The temporal advantage for individuating objects of expertise: Perceptual expertise is an early riser

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The identification of faces has a temporal advantage over that of other object categories. The orientation-specific nature of this advantage suggests that it stems from our extensive experience and resulting expertise with upright faces. While experts can identify objects faster than novices, it is unclear exactly how the temporal dynamics of identification are changed by expertise and whether the nature of this temporal advantage is similar for face and non-face objects of expertise. Here, we titrated encoding time using a backward-masking paradigm with variable stimulus-mask onset-asynchronies and mapped the resulting effect on recognition for upright and inverted faces (Experiment 1) and for cars among car experts and car novices (Experiment 2). Performance for upright faces and cars among car experts rose above chance between 33 and 70 ms before that for inverted faces or cars among car novices. A shifted exponential function fitted to these data suggested that performance started to rise earlier for experts than for novices, but that additional encoding time increased performance at a similar rate. Experience influences the availability of information early in processing, possibly through the recruitment of more category-selective neurons, while the rate of perceptual processing may be less flexible and limited by inherent physiological constraints.

Keywords: perceptual expertise, face processing, object processing, temporal dynamics

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Introduction

On an average day at work, shopping or strolling into town, we might recognize many familiar faces and encode those of many people we have never encountered before. The speed of individuation of familiar faces has been compared to that observed in other domains of expertise. For instance, a seasoned bird expert can identify a magnolia warbler as fast as they know it is a bird, while it takes the novice more time for such fine discrimination (Johnson & Mervis, 1997; Tanaka, 2001; Tanaka & Taylor, 1991). Likewise, most of us can identify a friend's face as fast as we recognize there is a face (Tanaka, 2001). There is evidence that this temporal advantage may arise during early perceptual processing stages (Tanaka, 2001). However, the temporal signatures of novice and expert perceptual encoding have yet to be characterized and compared. Thus, it is unclear whether the performance of experts and novices will differ from the very first glance or whether expert advantages only emerge after a minimum amount of perceptual processing necessary to categorize the object as belonging to an expert domain.

Despite evidence for faster subordinate-level recognition with training and the acquisition of expertise, evidence suggest that this may not be the case for all types of recognition judgments (e.g., Fabre-Thorpe, Delorme, Marlot, & Thorpe, 2001). Specifically, participants' response times and neurophysiological responses were generally unchanged after extensive training on a superordinate recognition task, detecting an animal in briefly flashed (20-ms) images (Fabre-Thorpe et al., 2001). One possibility is that it is only with more complex perceptual judgments, such as subordinate-level recognition, that the temporal benefits of experience can be observed. If the trained task only requires coarse-level perceptual information, there may be little benefit of experience. Thus, individuation or subordinate-level recognition training (e.g., identifying a dog as a Queensland Blue Heeler) may impact the temporal dynamics of perceptual processing, while training in basic- (e.g., detecting dogs) or superordinate-level recognition tasks (e.g., detecting animals) may not. Because objects within the same basic-level category share many visual features and a first-order arrangement of their parts, the neuronal populations that represent two objects within the same basic-level category are more likely to overlap than those of two objects differing at more abstract levels. Therefore, it is possible that, especially in the case of subordinate-level judgments (within a basic level), changes in the selectivity of visual neurons with expertise may reduce the overlap of neuronal populations representing the objects to be discriminated, thereby impacting the time-course of subordinate-level recognition.

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Consistent with this possibility, identification training has specific effects relative to other types of training that do not require identification, including faster categorization at the subordinate level for both trained and untrained exemplars (Scott, Tanaka, Sheinberg, & Curran, 2006; Tanaka, Curran, & Sheinberg, 2005) and more qualitative changes in processing that include increases in configural and holistic processing (Nishimura & Maurer, 2008; Wong, Palmeri, & Gauthier, in press). Thus, evidence supports the suggestion that the effect of experience on the time required to perceptually process an object may depend on the level of categorization at which objects are discriminated.

The reduction in the time to perform subordinate-level categorization decisions by experts is well documented (Gauthier & Tarr, 1997; Tanaka, 2001; Tanaka & Taylor, 1991) with evidence suggesting that this increase in speed arises, at least in part, due to changes in perceptual encoding time (instead of later decisional stages). The accuracy of subordinate-level categorizations of faces (e.g. recognizing that a face is "Bill Clinton") is not impacted by a reduction in encoding time (75 ms compared to 950 ms), while this same manipulation for dogs and cars (among novices with these categories) substantially impacts performance (Tanaka, 2001). Thus, it appears that sufficient perceptual information can be extracted during the first 75 ms of encoding to access identity-level representations for objects of expertise, but not for object categories for which an observer has less experience. These results have been interpreted as reflecting the development of specialized "perceptual routines" by visual experts that permit the rapid analysis of objects from the domain of expertise (Tanaka, 2001). At the same time, some have suggested that at least for one expert domain, that of face processing, there exist qualitatively distinct stages of processing: A first stage that categorizes a stimulus as a face followed by a later stage for identification (e.g., Anaki, Zio-Golumbic, & Bentin, 2007; Liu & Kanwisher, 2002). Characterizing how early expert advantages arise can help constrain how much time is available, if any, for a first stage of information processing that precedes expert processing.

Equally fast subordinate- and basic-level categorization performance has been used as a hallmark of visual expertise (Gauthier & Tarr, 1997; Tanaka, 2001; Tanaka & Taylor, 1991). Indeed, it has been used in expertise training paradigms as a criterion for successful training (Gauthier & Tarr, 1997, 2002; Gauthier, Tarr, Anderson, Skudlarski, & Gore, 1999). Notably, lab-trained experts who have achieved this benchmark of visual expertise show many other general characteristics associated with real-world expertise, including greater configural and holistic processing and the recruitment of face-selective areas of the brain for objects of expertise (Gauthier, Curran, Curby, & Collins, 2003; Gauthier, Skudlarski, Gore, & Anderson, 2000; Gauthier & Tarr, 2002; Gauthier et al., 1999; Wong et al., in press; but see McKone, Kanwisher, & Duchaine, 2007).

Neurophysiological recordings comparing expert and novice perception provide a relatively less consistent picture of the relevant temporal dynamics. The greater peak *amplitude* of the N170 potential evoked by faces compared to that evoked by non-face objects suggests that there may be important differences in relatively early perceptual processing stages between face and object processing (Bentin, Allison, Puce, Perez, & McCarthy, 1996). Itier and Taylor (2004) also reported a difference in the *timing* of the peaks of the N170 potentials in response to face and various non-face object categories. However, the size of the delay in Itier and Taylor's study varied across object categories. Similarly, Rossion et al. (2000) reported that the N170 peaks later for some, but not all, object categories relative to that for faces. Thus, as with most comparisons between different categories of stimuli, image differences such as contrast, complexity, and spatial frequency content could be contributing to the difference in latency of the N170 evoked by face and non-face objects.[1]

Fortunately, contrasts between upright and inverted faces provide a useful means of comparing expert and novice-like processing while controlling for low-level stimulus differences that can complicate the interpretation of findings.[2] Consistent with an effect of experience on perceptual processing, the peak of the N170 potential in response to inverted faces is delayed (~10 ms) compared to that for upright faces (Bentin et al., 1996; Rossion et al., 1999, 2000). In addition, Jacques, d'Arripe, and Rossion (2007) were able to demonstrate using an adaptation paradigm that the N170 evoked in response to same (repeated) and different faces could be distinguished approximately 30 ms earlier for upright than for inverted faces. An inversion effect in the latency of the N170 is also observed for objects but only among expert observers (Busey & Vanderkolk, 2005; Rossion, Gauthier, Goffaux, Tarr, & Crommelinck, 2002). Findings that inversion does not influence the latency of the N170 in novices is consistent with an expertise account of this component, rather than a general cost due to processing images in non-canonical orientations (Rossion et al., 2000).[3]

In sum, there is evidence that visual expertise speeds up the perceptual encoding of objects. However, it is unclear at what point in perceptual processing this advantage emerges. Does the shortest presentation time from which observers can extract sufficient information to perform above chance differ between experts and novices? Does expertise lead to an earlier onset of the evidence used for identification or does it reflect faster accumulation of information during perceptual encoding?

To provide insight into the impact of expertise on the temporal dynamics of object processing, we conducted three experiments in which we varied the time allowed to encode a study item in a sequential matching task. This methodology, unlike continuously measured ERPs, provides discrete snap shots of performance after perceptual processing is interrupted. Because we measure identification performance, which is constrained by all the processes that follow perceptual encoding, this methodology does not provide direct insight into perceptual encoding mechanisms as they unfold over time. However, by contrasting performance across novices and experts (or upright and inverted faces) we are able to infer how the advantage afforded by expertise varies as a function of presentation time. For instance, by systematically manipulating presentation time (without limiting subsequent processes) we can determine the shortest presentation time from which observers can extract sufficient information to perform above chance. Using this technique we mapped changes in upright and inverted face individuation performance (Experiment 1), car individuation performance among expert and novice participants (Experiment 2), and performance for upright and inverted cars among car novices (Experiment 3), as a function of encoding time. For the purpose of our experiments, the "onset time" of recognition was defined as the encoding time required before individuation performance exceeds chance-level. Thus, this point reflects the minimum time to detect successful encoding of an object at a resolution sufficient for above-chance individuation. This was estimated in two ways: through direct comparisons of behavioral performance measures with that of chance performance and estimations based on maximizing the fit of the observed data to that predicted by different onset times. Fitting these functions to the data also provided an estimate of the rate at which performance approached an asymptotic level.

Experiment 1

Experiment 1 aimed to measure the impact of encoding limitations on individuation performance for upright and inverted faces to provide insight into the source of the temporal advantage for upright compared to inverted face recognition. A fine-grained temporal sampling of performance was achieved by manipulating encoding duration with eight different stimulus-mask onset asynchronies in a sequential matching task using backward masking of the first stimulus. In manipulating stimulus presentation time, our aim was to selectively influence perceptual encoding (rather than later, decisional or response preparation stages). This assumption of the additive-factor method was recently supported by Woodman, Kang, Thompson, and Schall (2008). Previous work has also established the independence of object perception and recognition processes (Kent & Lamberts, 2006). In Experiment 1, we compare the performance level for upright and inverted faces at these eight different temporal encoding conditions and fit a curve to estimate the onset of performance and the rate of increase in performance with additional encoding time. This allows us to assess whether the temporal advantage for upright face recognition stems from an earlier onset of performance and/or from a faster rate of performance increase.

Methods

Participants

Participants were 34 individuals (age, $M = 18.94$, $SD = 3.25$, 25 females) with normal or corrected to normal vision. All participants provided informed consent and participated in return for course credit or cash payment.

Stimuli

Stimuli were 320 gray-scale, front-view images of faces. Images were obtained from the Max-Planck Institute for Biological Cybernetics in Tuebingen, Germany (Troje & Bülthoff, 1996), the Harvard Face database (Tong & Nakayama, 1999), and the Stirling and Nottingham scans face databases (http://pics.psych.stir.ac.uk/). There were 240 different facial identities, with the additional images including a modified copy of 80 of the faces. The adjusted faces were cropped differently around the outer edge (e.g., including more of less of the forehead and other peripheral regions of the face) and the overall luminance was adjusted in Photoshop. Images subtended 3.5 × 4.7 degrees.

Procedure

Seventeen participants were randomly assigned to either the upright (age, $M = 19.29$, $SD = 1.83$, 11 female) or inverted (age, $M = 18.59$, $SD = 0.94$, 14 female) conditions. Participants' heads were stabilized at a fixed distance (70-cm) from the screen using a standard chin-rest. The task consisted of a sequential matching task in

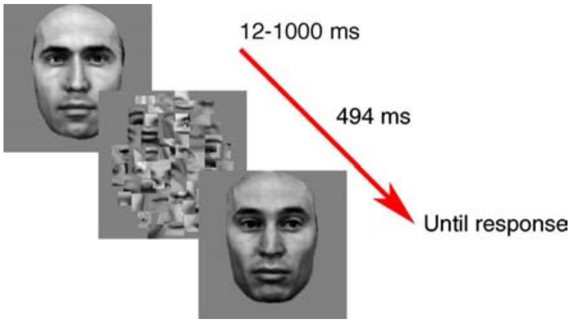

Figure 1. The sequence of events that occurred in each trial in Experiment 1. Participants were first presented with an upright or inverted face image that was masked after a 12-, 47-, 82-, 118-, 153-, 235-, 494-, or 1000-ms. The masked remained on the screen for 494-ms after which a second face image appeared and remained until participants made a key press indicating whether the two faces had the same or different identities.

which the first image was backward masked (Figure 1). Participants pressed a key to initiate each trial, which proceeded as follows: a face image appeared for either 12-, 47-, 82-, 118-, 153-, 235-, 494-, or 1000-ms followed by a mask for 494 ms. Finally, a second image of a face appeared and remained on the screen until the participant made a key-press indicating if this face had the same or different identity as the first (masked) face. The stimulus presentation durations were selected so as to be multiples of the refresh rate of the monitor (85 Hz). In addition, the stimulus presentation program synched the presentation of the stimuli with the monitor refreshes (Matlab, Mathworks Inc.). Timing markers embedded in the program also ensured that the stimulus presentation times were reliable. All images were presented centrally with a small random jitter of 0, ±5, or ±10 pixels vertically or horizontally. Participants performed 160 trials, which consisted of 20 trials of each of the eight presentations duration conditions.

The faces in "same" trials were always different in some superficial way, such as the manner in which the outer edge of the face was cropped, the lighting in the image, or the general luminance, to discourage image-based matching. Participants were instructed to base their decision solely on identity. In addition, face pairs that were subjectively highly similar were selected for the "different" trials, to further discourage participants from adopting a strategy based on salient low-level features.

Analysis

Trials with a response time <200 ms or >4000 ms were discarded (2.6%). For each participant, sensitivity (d') and response time (for correct responses) were calculated for each encoding duration condition for the upright and inverted orientations. An omnibus ANOVA was performed on both the reaction time and sensitivity data. In addition, planned *t*-tests were performed to identify time points in which sensitivity differed from chance (i.e. chance $d' = 0$) for upright and inverted faces (providing an estimate of the onset of performance) and to compare sensitivity for upright and inverted faces. The Kolmogorov-Smirnov test of normality (with Lilliefors significance correction) was applied to ensure that the assumption of normality held for these data (all *p*s > .05).

Results

Sensitivity analysis

A 2 (orientation; upright, inverted) × 8 (encoding duration; 12 ms, 48 ms, 83 ms, 118 ms, 153 ms, 236 ms, 495 ms, 1000 ms) ANOVA performed on the sensitivity measures (d') found main effects of presentation time, $F(7, 224) = 30.85$, $p \leq .0001$, and orientation, $F(1, 32) = 30.09$, $p \leq .0001$. Sensitivity was greater for longer encoding durations and for upright compared to inverted faces. There was an interaction between orientation and encoding duration, $F(7, 224) = 3.25$, $p = .0027$, with the benefit of longer encoding durations being greater for upright than inverted faces. Increased encoding duration led to a rapid increase in performance, although the rate of increase started to slow with approximately 153 ms encoding duration as performance neared the asymptote (Figure 2A).

Planned *t*-tests revealed that sensitivity for upright and inverted discrimination could be distinguished by the 83 ms encoding duration condition (12 ms; $t < 1$; 48 ms; $t(32) = 1.35$, $p = 0.185$; 83 ms; $t(32) = 2.69$, $p = 0.011$; for all other conditions ps < .005). Although sensitivity differed

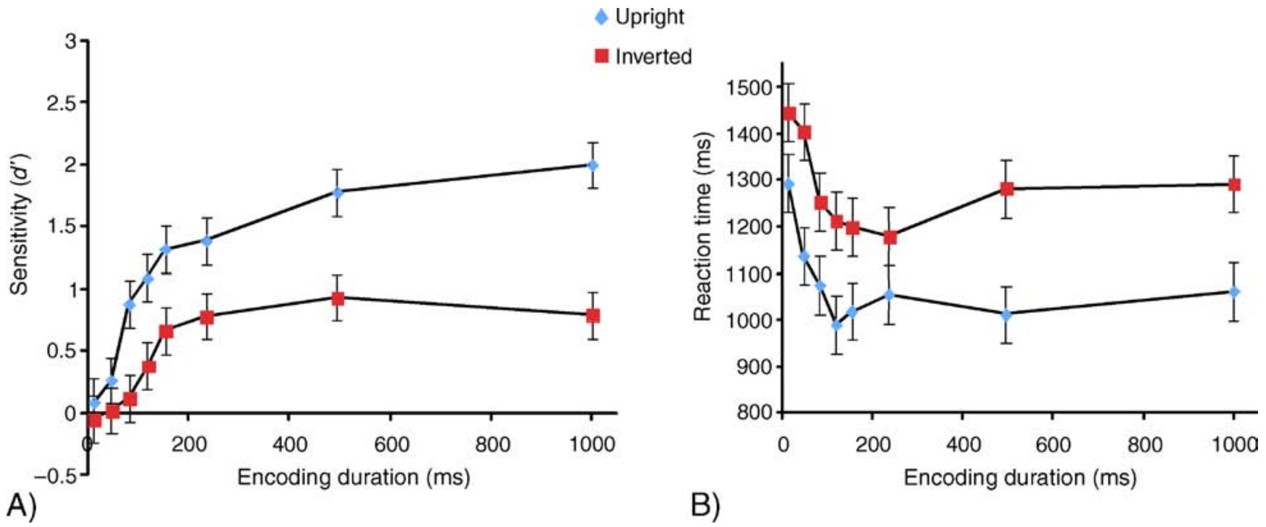

Figure 2. (A) Sensitivity (d') and (B) response time as a function of encoding duration in the backward masked sequential (identity) matching task with upright and inverted faces in Experiment 1. Error bars represent standard error of the mean.

from chance with as little as 48 ms encoding duration for upright faces (12 ms; $t < 1$; 48 ms; $t(16) = 2.38$, $p = 0.03$; for all other conditions $ps \leq .0005$), 118 ms encoding duration was required for above-chance sensitivity with inverted faces (12 ms, 48 ms, and 83 ms; $t < 1$; 118 ms; $t(16) = 2.8$, $p = 0.013$; for all other conditions $ps \leq .0006$).

An exponential function was fit to the data to estimate and compare performance parameters, namely the onset, rate of increase, and asymptotic level, for the individuation of upright and inverted faces (see Supplementary material; Lu & Dosher, 1998; Reed, 1976; Wickelgren & Corbett, 1977). The onset parameter refers to the intercept value of the exponential curve, which serves to estimate the encoding time required for performance to begin to rise above zero (chance-level). The rate of performance increase parameter refers to the rate at which performance approaches an asymptotic level and it can be thought of as estimating the rate at which task-relevant information is extracted. The asymptote parameter provides an estimate of the maximum performance level given ample encoding time. The best-fitting model ($r^2 = .9772$) not only confirmed the considerable difference in the asymptote level of performance between the two groups (.92 d' difference; upright asymptote, 1.83 d'; inverted asymptote, .91 d'), but it also suggests that the onset of recognition performance for upright faces occurs approximately 33 ms before that for inverted faces (upright onset, 27 ms; inverted onset, 60 ms). However, there was no evidence for a difference in the rate of perceptual encoding between upright and inverted faces.

Response time analysis

A 2 (orientation; upright, inverted) × 8 (encoding duration; 12 ms, 48 ms, 83 ms, 118 ms, 153 ms, 236 ms, 495 ms, 1000 ms) ANOVA performed on response times found main effects of encoding duration, $F(7, 224) = 9.03$, $p \leq .0001$, and orientation, $F(1, 32) = 4.75$, $p = .0369$. Response times were faster for longer encoding duration conditions and for judgments about upright compared to inverted faces. There was no interaction between orientation and encoding duration ($F < 1$). Increased encoding duration led to a relatively uniform reduction in reaction times until the 153 ms encoding duration condition, after which mean reaction times started to plateau for both upright and inverted faces (Figure 2B).

Discussion

The results of Experiment 1 suggest that individuation for upright and inverted faces not only differs in the maximum performance that can be attained under sequential matching conditions, but that the onset of the information available for identification of inverted faces was delayed relative to that for upright faces. This was supported by direct analyses on the behavioral data as well as a comparison of models applied to these data.

There are a number of possible explanations for the initial delay in the onset of performance for inverted, relative to upright, faces. One possibility is that this delay reflects the need to perform an additional process on inverted stimuli before they can be processed for recognition. For example, observers could apply some transformation, such as mentally rotating the inverted faces (but see Perrett, Oram, & Ashbridge, 1998). Thus, this delay could reflect an additional stage performed more generally when encoding inverted items. Alternatively, the earlier onset may reflect an advantage in processing afforded by experience with upright faces. Experience could increase the number of neurons responding to objects from a given category, which would provide more information for identification (Ashbridge, Perrett, Oram, & Jellema, 2000; Hung, Kreiman, Poggio, & DiCarlo, 2005). In Experiment 2, we explore these possibilities by manipulating expertise directly, removing the orientation confound.

Experiment 2

Although face inversion reduces many of the hallmarks associated with face processing (Curby & Gauthier, 2007; Curby et al., 2009; Tanaka & Farah, 1993; Tanaka & Sengco, 1997; Young, Hellawell, & Hay, 1987), there is also evidence that the processing of inverted faces may not be exactly equivalent to the processing of non-face objects in novice categories (e.g., Murray, 2004). Therefore, we sought to provide converging evidence for an early expertise advantage using a direct comparison of expert and novice performance with identical stimuli in the same orientation. We thus compared car identification among car experts and car novices. If the early advantage for upright, relative to inverted, face recognition reflects an acquired advantage due to our extensive experience with faces, car experts should show a similar “head start” for the recognition of cars, relative to car novices. Experiment 2 tests this prediction.

Methods

Participants

Thirty-eight (29 male) individuals with normal or corrected to normal vision who reported either extensive or minimal experience identifying cars were recruited. A self-report measure of participants’ car and bird expertise was obtained in the form of a rating on a scale of one to ten. Participants were informed that “five” corresponded to average skill at identifying cars or birds whereas “ten” reflected perfect skill recognizing these categories. An objective measure of car expertise was also obtained using a sequential matching task like that used in previous studies (Curby et al., 2009; Gauthier, Curby, Skudlarski, & Epstein, 2005; Gauthier et al., 2003, 2000). In this task, participants made same/different judgments about images of cars at the level of model, regardless of year. This task can be performed at least to some minimal degree by all participants, regardless of their level of experience with cars, as it does not require knowledge of car names. To provide a baseline of their perceptual skills, participants also performed the same task with birds, making same/different decisions at the level of species for images of passerine birds. A car expertise index was defined as (car d'-bird d'). Participants with a car expertise index ≥ 1 and a d' for cars ≥ 2 were classified as experts (Gauthier et al., 2000). Nineteen participants (15 males) met the criteria for car expertise (age, $M = 24.37$, $SD = 5.02$, car d' $M = 2.78$, bird d' $M = 0.94$), while 19 (14 males) were classified as car novices (age, $M = 23.42$, $SD = 3.55$, car d' $M = 0.99$, bird d' $M = .90$).[4]

Stimuli

Stimuli were 320 gray-scale profile images of recent cars available in the United States. There were 240 different car models, with the additional images including a modified copy of 80 of the car models. Similar to the duplicate face images used in Experiment 1, the overall luminance and/or shade of gray of the car panels and/or the tinting of the windows were adjusted. All the wheel-covers on the cars were replaced with one of six different kinds in such a way that cars appearing within a given trial always had the same wheel covers. Images subtended 2.9 × 6.7 degrees of visual angle at the fixed viewing distance of 70-cm.

Procedure

The procedure was similar to that used in Experiment 1, except that images of cars, instead of faces, were used as stimuli, and all participants viewed the cars in an upright orientation. As in Experiment 1, the images in the "different" trials were paired together in such a way as to maximize their similarity. In addition, the cars in "same" trials were always different in some superficial ways, such as the tinting on the windows, the lighting in the images, and/or the color (shade of gray once the images were converted to grayscale) of the car (Figure 3). Participants were instructed to ignore such superficial differences and to base their decision solely on the model of the car.

Analysis

Analysis was the same as in Experiment 1. Data from one participant in the novice group, whose average performance did not exceed chance (50%), were excluded from further analyses. In addition, response times were found to differ between the expert and novice groups, with experts responding more slowly than novices. This introduced a potential speed-accuracy tradeoff (not present in Experiment 1). The five novices with the fastest average response times were excluded from the analysis and as a result there was no longer a significant difference in the response times between the two groups. This also resulted in an equal number of participants in the novice and expert groups (as described earlier). The Kolmogorov-Smirnov test of normality (with Lilliefors significance correction) was applied to the data to ensure that the assumption of normality held for these d' data. All conditions, except the 1000 ms condition among experts, were non-significant (all other $ps > .05$). Upon inspection of the data this appeared to result from a ceiling effect in this one condition.

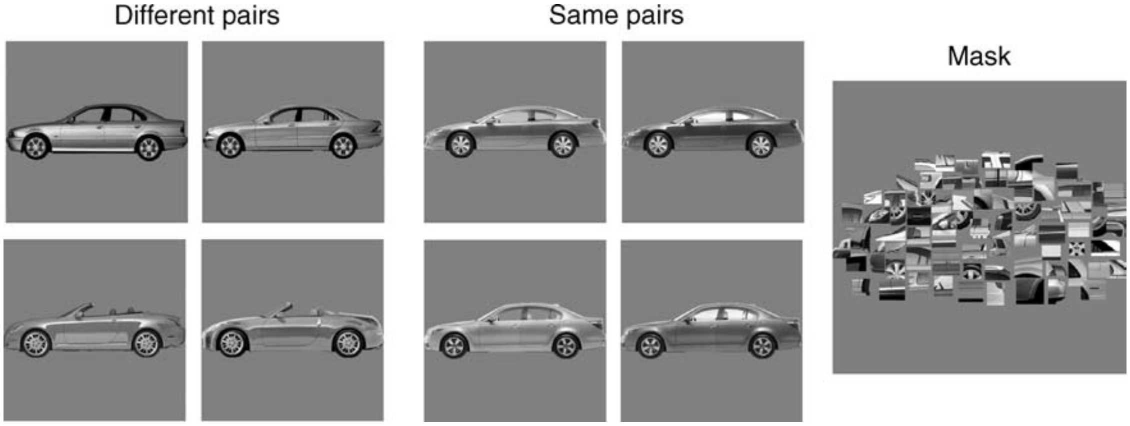

Figure 3. Examples of pairs of stimuli that appeared in Experiments 2 and 3 for which the correct response was "different" (left) and "same" (middle). The tinting of the windows and the overall luminance was changed for stimuli appearing in the "same" trials. A mask (right), presented after the first image in a pair, was used to interrupt perceptual processing at specific points in time.

This condition is not critical to our conclusions and as such, no further action was taken to address this problem.

Results

Sensitivity analysis

A 2 (group; expert, novice) × 8 (encoding duration; 12 ms, 48 ms, 83 ms, 118 ms, 153 ms, 236 ms, 495 ms, 1000 ms) ANOVA performed on the sensitivity measures (d') found main effects of encoding duration, $F(7, 252) = 49.13$, $p \leq .0001$, and expertise group, $F(1, 36) = 58.43$, $p \leq .0001$. Sensitivity was greater among car experts than car novices and was also greater for longer encoding durations. There was also an interaction between expertise group and encoding duration, $F(7, 252) = 3.71$, $p = .0008$, with the benefit of longer encoding durations being greater for car experts than car novices. Increased encoding led to a rapid increase in performance, although the rate of increase started to slow with approximately 153 ms encoding time as performance approached the asymptote (Figure 4A).

Planned t-tests revealed that sensitivity among car experts and car novices could be distinguished at 48 ms and greater encoding durations (12 ms; $t < 1$; 48 ms; $t(36) = 2.09$, $p = .044$; for all other conditions $ps < .004$). In addition, sensitivity differed from chance with as little as 48 ms encoding time among car experts (12 ms; $t < 1$; 48 ms; $t(18) = 3.06$, $p = .0068$; for all other conditions $ps \leq .0001$), while 118 ms was required for car novices' sensitivity to increase above chance (12 ms, 48 ms, 83 ms; $t < 1$; 118 ms; $t(18) = 3.41$, $p = .0032$; for all other conditions $ps < .004$).

As for Experiment 1, an exponential function was fit to the data to estimate and compare performance parameters, namely the onset, rate of increase, and asymptotic level, for the individuation of cars by the car expert and car novice groups (See Supplementary material). The best-fitting model ($r^2 = .9912$) not only confirmed the considerable difference in the asymptote level of performance between the two groups (1.18 d' difference; expert asymptote; 2.46 d'; novice asymptote; 1.28 d'), but it also suggested that the onset of recognition performance among car experts occurs approximately 43 ms before that among car novices (expert onset; 12 ms; novice onset; 55 ms). In addition, the best-fitting model suggests that the rate of performance increase among car experts and car novices does not differ.

Response time analysis

A 2 (group; expert, novice) × 8 (encoding duration; 12 ms, 48 ms, 83 ms, 118 ms, 153 ms, 236 ms, 495 ms, 1000 ms) ANOVA performed on the response time data found a main effect of encoding duration, $F(7,252) = 12.58$, $p \leq .0001$, but no main effect of expertise, $F < 1$. There was also no interaction between expertise and encoding duration, $F(7,252) = 1.48$, $p = .174$. Therefore, although response times were faster with longer encoding durations, they did not differ across the expert and novice groups, reflecting our matching of response times across groups. Increased encoding led to a reduction in reaction time until the 153 ms encoding duration condition after which the mean reaction times appeared to reach a plateau for both experts and novices (Figure 4B).

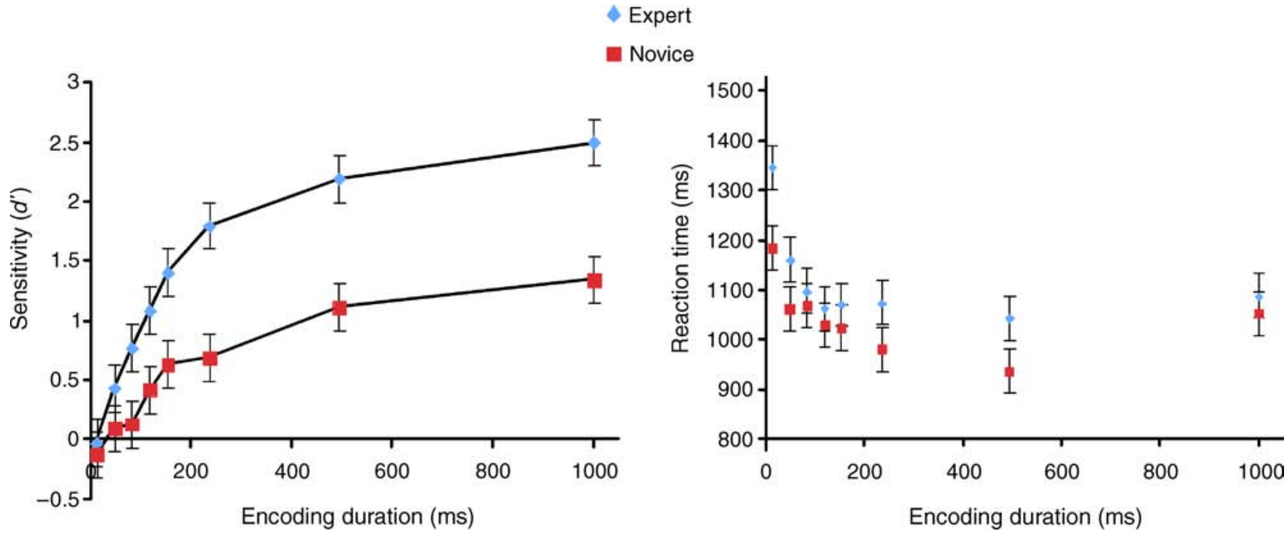

Figure 4. (A) Sensitivity (d') and (B) reaction time as a function of encoding time in the backward masked sequential matching task with cars among groups of car experts and car novices in Experiment 2. Error bars represent standard error of the mean.

Discussion

The similarity between the effect of inversion on face individuation and the effect of expertise on car individuation when encoding time is limited is consistent with a general effect of experience on the temporal dynamics of encoding for both categories. Specifically, both behavioral performance and the model fitting this performance reveal that experience provides perceptual encoding processes with a "head-start," as suggested by the 33–70 ms earlier onset for upright compared to inverted face recognition and for expert compared to novice car recognition. These results suggest that the temporal advantage for visual experts, relative to novices, previously demonstrated in subordinate-level recognition tasks (Tanaka, 2001; Tanaka & Taylor, 1991) results from an accumulation of evidence that begins earlier for experts but proceeds at the same rate regardless of expertise.[5] While the similar "head start" observed for car experts compared to car novices as seen for upright compared to inverted faces suggests that experience can produce this effect, it does not rule out the possibility that a more general effect of orientation may also contribute to the face effect. Experiment 3 explores this possibility.

Experiment 3

It is possible that the earlier onset of performance observed in Experiment 1, comparing upright and inverted faces, may be a combination of both an effect of our expertise with faces (as suggested by the results of Experiment 2 testing car experts) and a general effect of inversion (i.e., processing objects in their non-canonical orientations). To address this possibility, in Experiment 3 we examine the effect of encoding limitations on individuation of upright (from Experiment 2) and inverted cars by car novices. If car inversion also produces a delayed onset of perceptual encoding in car novices, we should see a difference in the onset of performance between car novices individuating upright cars and car novices performing the same task with inverted car stimuli. This prediction is tested in Experiment 3.

Methods

Participants

Twenty-seven (25 male, age $M = 21.9$, $SD = 5.18$) individuals with normal or corrected to normal vision were recruited. As in Experiment 2, a self-report and perceptual measure of participants' expertise with cars was obtained to ensure that none of the participants met the criteria for car expertise (self-report rating, $M = 5.5/10$; mean car d' $M = 0.96$, bird d' $M = .92$ on the car perceptual expertise test).

Stimuli, procedure, and analysis

The stimuli and procedure were the same as those used in Experiment 2, except that the cars were presented in an inverted orientation and the presentation durations differed slightly (10-, 50-, 81-, 121-, 151-, 232-, 495-, and 1000 ms) due to a change in monitor (and thus refresh rate). Presentation duration varied by no more than 3-ms from those used in Experiments 1 and 2. The analyses were the same as those used in Experiment 2.

Results

Sensitivity analysis

A 2 (orientation) × 8 (encoding duration) ANOVA performed on the sensitivity measures (d') found main effects of encoding duration, $F(7, 308) = 20.389$, $p \leq .0001$, and orientation, $F(1, 44) = 10.31$, $p = .003$. Sensitivity was greater for upright compared to inverted cars and was also greater for longer encoding durations. There was also an interaction between orientation and encoding duration, $F(7, 308) = 2.64$, $p = .012$ with the benefit of longer encoding durations being greater for upright compared to inverted cars (Figure 5A).

Planned t-tests revealed that sensitivity for upright and inverted car individuation could only be distinguished at 151-ms and greater encoding durations (10-, 50-, 81-, 121-, all $ps > .150$; for all other conditions $ps < .021$). In addition, as for the upright car condition, 121-ms was required for car novices' sensitivity to increase above chance with inverted cars (10-, 50-, 81-ms; $t < 1$; 121-ms; $t(26) = 2.347$, $p = .013$). Performance was marginally significant from chance for the 151-ms condition, $t(26) = 1.487$, $p = .075$ (all other conditions $ps < .004$).

An exponential function was fit to the data to estimate and compare performance parameters, namely the onset, rate of increase, and asymptotic level, for the individuation of upright and inverted cars by car novices (see Supplementary material). The best-fitting model ($r^2 = .9347$) not only confirmed the difference in the asymptote level of performance between the two conditions (.58 d' difference; upright asymptote; 1.27 d'; inverted asymptote; .69 d'), but it also suggested that the onset of recognition performance for upright and inverted cars is indistinguishable (57-ms). In addition, this model also suggested that the rate of performance increase did not differ for upright and inverted cars.

Response time analysis

A 2 (orientation) × 8 (encoding duration) ANOVA performed on the response time data found a main effect of encoding duration, $F(7, 308) = 7.76$, $p \leq .0001$, but no main effect of orientation, $F < 1$. There was also no interaction between orientation and encoding duration,

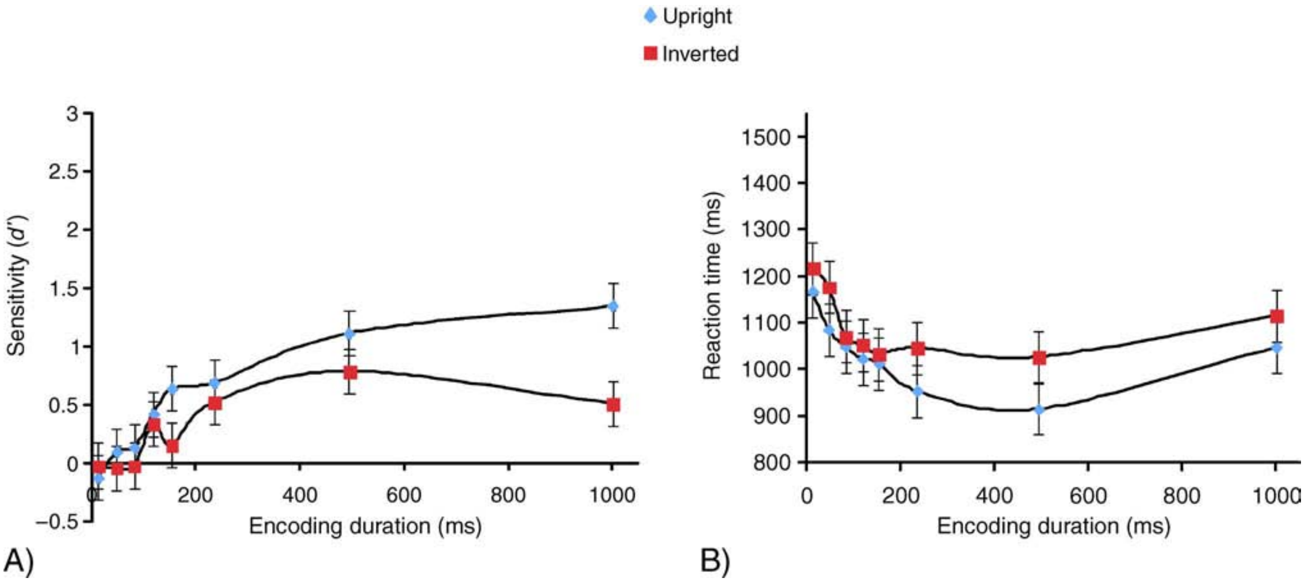

Figure 5. (A) Sensitivity (*d*′) and (B) response time as a function of encoding duration in the backward masked sequential (identity) matching task with upright and inverted cars in Experiment 3. Error bars represent standard error of the mean.

$F < 1$. Therefore, although response times were faster with longer encoding durations, they did not differ across upright and inverted conditions. (Figure 5B).

Discussion

The results of Experiment 3 suggest that, unlike expert perception, the effective onset of perceptual encoding in novice perception is not affected by orientation. This result is even more striking given that this is the case despite the fact that novice perception is ultimately limited by inversion, since performance with inverted cars never reaches that for upright cars. Therefore, a non-trivial effect of familiarity with a canonical orientation for an object category is not sufficient to provide an advantage at very brief presentation times. This is consistent with other results suggesting that familiarity and expertise are not synonymous (Tanaka et al., 2005; Wong et al., in press). In addition, the finding of a general, but smaller, cost of inversion for objects of non-expertise is consistent with reports of a disproportionately larger cost of inversion for faces compared to other (non-expert) object categories (Yin, 1969).

General discussion

Our results suggest that visual expertise alters the very first stages of object perception. The magnitude of the advantage revealed in Experiments 1 and 2 for face and expert non-face object recognition is generally consistent with findings from previous behavioral and electrophysiological studies (Caldara et al., 2003; Itier & Taylor, 2004; Rossion et al., 2000; Tanaka & Taylor, 1991). Our results extend previous work by providing a more thorough mapping of how the advantages afforded by expertise depend on encoding duration. In addition, our findings suggest that the temporal advantage demonstrated previously results from the earlier onset of perceptual encoding among experts, relative to novices, rather than from a difference in the processing rate between the groups. Our findings suggest that the rate of *perceptual* encoding is not affected by expertise. Possibly, it may be limited by hard-wired physiological constraints within the visual system, although we should be careful concluding this on the basis of a failure to find an effect of expertise on this particular parameter. For instance, other work in which the time to make a decision, rather than encoding time, is manipulated, suggests that expertise can influence the rate of later, post-encoding, aspects of expert categorization (Mack, Wong, Gauthier, Tanaka, & Palmeri, 2007).

An additional potentially interesting implication of our findings relates to Rolls and colleagues' studies exploring the neurophysiological basis of backward masking (Rolls & Tovée, 1994; Rolls, Tovee, & Panzeri, 1999). Their findings not only support the assumption that backward masking disrupts early perceptual processing and provide insight into the mechanisms underlying this disruption, but of particular relevance for the findings reported here is their use of face stimuli (Rolls & Tovée, 1994; Rolls et al., 1999). Their results suggest that face-selective neurons in inferior temporal cortex can perform the necessary computations to identify a face in 20–30-ms. The findings reported here of an earlier onset of performance for faces and other objects of expertise, relative to that for objects of non-expertise, raise that possibility that this timeframe may differ depending on one's level of perceptual expertise with a given stimulus category.

An additional noteworthy implication of our results is that the rate of approach to asymptote and the onset of performance appear unaffected by the cost incurred when processing objects in unfamiliar orientations (Yin, 1969). That is, the effect of inversion on the time course of face processing is closely mimicked by the effect of expertise on the time course of object processing, suggesting little, if any, contribution of inversion *per se* in changing the temporal dynamics of perceptual encoding. The fact that inversion only limits asymptotic performance in novice car perception is also consistent with the failure of orientation to impact the onset of effective encoding and the rate of accumulation of perceptual information.

While our results suggest that the advantage in expert identification judgments lies at least in part in an earlier onset of perceptual encoding, the mechanism underlying this advantage cannot be determined based on behavior alone. That is, because our inferences are based on the behavioral responses of observers, rather than the activity at a given neural stage of processing (e.g., Hung et al., 2005; Woodman et al., 2008), we cannot distinguish between models that vary in their specific neurophysiological sub-stages. For instance, it is possible, although unlikely, that onset of activity differs between novices and experts as early as V1. Alternatively, our effects could depend on the responses of object-selective inferotemporal neurons. These neurons may become more numerous, and/or more selective, with expertise (Ashbridge et al., 2000; Booth & Rolls, 1998; Kobatake, Wang, & Tanaka, 1998; Logothetis, Pauls, & Poggio, 1995; Sheinberg & Logothetis, 2001) and lead to earlier responses in decisional units they feed into, or they may start to respond with different onsets as they themselves accumulate more information in categories of expertise from feature-selective neurons in earlier areas. Thus, the specific locus of change with expertise is a question for neurophysiological studies. However, fMRI experiments suggest that face-selective regions of the ventral temporal lobe (FFA in humans) would be a good candidate area to consider, because this area shows both an inversion effect for faces (Gauthier et al., 1999; Yovel & Kanwisher, 2005) and an expertise effect (Gauthier et al., 2005, 2000; Xu, 2005) that is specific to upright objects of expertise (Gauthier et al., 1999; Moore, Cohen, & Ranganath, 2006).

Alternatively, rather than a quantitative change such as the number of neurons at a given stage of processing, or the sharpness of their selectivity, the difference in onset between expert and novice performance may reflect an additional cost incurred by novices to implement a processing mechanism that occurs automatically among experts. For example, expertise may rely on acquired patterns of attentional allocation that allow for the extraction of the most diagnostic information, whether it be the precise configuration of features within a face or the subtle contours of a car. This may be a critical aspect of the "perceptual routines" proposed by Tanaka (2001) to explain the faster subordinate level recognition performance of experts compared to novices. In a task switching procedure, Waszak, Hommel, and Allport (2003) demonstrated that attentional settings can become associated with objects as a function of experience, leading to the relatively automatic processing of items in a manner consistent with this history. By extension, it is possible that attentional weighting of diagnostic features is performed automatically for objects of expertise, while novices may have to establish an attentional set and select features that appear most diagnostic for each new object. In addition, a possible role for top-down attention in the expert onset advantage could be explored by measuring the time course of expert encoding under conditions where observers cannot predict whether an object of expertise will have to be encoded on any given trial. However, because the typical expert advantage in the speed of identification does not depend on the predictability of an object's category (Tanaka & Taylor, 1991), we conjecture that such a manipulation would not change the nature of the difference between novice and expert time courses.

Finally, another possibility for a more qualitative account of the onset difference is that the longer onset in novices is associated with the automatic selection of information most relevant for basic-level recognition among novices despite the fact that the task requires individuation of the items.[6] Consistent with this possibility, the basic-level has been shown to have a privileged status among novices, serving as the entry-point of recognition, while basic and subordinate-levels are equally accessible to experts (Tanaka, 2001; Tanaka & Taylor, 1991). Thus, novices may automatically process information that is diagnostic of basic-level membership. Because the information that is most diagnostic for recognition at different levels of specificity is unlikely to be the same, this could create a delay in the onset of performance if a default basic-level categorization proved to be more difficult to override for novices than experts. For example, to recognize that an object is a car, an important feature that should be weighted heavily for this recognition judgment might be the wheels. However, to distinguish two cars that share most features, weighting the wheels will be of little value (especially in our task) relative to other features such as the contours of the hood. Further studies are required to evaluate the possible role of such automatized processes in contributing to the earlier onset of expert processing.

In summary, our work provides a window into the temporal dynamics of expert visual processing. The results reported here extend previous work by suggesting that the temporal advantage for the perceptual processing of objects of expertise stems from a very early difference in the onset of information available for perceptual encoding. That an expert advantage arises with presentation times as brief as 48 ms places important constraints on models that would have a basic-level processing stage cause the recruitment of specialized individuation processes. Our results, especially when combined with other work revealing how expertise changes the temporal dynamics of post-encoding categorization judgments, begin to provide a more fine-grained picture of how perceptual expertise changes the flow of information processing.

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Footnote

[1] Although see Bentin et al. (2007) for an argument against a role of interstimulus perceptual variance in contributing to the larger N170 for faces compared to other objects.

[2] Although previous findings by Murray (2004) suggest that the processing of inverted faces may differ from that for other novice categories (e.g. upright cars among car novices), our previous work has established an effect of inversion of similar magnitude for non-face objects of expertise among car experts, but not car novices (Curby, Glazek, & Gauthier, 2009).

[3] Note that some authors have suggested that the N170 is primarily influenced by familiarity while expertise per se may affect a later ERP component (the N250; Scott et al., 2006).

[4] Participants' self-reports were consistent with their performance on the subordinate car matching task, with participants meeting the criteria for car expertise on the task rating themselves an average of 8.45 on a scale of 10; those who were classified as novices, on average, rated their skill as 4.97 on a scale of 10. There was a highly significant correlation between participants' self reported car expertise and their d' score on the car trials in the car expertise test ($p \leq .0001$, $r_{\text{adjusted}} = .849$) and also their car expertise index ($p \leq .0001$, $r_{\text{adjusted}} = .746$).

[5] Note that the absolute value of the advantage cannot be compared because of task and stimulus differences.

[6] Note that recent computational modeling has demonstrated that some apparently qualitative changes in object processing, specifically those related to automatization of processing, can be accounted for by quantitative changes in a categorization model (Mack et al., 2007). Thus, it is still an open question as to the extent that the apparently qualitative changes in processing that occur with the development of perceptual expertise are supported by quantitative changes in processing.

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