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# Visual expertise with pictures of cars correlates with RT magnitude of the car inversion effect

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**Abstract.** In their seminal study Diamond and Carey (1986, *Journal of Experimental Psychology: General* **115** 107 – 117) found a larger inversion effect for dog pictures in dog experts than novices, supporting a role of visual expertise in the observation of particularly large inversion effects for faces. However, subsequent studies have provided mixed results, and very few have compared the inversion effects for faces and familiar non-face object categories. Here we tested the effect of inversion on faces and cars in car experts and novices, using a delayed matching task across viewpoint changes. Inversion affected accuracy much more for pictures of faces than of cars for both groups, with no interaction between expertise and category. However, for car experts only there was a significant correlation between the magnitude of the inversion cost in RT for car pictures and the level of expertise as measured in an independent task. These observations support the view that the particularly large inversion effect found for faces is related to expert visual processes which can be at least partially recruited to process other non-face object categories.

## 1 Introduction

Presenting pictures upside-down (either flipped vertically or rotated 180°) affects the recognition of faces disproportionately more than the recognition of many other non-face objects, a phenomenon known in the literature as the face-inversion effect (Yin 1969; for reviews see Rossion 2008; Rossion and Gauthier 2002; Valentine 1988). Together with the observation of recognition impairments specific for faces (prosopagnosia—Bodamer 1947) and of infero-temporal cortex neurons responding selectively to faces in the monkey brain (Gross et al 1972), this largest inversion cost for faces is at the root of the idea that face recognition is subtended by specific brain mechanisms (ie those that are particularly affected by inversion—Yin 1969). However, a classic study by Diamond and Carey (1986) suggested that the large inversion costs for faces might not be due to the geometry of face stimuli per se, but rather to our largest amount of visual experience with the category of faces as compared to other object categories. In the critical experiment reported by these authors (experiment 3), self-reported dog experts showed an inversion effect of comparable magnitude for faces as for pictures of dog breeds they were experts at recognizing. The authors concluded that recognition of photographs of individual dogs could be as vulnerable to inversion as is face recognition, but only for dog experts. This was a very important observation in the field of face processing because it suggested that mechanisms thought to be domain-specific or modular (ie applied only to the domain of faces) might in fact be recruited to recognize other object categories following visual-expertise training.

Since then, there has also been a tremendous amount of research on the nature of the face-inversion effect (ie what facial cues are particularly affected by inversion—eg Barton et al 2001; Collishaw and Hole 2000; Freire et al 2000; Goffaux and Rossion 2007; Leder et al 2001; Le Grand et al 2001; Rhodes et al 1993; Russell et al 2007; Searcy and Bartlett 1996; see Rossion 2008 for a review), but surprisingly few studies comparing the effects of inversion on objects and faces since the experiment of Yin

(Ashworth et al 2008; Diamond and Carey 1986; Husk et al 2007; Leder and Carbon 2006; Loftus et al 2004; Robbins and McKone 2007; Rossion et al 2002; Scapinello and Yarmey 1970; Valentine and Bruce 1986). Moreover, besides Diamond and Carey's work on dog experts, inversion costs in performance between experts and novices with non-face objects were only compared in a few recent studies. Some of these studies reported significant increases of inversion costs with expertise either in RT or accuracy (Behrmann and Ewell 2003; Rossion et al 2002; Xu 2005), while others did not find significant effects (Bruyer and Crispeels 1992; Busey and Vanderkolk 2005; Gauthier and Tarr 1997; Gauthier et al 1998, 2000; Robbins and McKone 2007). Apart from one experiment with novel objects (Greebles, in Rossion et al 2002), no face stimuli were compared to the objects in these studies. In a recent study, Husk et al (2007) compared performance between faces and textures at two orientations, before and after training on the textures. However, stimuli differed too much to allow a fair comparison of the magnitude of inversion effects for the two kinds of stimuli (textures were low-pass filtered and familiar to the observers, unlike unfamiliar unfiltered faces).

Here we investigated this issue further by testing the effect of inversion on photographs of faces and cars, using a simple delayed forced-choice matching task, on twenty participants who reported being experts at recognizing cars (self-reported expertise), and twenty participants who reported no such car expertise. Importantly, car expertise was assessed with a behavioral matching task to derive a car expertise index (Gauthier et al 2003) independently of the performance measures in the inversion experiment. Inversion costs in accuracy and RTs were measured and compared for both experts and novices, and the relationship between inversion costs and the expertise index was also assessed through correlation measures. We were particularly interested in the extent to which a relationship between inversion effects and expertise would be observed when expertise was quantified as a continuous variable and correlated with inversion effects, rather than only dichotomizing subjects into separate groups of experts and novices and thereby ignoring within-group variance.

## 2 Methods

### 2.1 *Subjects*

Twenty self-reported car experts and twenty novices with normal or corrected vision gave informed consent and participated in this study, approved by the Human Research Committee at University of Colorado at Boulder, for payments or partial course credit. All subjects were male. One expert subject was excluded because of extremely poor accuracy in all conditions, including upright faces and cars (below 65%), and replaced with another self-reported expert. Age was matched between experts (mean = 20.15 years, SD = 0.88 years, range = 19 to 22 years) and novices (mean = 20.50 years, SD = 1.24 years, range = 18 to 22 years), $t_{38} = 1.03$, SE = 0.34, $p = 0.31$.

### 2.2 *Car expertise test*

Subjects' car expertise was tested as in previous work (Gauthier et al 2003), yielding a quantitative estimate of their ability relative to their performance with birds (used here as a baseline for novice-level performance). Subjects matched sequentially presented ($256 \times 256$) grayscale images of cars and birds on the basis of their model or species (224 trials). The first image was presented for 1000 ms followed by a mask for 500 ms, and then the second image appeared and remained till the subject made a response or 5000 ms had passed. Matching stimuli were not physically identical, but were different exemplars of the same bird species or the same make/model of car produced in different years and shown from different perspectives. An index of car expertise ($\Delta d'$) was computed as the $d'$ difference between the car and bird conditions.

Self-reported car experts yielded $\Delta d' = 1.35$, which was significantly larger than $\Delta d'$ of car novices (0.52) ($t_{38} = 5.53$, $p < 0.0001$). According to the index of expertise to define the two groups (median-split), only four self-reported experts would be considered to be novices. Note that this difference was mainly due to car experts performing better than car novices with pictures of cars (2.39 versus 1.53, $t_{38} = 6.37$, $p < 0.0001$). The two groups did not differ significantly in their accuracy with pictures of birds (1.04 versus 1.01, $t_{38} = 0.31$, $p = 0.76$).

### 2.3 *Stimuli*

2.3.1 *Faces.* 24 photographs of faces of undergraduate students, 12 males and 12 females of neutral expression, without glasses, facial hair and make-up, were used. There were 2 pictures for each face or car, one full front and one at 3/4 profile (figure 1). All face photographs were edited in Adobe Photoshop to remove backgrounds and haircut, and everything below the chin. On average, the size of each face photograph on the monitor was 5.6 cm wide (about 3.2 deg at 100 cm from the monitor) and 8.27 cm high (4.74 deg) for full front, and 5.6 cm × 7.92 cm for 3/4 views (3.2 deg × 4.54 deg). They were presented in grayscale.

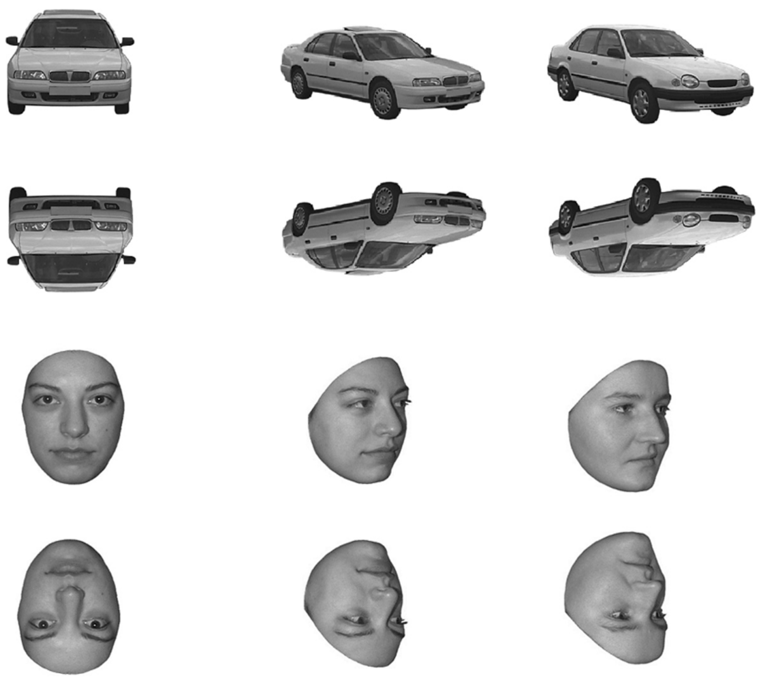

**Figure 1.** Examples of stimuli used in the experiment. The target face was presented as a full front picture (leftmost column), followed by two 3/4 profile pictures of the target and a distractor. Orientation was constant between the first and second items.

2.3.2 *Cars.* A total of 24 photographs of cars were used. They were mostly European and Japanese cars,[(1)] also used in previous behavioral and ERP studies (eg Rossion et al 2007) with American car experts who were not exposed to these particular models of cars, their expertise being with the category as a whole. There were 2 pictures per car, one full front (about 10 cm × 5 cm; 5.72 deg × 2.86 deg) and one 3/4 profile (8 cm × 6 cm; 4.58 deg × 3.44 deg) (figure 1). Each picture was presented upright, or flipped in the vertical axis. Cars were presented in grayscale to minimize color differences.

[(1)] To our knowledge, most of these European and Japanese cars used as stimuli models are available on the American market, but rarely seen.

2.4 *Procedure*
Subjects were seated in front of the monitor, at a distance of 100 cm. A trial included the presentation of a full-front target stimulus in one of the four conditions (car or face, upright or inverted) for 2000 ms in the center of the screen. After a blank screen lasting 1000 ms, two pictures of 3/4 face or car profiles were presented side-by-side until the participant's response. The next trial started 1000 ms after the participant's response. Upright/inverted stimuli were always followed by upright/inverted stimuli (ie the orientation of the test stimuli was the same as that of the target stimulus). There were 36 trials of each condition, 12 stimuli of each category appearing once as target, 12 stimuli twice to have more trials. Distractors were selected to be visually similar to targets, and each target could be paired with either one of two similar distractors. There were 144 trials (2 blocks of 72) in total, and 6 practice trials. The order of all trials was fully randomized. The participant's task was to press a left key or a right key when the target was presented on the left or right, respectively, as accurately and as fast as possible. Because stimuli remained on the screen until the subject's response, RTs longer than 3 SDs by condition were removed.

## 3 Results
Figure 2 illustrates the mean accuracy rates and correct RTs for each experimental condition, for novices and experts. As can be seen, accuracy was above 90% in all conditions, except for inverted faces, for which it dropped to 75% for both groups. The data were entered into an ANOVA with category (faces, cars) and orientation (upright, inverted) as within-subjects factors, and subject group as between-subjects factor.

For accuracy rates, there were significant main effects of category and orientation ($F_{1,38} = 78.6, p < 0.0001$; $F_{1,38} = 215.4, p < 0.0001$, respectively). This was qualified by a strongly significant interaction between two factors ($F_{1,38} = 73.3$, $p < 0.0001$): the effect

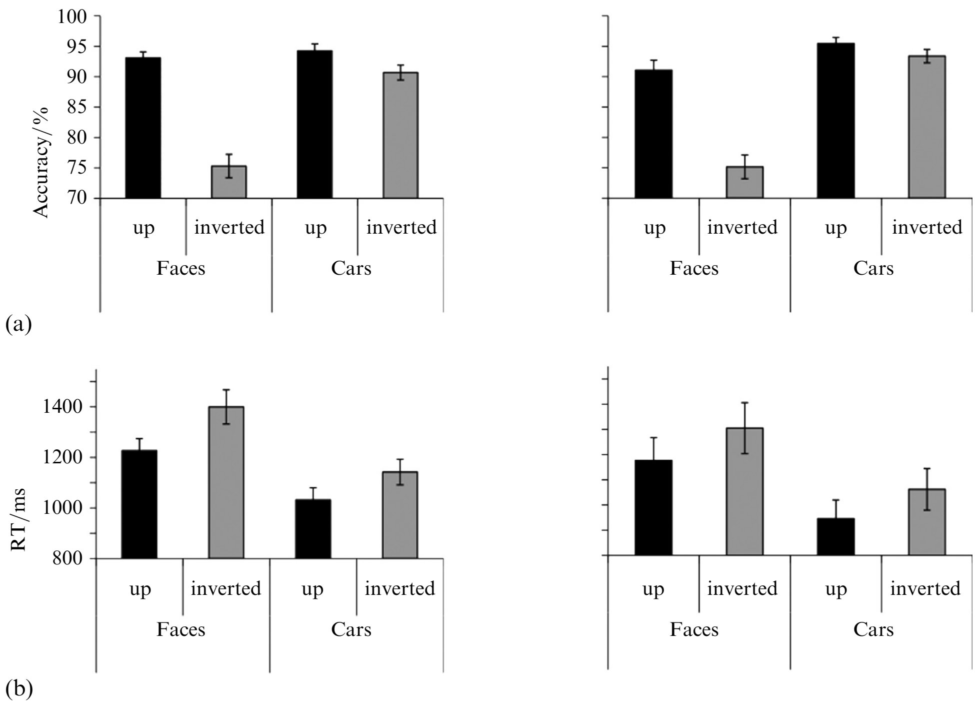


**Figure 2.** (a) Accuracy rates (± SE) in the two-alternative forced-choice task. (b) Correct RTs (± SE). Scores for car novices (left) and for car experts (right).

of orientation was significant for faces ($p < 0.0001$) and cars ($p < 0.005$), but was much larger for faces than for cars ($p < 0.0001$). Thus, inversion slightly affected car recognition, while accuracy dropped dramatically for faces presented upside-down. The three-way interaction of group, category, and orientation was not significant ($F_{1,38} = 0.01$, $p = 0.91$). An analysis based on a median-split of participants' matching tasks scores gave the same results (ie triple interaction: $F_{1,38} = 0.02$, $p = 0.91$).

For correct RTs, there were also significant main effects of category and orientation ($F_{1,38} = 152.9$, $p < 0.0001$; $F_{1,38} = 76.8$, $p < 0.0001$, respectively). Participants responded faster to upright pictures, and for cars in general (figure 2b). There was no main effect of group ($F_{1,38} = 0.99$, $p = 0.33$), and an interaction between category and orientation, which was close to significance ($F_{1,38} = 3.34$, $p = 0.08$; all other effects, $p > 0.23$). Even though the three-way interaction of group, category, and orientation was not significant ($F_{1,38} = 1.47$, $p = 0.23$), we examined the inversion effect for each group of subjects in separated $2 \times 2$ repeated-measures ANOVAs. For novices, there was a significant interaction between category and orientation, the inversion effect being larger for faces than for cars ($F_{1,19} = 4.21$, $p = 0.05$), while there was no such effect for experts (small non-significant difference in the other direction: $F_{1,19} = 0.268$, $p = 0.66$). This was best observed when considering the normalized inversion costs (RT difference between upright and inverted divided by the sum of RTs for upright and inverted conditions; figure 3).

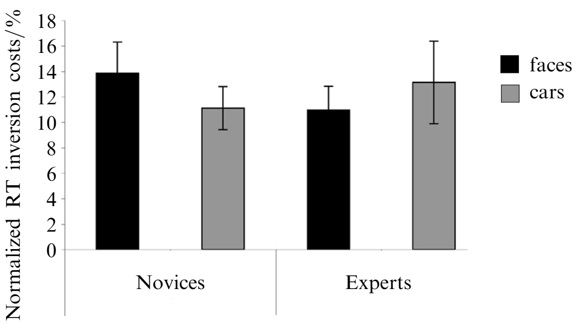


**Figure 3.** Normalized RT inversion costs (RT difference between upright and inverted divided by the sum of RTs for upright and inverted conditions).

Analyses based on the two groups of subjects separated by a median-split of accuracy in the expertise test gave the same results for both accuracy rates and response times, with the interaction between group, orientation, and category on correct RTs failing to be significant ($F_{1,38} = 1.66$, $p < 0.20$). Yet, in separated analyses of variance for each group of subjects, the RT inversion effect was larger for faces than for cars in the group of novices ($F_{1,19} = 4.40$, $p = 0.048$), while there was no such effect for experts (small non-significant difference in the other direction: $F_{1,19} = 0.114$, $p = 0.74$).

Most importantly, there was a significant correlation between the normalized RT inversion costs for car pictures and the degree of expertise measured independently with the matching task ($r = -0.33$, $p = 0.036$). Interestingly, this correlation appeared to be driven by the population of experts, because there was a smaller variance in the expertise index data of the self-reported novices (figure 4; SD of the expertise index for novices: 0.34; experts: 0.58; Levene's test for equality of variances: $F = 6.4$, $p = 0.016$). Separating self-reported experts and novices in the analysis revealed a highly significant correlation between level of expertise and RT costs of inversion in experts ($r = -0.53$, $p = 0.016$) but no effect at all in novices ($r = 0.05$, $p = 0.808$).

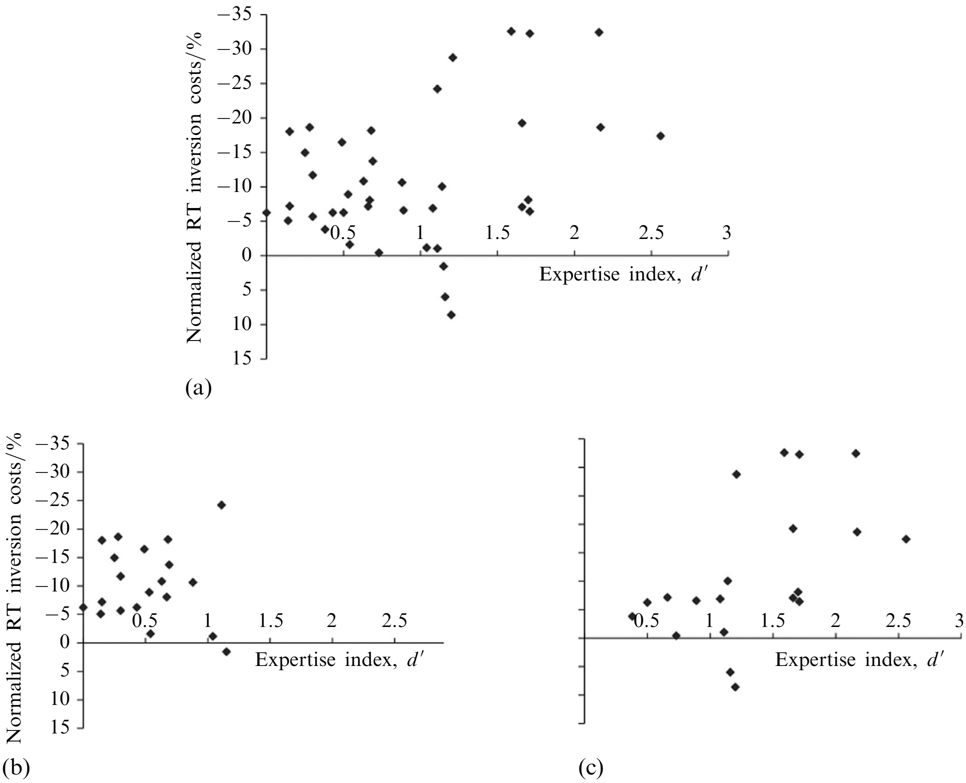


**Figure 4.** Correlations between the normalized RT inversion costs and the expertise index, $d'$, measured independently in the inversion experiment. (a) Correlation for the whole sample of subjects ($r = -0.33$, $p < 0.036$). (b) Correlation pattern for novices ($r = 0.05$, $p = 0.8$, ns). (c) Correlation pattern for experts ($r = -0.53$, $p < 0.016$). The scale is identical for the three samples to illustrate the lack of variance in the novices' data, contributing to an absence of correlation for these subjects.

## 4 Discussion

Using a delayed forced-choice matching task, we found much larger inversion costs for pictures of faces than for a highly familiar object category, cars. This effect replicates previous evidence obtained in old/new recognition tasks for pictures of faces contrasted with various mono-oriented object categories (Diamond and Carey 1986; Leder and Carbon 2006; Robbins and McKone 2007; Rossion et al 2002; Scapinello and Yarmey 1970; Valentine and Bruce 1986; Yin 1969). Importantly, inversion affected the recognition both of faces and of cars, but the effect on car pictures was particularly small in accuracy rates. The interaction between accuracy rates for faces and objects across inversion has been taken as evidence that 'faces are special' by some authors (Yin 1969), whereas others suggested that this effect rather reflects our largest amount of visual expertise with face stimuli compared to other objects (Diamond and Carey 1986). These positions are often confronted in the face literature in the context of the more general debate about the modularity of face-processing mechanisms (eg Ellis and Young 1989; Nachson 1995; Tarr and Gauthier 2000), to which we will briefly return at the end of the discussion section.

Evidence suggesting a direct relationship between non-face object expertise and inversion costs is mixed. Diamond and Carey (1986) showed an inversion cost in accuracy rates for dog experts, which was absent in novices. Furthermore, the effect of inversion was equally large for pictures of faces and dogs in dog experts. Robbins and

McKone (2007) recently failed to replicate these results. These authors speculated that Diamond and Carey (1986) found particularly large inversion costs for dog pictures because experts in that study were familiar with these particular pictures of dogs. Because familiarity with a particular set of images may increase inversion costs for these images (eg Husk et al 2007), this factor may have contributed to the large effect found by Diamond and Carey, even though this explanation remains speculative. Because Robbins and McKone did not replicate the findings of Diamond and Carey with familiar images, it is difficult to attribute the previously reported strong evidence by Diamond and Carey to such a 'familiarity' bias. Moreover, in other studies inversion costs were found with expertise either in RT or accuracy measures with unfamiliar exemplars of common objects (Husk et al 2007; Xu 2005) or novel object categories (Behrmann and Ewell 2003; Husk et al 2007; Rossion et al 2002), albeit not within the range of the large inversion effects (20% accuracy) found by Diamond and Carey for their dog experts. In our study, the effect of inversion on accuracy was also much larger for photographs of faces than photographs of cars, both in novices and in experts.

Nevertheless, it is interesting to note that we observed an effect of expertise on the inversion effect for the non-face object category tested: while the costs in RTs were larger for faces than cars in novices, they were equally large in experts. Thus, despite the absence of triple interaction between category, expertise, and inversion for correct RTs, this differential pattern should not be ignored and may suggest that visual expertise increases the inversion effect for non-face object categories, but to an extent that remains below the spectacular effect found for faces. Interestingly, we tested American car experts who were not exposed to the particular Japanese and European models of cars used in the study, so that the effect certainly cannot be attributed to a familiarity bias with a set of images, as mentioned above. It seems that the important factor here is the visual expertise with exemplars of a visual category, in this case cars, which can be applied to various members of the category.

Most significantly, for the first time to our knowledge, we observed a correlation between inversion costs, as measured in RTs, and the degree of visual expertise with a non-face object category as measured independently. To our knowledge, only in one study such correlations between expertise and inversion costs have been tested (Robbins and McKone 2007). Although Robbins and McKone did not find significant correlations between the size of the inversion effect and other measures of expertise in their study on dog experts (number of lifetime dogs seen, years of experience), their correlation was substantial ($r = 0.32$). In fact, it was of the same magnitude as in the present study ($r = 0.33$), but, with half the number of participants tested by them, it failed to reach significance ($p > 0.2$ in that study).

Importantly, we found a much larger ($r = 0.53$) and highly significant correlation when we considered the group of experts separately from the novices, the latter group showing lower variance in the expertise index. A closer look at our data shows that participants who were both self-proclaimed experts and whose performance at an independent car-matching task proved to be maximal were the ones who showed the largest inversion costs for cars, in correct RTs. However, a substantial number of self-reported experts did not show larger costs of inversion for cars than novices (figure 4). This pattern of observations suggests that a group comparison through an ANOVA or a $t$-test, as done in previous studies between experts and novices, may not be the most sensitive measure to disclose inversion effects related to expertise, because these statistics treat the variance within the group of experts as noise (Irwin and McClelland 2003)—whereas the significant correlation observed here demonstrates that this variance actually contributes to the correlation. This should encourage future studies in this area of research to correlate the level of expertise with other dependent variables, either behavioral or neural measures (eg Gauthier et al 1999, 2000) separately in experts and novices. It should also be noted that, as in previous studies (Gauthier et al 2003; Rossion et al 2007), the car experts recruited in the present study were college students who replied to flyers posted on campus and claimed to be experts with cars. This is likely to make our expert group highly variable. However, this method has yielded reliable expertise effects in these previous studies, in which the variance in the expertise indexes between self-reported experts and novices was identical (eg Rossion et al 2007—car experts; SD of the two groups of twenty participants was 0.59 for experts and 0.61 for novices).

Presumably, some participants' high level of expertise allowed them to use certain cues to discriminate pictures of cars, and these cues were particularly affected by inversion. What kind of cues used to recognize cars can be particularly affected by inversion? Studies of face processing show that inversion affects both the processing of local features (defined by shape as well as surface-reflectance properties) and the relative distances between features. The latter kind of cues is generally more affected than the former (eg Freire et al 2000; Goffaux and Rossion 2007; Leder and Bruce 2000; Leder and Carbon 2006; Le Grand et al 2001; Sergent 1984). According to a qualitative account of the face-inversion effect, this relatively larger disruption of the perception of relative distances between features is not the cause of the face-inversion effect, but rather a consequence (Rossion 2008). That is, inverted faces cannot be processed globally—or holistically (eg Tanaka and Farah 1993)—so that it is more difficult for a human observer to detect changes on a face stimulus that involve multiple elements or are located far away from fixation (Rossion 2008). If this view is correct, the best car experts in our sample, those who showed the largest inversion costs for pictures of cars, might have learned to process upright car pictures holistically, processing the multiple features of the stimulus as a single global representation. Evidence for increased holistic processing of cars has been reported in car experts (Gauthier et al 2003), supporting this hypothesis. Expertise in recognition of novel 3-D objects, 2-D patterns, or fingerprints has also been shown to rely on increased holistic processing (Behrmann and Ewell 2003; Busey and Vanderkolk 2005; Gauthier and Tarr 1997). However, visual expertise with non-face objects has not always been associated with increase in holistic/configural processing (eg McKone et al 2007; Tanaka and Gauthier 1997), indicating that local cues that can be processed independently from each other may also subtend the gain in visual expertise. Admittedly, inversion of the face stimulus may also affect the processing of isolated features (Rakover and Teucher 1997), albeit to a level that cannot predict the inversion costs for the whole face (Bartlett et al 2003). Thus, one cannot exclude that the increased inversion costs found in car experts here are related to their greater ability to extract local surface and shape details (eg the shape of the lights, texture of the grid ...) perceived independently of the whole stimulus.

In any case, there cannot be a general answer to a question such as whether visual expertise with non-face objects increases inversion costs: increased inversion costs with expertise are likely to be found insofar as the cues that are diagnostic to recognize members of the category of expertise are particularly affected by inversion. For instance, unlike car experts, bird or butterfly experts may rely largely on texture and color cues, which could be largely unaffected by inversion.

Finally, where should these data stand in the face literature in the context of the general debate about the modularity of face-processing mechanisms? On the one hand, it may be argued that, because faces always give rise to the largest inversion costs, this favors the domain-specific hypothesis (ie faces subtended by a modular system). On the other hand, one does not have to show that objects of expertise give rise to equally strong effects of inversion as faces, but simply that inversion costs may be related to some extent to one's level of expertise with the stimulus category. In this context, the significant correlation found here between car expertise and the inversion effect in speed of processing for pictures of cars is notable, especially since some authors have taken a rather strong position on this issue, dismissing any evidence indicating a relationship between inversion effects and visual object expertise (Robbins and McKone 2007). While our data by no means replicate the spectacular effects of inversion found by Diamond and Carey (1986) in dog experts, they point to a certain relationship between visual expertise and the magnitude of the inversion effect for non-face pictures, qualifying the claims of Robbins and McKone (2007). More generally, there is no doubt that, compared with other objects, faces are a 'special' kind of stimulus for us, if only because of the diversity of cues they convey and their importance for efficient social interactions. Moreover, our visual experience with faces is unique: it is quantitatively larger and qualitatively different from that for other objects, at least for most humans, even experts with car, dog, or bird categories, let alone Greebles experts trained for about 10 h. Our adult face-processing system is able to extract diagnostic cues from faces extremely efficiently (Bruce and Young 1998), following a combination of biological constraints and extensive visual experience during development. Some of the processes developed to extract diagnostic cues are dramatically affected by picture-plane inversion. Observing increased effects of inversion correlated with the amount of visual experience for non-face objects suggests that these processes—perhaps holistic in nature—are plastic enough to be recruited, at least partly, for certain non-face object categories following visual expertise.

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