories × two target orientations), each quadrant was selected 10 times. Finally, trial order was randomized.

Analyses

For the discrimination experiment, hit rates (proportion of different responses when two different exemplars were presented sequentially) and false alarm rates (proportion of different responses when the same exemplar was presented sequentially) were z-transformed and converted to the sensitivity measure d' (applying the 1/(2N) rule for rates of zero or one; Macmillan & Kaplan, 1985). Discrimination sensitivity for upright stimuli in these sequential matching experiments was taken as the measure of perceptual expertise for cars and faces, respectively (e.g., Gauthier et al., 2000; McGugin et al., 2012). Inversion effects for cars and faces were computed as the difference in discrimination sensitivity between upright and inverted stimuli.

For the b-CFS experiment, only trials with correct localization responses ($M = 98.4\%$, $SD = 1.8\%$) were included in the analyses of suppression times. A repeated-measures analysis of variance (ANOVA) with the factors category (cars, chairs, and faces) and orientation (upright, inverted) revealed no significant differences in localization accuracy, all $p > .397$. Suppression times were first analyzed using an omnibus ANOVA with the factors category and orientation. Post hoc paired t tests were then carried out to test whether inversion significantly prolonged suppression times for each category and whether the effect of inversion differed between individual object categories.

Inversion effects obtained in the b-CFS experiment were then correlated with sensitivity scores from the discrimination experiment, separately for cars and faces. We conducted two correlation analyses for each category, testing for positive correlations between b-CFS inversion effects and overall discrimination sensitivity for upright cars and faces, and for positive correlations between b-CFS inversion effects and inversion effects in discrimination sensitivities.

Because of the clear directional hypothesis regarding the influence of inversion on suppression times (shorter for upright target objects) and discrimination sensitivity (better for upright objects), inversion effects were assessed with one-tailed tests. For the comparison of inversion effects between object categories, we used two-tailed tests. Finally, because of the clear directionality of our hypothesis and to maximize power, we used one-tailed tests to test for positive correlations between b-CFS inversion effects and discrimination sensitivity scores (Gauthier, Curby, Skudlarski, & Epstein, 2005; McGugin, Van Gulick, Tamber-Rosenau, Ross, & Gauthier, 2014).[1]

Results and Discussion

Discrimination Experiment

A repeated measures ANOVA with the factors category (cars, faces) and orientation (upright, inverted) on the d' scores from the discrimination tasks revealed a significant main effect of category, $F(1, 29) = 22.36$, $p < .001$, $\eta_p^2 = .44$, with higher performance for faces ($M = 1.56$) than for cars ($M = 0.90$). The relatively low performance for cars reflects our attempt to create a challenging task sensitive to interindividual differences in car discrimination performance in our sample of self-proclaimed car experts. Note that we did not attempt to match overall performance for faces and cars, because we were interested in performance differences within these categories and their relationship with b-CFS inversion effects. The main effect of orientation was also significant, $F(1, 29) = 132.29$, $p < .001$, $\eta_p^2 = .82$, reflecting greater discrimination sensitivity for upright ($M = 1.67$) than for inverted ($M = 0.79$) stimuli. The category-by-orientation interaction was not significant, $F(1, 29) = 0.92$, $p = .346$, $\eta_p^2 = .03$, meaning that the size of the inversion effect did not differ significantly between cars ($M = 0.95$) and faces ($M = 0.81$; see Figure 2b).

While several previous studies found an effect of inversion on the discrimination of objects from categories other than faces, even in novices, these inversion effects were usually of much smaller magnitude than those obtained for faces (e.g., Busigny et al., 2014; Robbins & McKone, 2007; Rossion & Curran, 2010; Valentine & Bruce, 1986; Yin, 1969). To the best of our knowledge, car inversion effects of comparable numerical magnitude as in the present experiment were previously reported by only two studies on car experts (Gauthier et al., 2000, d' difference 0.84; Xu et al., 2005, d' difference 0.87). Thus, these large car inversion effects provide an a posteriori validation that our participants were, on average, car experts.

To further assess whether our participants were indeed car experts, we compared discrimination performance to an independent sample of self-proclaimed car novices ($N = 13$, 7 women, 6 men, mean age 28.4 years, $SD = 5.1$ years). A mixed repeated-measures ANOVA with the factors group (self-proclaimed car experts, novices), category (cars, faces) and orientation (upright, inverted) on the d' scores yielded a three-way interaction, $F(1, 41) = 10.46$, $p = .002$, $\eta_p^2 = .20$. For faces, neither overall performance (experts, $M = 1.56$, novices, $M = 1.75$; $F(1, 41) = 1.91$, $p = .175$, $\eta_p^2 = .04$) nor inversion effects (experts, $M = 0.81$, novices, $M = 1.03$; $F(1, 41) = 1.18$, $p = .284$, $\eta_p^2 = .03$) differed significantly between self-proclaimed car experts and novices. For cars, by contrast, self-proclaimed car experts had significantly greater discrimination sensitivity (experts, $M = 0.90$, novices, $M = -0.25$; $F(1, 41) = 23.14$, $p < .001$, $\eta_p^2 = .36$), and inversion

[1] One-tailed test were deemed appropriate because no significant correlation as well as a significant correlation in the opposite direction (negative correlation between b-CFS inversion effects and discrimination sensitivity) would both have been regarded as no evidence for a relationship between expertise and b-CFS inversion effects.

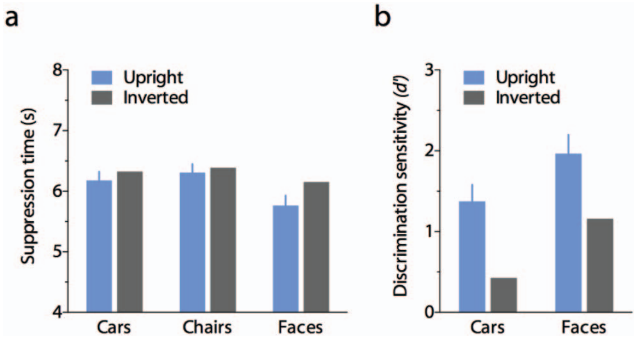

Figure 2. (a) Results from the b-CFS experiment. Bars show mean suppression times for cars, chairs, and faces, separately for stimuli in upright and inverted orientation. Error bars denote the 95% confidence interval (CI) for the mean difference between upright and inverted stimuli within each object category. (b) Results from the sequential matching tasks. Bars show mean discrimination sensitivity for cars and faces, separately for upright and inverted stimuli. Error bars denote the 95% CI for the mean difference between upright and inverted stimuli within each object category, respectively. See the online article to see the color version of this figure.

effects (experts, $M = 0.95$, novices, $M = -0.24$; $F(1, 41) = 14.55$, $p < .001$, $\eta_p^2 = .26$) than novices. These results confirm that the self-proclaimed car experts who took part in the present study had greater car expertise than self-proclaimed car novices.

b-CFS Experiment

For the b-CFS experiment, we only tested self-proclaimed car experts to avoid selection biases and to exclude potential confounds related to comparing experts and novices (e.g., differences in overall motivation or vigilance). Mean suppression times from the b-CFS experiment (see Figure 2a) were analyzed in a repeated-measures ANOVA with the factors category (cars, chairs, and faces) and orientation (upright, inverted). The main effect of category was significant, $F(2, 58) = 12.59$, $p < .001$, $\eta_p^2 = .30$, reflecting overall shorter suppression times for faces ($M = 5.96$ s) than for cars ($M = 6.25$ s) and for chairs ($M = 6.35$ s). The main effect of orientation was also significant, $F(1, 29) = 21.44$, $p < .001$, $\eta_p^2 = .43$, with overall shorter suppression times for upright targets ($M = 6.08$ s) than for inverted targets ($M = 6.29$ s). More important, the interaction between category and orientation was significant, $F(2, 58) = 5.41$, $p = .007$, $\eta_p^2 = .16$. As can be seen from Figure 2a, inversion significantly prolonged suppression times for faces, $t(29) = 4.87$, $p < .001$, one-tailed, $d = 0.89$. A statistically significant inversion effect was also found for cars, $t(29) = 2.08$, $p = .024$, one-tailed, $d = 0.38$, but not for chairs, $t(29) = 1.11$, $p = .137$, one-tailed, $d = 0.20$. Furthermore, the face inversion effect was significantly larger than the effect of inversion on suppression times for cars, $t(29) = 2.64$, $p = .013$, two-tailed, $d = 0.48$, and for chairs, $t(29) = 2.80$, $p = .009$, two-tailed, $d = 0.51$. Finally, the effect of inversion did not differ significantly between cars and chairs, $t < 1$. While the larger b-CFS inversion effect for faces compared to other object categories replicates previous findings (Stein et al., 2012; Zhou et al., 2010), the statistically significant advantage for upright over inverted cars in breaking suppression indicates that in self-proclaimed experts orientation can modulate access to awareness also for objects from their category of expertise. As previous b-CFS studies did not find statistically significant inversion effects for inanimate object categories (Stein et al., 2012; Zhou et al., 2010), this inversion effect for cars provides a first indication that expertise may be related to b-CFS inversion effects. Next, we directly related individual differences in perceptual expertise to inversion effects obtained with b-CFS.

Correlation Analyses

First, we tested the association between car inversion effects from b-CFS and overall car discrimination ability, using sensitivity scores for upright cars as the measure of expertise (e.g., Gauthier et al., 2000; McGugin et al., 2012). As shown by Figure 3a, there was a significant positive correlation between d' scores for upright cars and b-CFS inversion effects for cars, $r(28) = .419$, $p = .011$, one-tailed. Thus, car expertise was associated with larger car inversion effects in b-CFS, indicating that perceptual expertise results in configural processing of objects in access to awareness. Second, we analyzed the relationship between car inversion effects

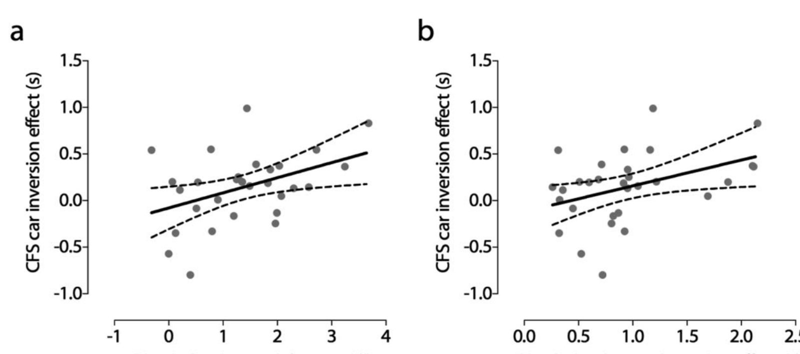

Figure 3. (a) Correlation between sensitivity in the car discrimination task and the car inversion effect obtained with b-CFS. Each dot represents a participant. (b) Correlation between the inversion effect in the car discrimination task and the car inversion effect from b-CFS. In these and in the other correlation plots, the solid line shows the best-fitting linear regression line and the dashed lines the associated 95% confidence intervals.

in b-CFS and inversion effects in car discrimination sensitivity. As can be seen from Figure 3b, the correlation between discrimination inversion effects and b-CFS inversion effects for cars was significant, $r(28) = .401$, $p = .014$, one-tailed. Thus, there is a link between configural processing in exemplar-level identification and configural processing in conscious access for objects of expertise.

We then repeated these analyses for faces. Similar to cars, there was a significant positive correlation between d' scores for upright faces and b-CFS face inversion effects, $r(28) = .366$, $p = .023$, one-tailed (see Figure 4a), as well as a significant correlation between face inversion effects from the sequential matching task and the face inversion effects obtained with b-CFS, $r(28) = .364$, $p = .024$, one-tailed (Figure 4b). Thus, also for this natural category of expertise, recognition skills and the extent of configural processing in identification are related to configural processing in access to awareness.

Category-Specificity

To exclude the possibility that these correlations were because of a more general cognitive process unrelated to category-specific perceptual expertise, we conducted a series of control analyses. First, we tested for cross-category correlations between cars and faces. There were no significant positive correlations of b-CFS car inversion effects with upright face discrimination, $r(28) = .068$, $p = .361$, one-tailed, or with face discrimination inversion effects, $r(28) = .076$, $p = .346$, one-tailed. Similarly, there were no significant positive correlations of b-CFS face inversion effects with upright car discrimination, $r(28) = .182$, $p = .168$, one-tailed, or with car discrimination inversion effects, $r(28) = -.051$.

Second, we tested whether discrimination abilities for cars and faces correlated with b-CFS inversion effects for chairs. There were no significant positive correlations between d' scores for upright cars or car discrimination inversion effects and b-CFS inversion effects for chairs, $r(28) = -.283$, and $r(28) = -.146$, respectively. Similarly, there were no significant positive correlations between upright face discrimination or face discrimination inversion effects and b-CFS chair inversion effects, $r(28) = -.190$, and $r(28) = -.210$, respectively.

Third, we tested whether the correlations between discrimination abilities and b-CFS inversion effects for cars and faces persisted when the b-CFS inversion effect for chairs was subtracted. Also with this analysis there were significant positive correlations of b-CFS car inversion effects from which b-CFS chair inversion effects were subtracted with d' scores for upright cars, $r(28) = .512$, $p = .002$, one-tailed, and with car discrimination inversion effects, $r(28) = .400$, $p = .014$, one-tailed. Similarly, there were significant positive correlations of b-CFS face inversion effects from which b-CFS chair inversion effects were subtracted with upright face discrimination, $r(28) = .377$, $p = .020$, one-tailed, and with face discrimination inversion effects, $r(28) = .388$, $p = .017$, one-tailed.

Finally, we computed partial correlations between discrimination performance and b-CFS inversion effects for cars and faces, controlling both for discrimination performance for the other category and for b-CFS inversion effects for chairs. There were significant positive correlations of b-CFS car inversion effects with upright car discrimination, $r(26) = .453$, $p = .008$, one-tailed, controlling for upright face discrimination and b-CFS chair inversion effects, and with car discrimination inversion effects, $r(26) = .417$, $p = .014$, one-tailed, controlling for face discrimination inversion effects and b-CFS chair inversion effects. Similarly, there were significant positive correlations of b-CFS face inversion effects with upright face discrimination, $r(26) = .323$, $p = .047$, one-tailed, controlling for upright car discrimination and b-CFS chair inversion effects, and with face discrimination inversion effects, $r(26) = .346$, $p = .035$, one-tailed, controlling for car discrimination inversion effects and b-CFS chair inversion effects.

Thus, these control analyses demonstrate that the correlations between discrimination performance and b-CFS inversion effects are category-specific, do not generalize to chairs, and persist when perceptual performance for other categories is partialed out. These results provide evidence that the relationship between discrimination skills and b-CFS inversion effects for cars and faces reflects category-specific perceptual expertise rather than a more general cognitive process.

General Discussion

The present study tested whether privileged access to awareness is mediated by perceptual expertise. We recruited a sample of self-proclaimed car experts who varied in their degree of objec-

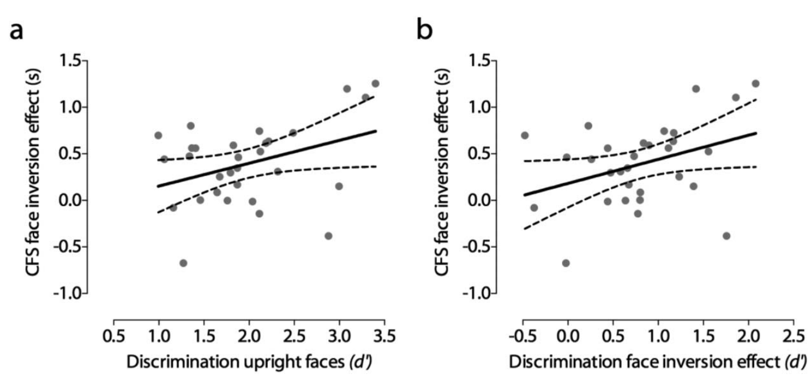

Figure 4. (a) Correlation between sensitivity in the face discrimination task and the face inversion effect obtained with b-CFS. (b) Correlation between the inversion effect in the face discrimination task and the face inversion effect from b-CFS.

tively assessed car and face expertise and measured the time upright and inverted photographs of faces, cars, and chairs needed to overcome CFS and break into awareness. Consistent with previous research (Stein et al., 2012; Zhou et al., 2010), the advantage of upright over inverted stimuli in breaking CFS (b-CFS) was larger for faces than for cars and chairs. More important, however, the size of the car inversion effect in b-CFS varied as a function of perceptual expertise for cars: Greater car expertise was associated with larger car inversion effects in b-CFS. This is the first evidence that discrimination expertise is related to configural processing underlying conscious access. Indeed, we found that larger effects of inversion in car discrimination were associated with larger car inversion effects in b-CFS, indicating that these two tasks recruit similar or shared configural mechanisms. Finally, a similar association between identification performance and b-CFS inversion effects was found for faces, providing further evidence for shared configural processing mechanisms underlying exemplar-level discrimination and access to visual awareness.

Inversion Effects for Objects of Expertise in b-CFS

With this b-CFS method, previous work had shown that upright faces and bodies have an advantage over inverted faces and bodies in accessing visual awareness and that these inversion effects are much larger for faces and bodies than for a wide range of other familiar animate and inanimate object categories (Stein et al., 2012; Zhou et al., 2010). This particular sensitivity to the upright configuration of faces and bodies may reflect either a domain-specific, inborn detection mechanism (Johnson, 2005; McKone et al., 2007) or our extensive experience in recognizing and individuating other people (Diamond & Carey, 1986; Gauthier & Tarr, 1997, 2002). The association between better car and face identification and larger inversion effects in b-CFS obtained in the present study now provides more evidence that the perceptual mechanisms governing access to visual awareness are shaped by expertise. Although these findings do not categorically rule out an additional contribution of inborn mechanisms to the detection of conspecifics (Farroni et al., 2005; Johnson et al., 2015; Simion, Regolin, & Bulf, 2008; Stein et al., 2011b, 2012), they demonstrate that perceptual expertise alone can influence conscious access for the category of expertise.

It is currently debated whether such access prioritization as measured with b-CFS reflects nonconscious processing that is specifically tied to the technique of interocular suppression or the visual system's sensitivity to different stimulus categories more generally. The present findings could therefore reflect differences in general detectability between upright and inverted stimuli that vary with the observer's discrimination expertise. It should be noted that such increased sensitivity in simple detection implies enhanced visual processing before stimuli become available for conscious access, which can be regarded as a form of nonconscious visual processing (e.g., Kaunitz, Fracasso, Lingnau, & Melcher, 2013; Stein, Kaiser, & Peelen, 2015). We interpret our findings as indicating that perceptual expertise is associated with increased sensitivity to configural stimulus properties, resulting in privileged access to awareness for objects of expertise. This increased sensitivity boosts access to awareness under CFS and may also increase detectability more generally, independent of the specific technique of interocular suppression.

Several previous b-CFS studies compared effects obtained under CFS to control conditions not involving interocular suppression to rule out possible response biases and to infer CFS-specific nonconscious processing. Because there are a number of theoretical and practical issues with relying on such control conditions (see Gayet et al., 2014; Stein et al., 2011a; Stein & Sterzer, 2014; Yang, Brascamp, Kang, & Blake, 2014), here we did not include such a binocular control condition. While a contribution of response biases to the present findings cannot be excluded, this possibility seems unlikely given that correlations were computed between inversion effects from b-CFS (rather than overall suppression times for upright stimuli) and criterion-free indices of discrimination sensitivity.

Expertise Enhances Configural Processing in Conscious Access

The enhanced perceptual sensitivity related to expertise is consistent with previous research showing faster categorization of objects of expertise in visual search arrays (Hershler & Hochstein, 2009) and in real-world scenes (Reeder et al., 2015). The current results extend these previous findings in two important ways: First, the method of b-CFS taps a more basic level of visual processing. In previous studies, participants were faster in categorizing an object presented among distractors as a target when this object was from their category of expertise and distractors were from other object categories. That is, in these studies the category of the target object needed to be discriminated from the category of simultaneously presented distractor objects. Thus, better categorization might have reflected more efficient top-down attentional guidance toward the category of expertise. In contrast, in the present b-CFS experiment no such selection requirements existed; the target category was not cued and indeed not even directly relevant to the task. Participants simply needed to discriminate a single target object presented to one eye from the CFS masks presented to the other eye to localize the initially invisible target. Thus, differences in the efficiency of top-down attentional guidance are unlikely to explain the effect in the present study. Rather, the current results indicate that representations of objects of expertise can be enhanced even before they become available for conscious access, thus demonstrating that expertise can modulate processing throughout the visual hierarchy.

Second, while previous studies found a general advantage for upright objects of expertise over upright objects from other categories (Hershler & Hochstein, 2009; Reeder et al., 2015), here we studied the relationship between expertise and the effect of inversion on suppression times obtained with b-CFS. This is important because it allowed us to more precisely determine the type of nonconscious stimulus representations that are modulated by perceptual expertise. As all image-level features are identical in upright and inverted stimuli, our findings indicate that the visual system of experts is specifically tuned to the upright orientation of objects from their category of expertise rather than to isolated diagnostic features or parts (e.g., the wheel of a car). Most commonly, inversion is believed to interfere with the visual system's sensitivity to the normal upright spatial configuration of object parts (Curby & Gauthier, 2010; Diamond & Carey, 1986). While previous studies revealed larger inversion effects for objects of expertise in discrimination tasks (e.g., Curby et al., 2009; Diamond

& Carey, 1986; Gauthier et al., 1998, 2000; Rossion et al., 2002; Xu et al., 2005), hence demonstrating enhanced configural processing for objects of expertise in these tasks, the present findings are the first demonstration that perceptual expertise is related to enhanced configural processing in conscious access.

This relationship between identification and inversion effects in access to awareness was category-specific: The relative level of discrimination performance for a specific category (cars, faces) predicted the size of the b-CFS inversion effect for that category, but not for the other category, and vice versa. This category-specificity indicates that our findings are specifically tied to perceptual expertise rather than to a more general cognitive process. One limitation of the present approach is that performance in the discrimination task may not represent a pure measure of perceptual expertise. Although exemplar-level discrimination ability represents the standard index and operationalization of perceptual expertise, factors other than expertise may also influence performance on this task. To isolate the role of perceptual expertise, discrimination skills would need to be examined for an additional object category (e.g., chairs) for which observers do not differ in expertise. This would rely on the premise that no meaningful differences in perceptual expertise exist for this additional object category. However, even novices may show variability in perceptual expertise, such that a positive correlation (e.g., for chairs) could similarly reflect differences in expertise. In the absence of methods to separate distinct sources of variance that influence discrimination performance, it thus remains possible that the correlations between identification and b-CFS inversion effects reflect additional factors unrelated to expertise.

Similar Perceptual Mechanisms for Identification and Access to Awareness

The fact that perceptual expertise is associated with larger inversion effects in both exemplar-level discrimination tasks and in conscious detection suggests that these two distinct tasks recruit partly overlapping perceptual mechanisms. Indeed, we found that for both cars and faces the inversion effect in discrimination performance was correlated with the size of the b-CFS inversion effect. This correlation between configural processing (as captured by inversion effects) may seem surprising, because the two tasks rely on fundamentally different abilities: Whereas successful identification requires the ability to distinguish subtle differences among exemplars within an object category, successful detection requires the ability to generalize across exemplars. One possibility is that for objects of expertise both detection and discrimination are achieved through view-invariant, holistic templates (Hershler & Hochstein, 2009). Indeed, the "experience-based holistic account" of face perception by Rossion and Michel (2011) proposes that for faces, recognition is achieved by matching an experience-derived template representing the global structure of an average face to the visual input. This account has not only been used to explain the impact of experience on configural face processing in discrimination tasks but also to account for the finding that the face inversion effect in b-CFS is larger for faces from the observer's own race and age group (Stein et al., 2014). In a similar way, expertise with another object category such as cars may entail the development of an experience-shaped holistic template for that category that supports both exemplar-level discrimination and conscious detection. An important question for future research is to determine how such a single template could be dynamically scaled to enable both fine-grained discrimination at the fovea and detection over the whole visual field (cf. Hershler & Hochstein, 2009).

Putative Neural Mechanisms

The disproportionally large face inversion effect obtained with b-CFS has previously been linked to stronger neural responses to upright than to inverted faces in the subcortical face detection pathway (Stein et al., 2011b; Zhou et al., 2010). The present finding of expertise-dependent inversion effects for cars now demonstrates that configural processing effects in access to awareness under CFS do not need to involve innate subcortical face-specific neural mechanisms. Instead, our results suggest that access to awareness under CFS is more likely related to cortical representations of objects known to be strongly shaped by visual experience and perceptual expertise (e.g., McGugin et al., 2012). For example, interindividual differences in face recognition abilities are associated with responses to faces in the fusiform face area (FFA; Furl, Garrido, Dolan, Driver, & Duchaine, 2011) and interindividual differences in the effect of inversion on face identification are related to activity in the FFA (Yovel & Kanwisher, 2005). The correlation between the effect of inversion on face identification and suppression times may thus reflect differential activity in cortical areas such as the FFA. Access to awareness for nonface objects of expertise may similarly involve activity in regions of high-level visual cortex representing these objects. Previous work has shown that these regions may partially overlap with the face-selective FFA (Gauthier et al., 2000; McGugin et al., 2012). Future work needs to determine whether the extent of nonconscious activity in face-sensitive cortical areas (Sterzer, Haynes, & Rees, 2008; Sterzer, Jalkanen, & Rees, 2009) indeed predicts access to awareness for faces and objects of expertise (cf. Schmack, Burk, Haynes, & Sterzer, 2015).

Conclusion

In conclusion, the present study provides evidence that configural processing in conscious access is related to exemplar-level discrimination skills and modulated by perceptual expertise. For both faces and cars overall discrimination performance and the effect of inversion on discrimination performance were related to inversion effects obtained with b-CFS. These findings indicate that access to awareness and exemplar-level discrimination rely on partially shared perceptual mechanisms. Moreover, the increased advantage of upright over inverted cars in gaining access to awareness in observers with greater car expertise suggests that extensive discrimination training does not only improve identification but can even determine whether an object is seen in the first place.

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