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Face recognition and brain potentials: Disruption of configural information reduces the face inversion effect.

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Abstract

The face inversion effect (FIE) refers to the decline in performance in recognizing faces that are inverted compared to the recognition of faces in their normal upright orientation (Yin, 1969). Event-related potentials (ERPs) were recorded while subjects performed an Old/New recognition study on normal and Thatcherised faces presented in upright and inverted orientation. A large difference in processing between normal upright faces and normal inverted faces was observed at occipital-temporal sites about 165 ms following stimulus onset, mainly in the right hemisphere. Thus electrophysiological activity, which corresponds to the previously described N170, had larger amplitude and was delayed for normal inverted faces as compared to normal upright ones. By contrast, the activity for Thatcherised inverted faces was not significantly changed or delayed as compared to Thatcherised upright stimuli. These results combine to show how the effect of face inversion on the N170 is reliably greater when the faces are normal rather than Thatcherised. Finally, these finding complement, at a neural level, our behavioral studies which suggest that the loss of some configural information affects the FIE.

Keywords: Face inversion effect; N170; configural information.

Introduction

The face inversion effect (FIE) is a reduction in recognition performance for inverted faces compared to upright faces that is greater than that typically observed with other stimulus types (e.g. pictures of houses; Yin, 1969). Nevertheless, the demonstration that the inversion effect in recognition memory can be as strong with images of dogs as with faces when the subjects are experts in specific dog breeds (Diamond & Carey, 1986), suggests that there may be other factors,such as expertise, which give rise to the FIE. Diamond and Carey (1986) proposed that there is a special type of information, "second order relational information" that we depend on with increasing expertise. Their analysis was that human faces all have the same group of features (eyebrows, eyes, nose, mouth, etc.). All these faces tend to have in common the same basic disposition of components, such that the eyes are always above the nose and so on. Thus, "first order relational information" corresponds to the spatial relationship between the features of a face, and "second order relational information" corresponds to the small variations in the spatial relationships between these features that individuate the faces. This information can also be considered to be a type of configural information. Diamond and Carey (1986) suggested that a large inversion effect will be obtained only if three conditions are met. Firstly, the members of the class of stimuli must share a basic configuration. Secondly, it must be possible to individuate the members of the class through second-order information. Finally, individuals must have the expertise to exploit such second-order information. Thus, recognition of exemplars of such a class differs from other types of recognition in its reliance on second-order relational features and requires a certain expertise to use these features. This interpretation of the effect of expertise is supported by the role of a prototype in face recognition.In one of their papers Valentine and Bruce (1986a) suggested that a face prototype was a result of overlaying many examples of faces in a distributed memory network (e.g. as in McClelland & Rumelhart, 1985). Therefore, the emergence of a face prototype is not something special for faces, but occurs simply because facial stimuli constitute a homogeneous category of which many exemplars are experienced. Thus, prototype extraction would be expected to arise for any set of stimuli that satisfies the three conditions previously described for a large inversion effect. Conversely then, evidence of prototype extraction can be used to determine whether or not an observer possesses expertise in discriminating within a stimulus category. The suggestion from some theories of perceptual learning (e.g. McLaren, 1997) is that expertise for faces acts directly on the representation of the information in a face, and confers the ability to make better use of it by effectively reducing the salience of first order relational information, leaving second order relational information relatively salient which aids discrimination. Thus, if the configural information in upright faces is disrupted, or our ability to extract it is (e.g. by inversion), the benefits conferred by our expertise with those faces would tend to decrease, making them less easy to discriminate from one another. This explanation for the effect of expertise in face processing has some empirical support. The key finding is that it has been shown that experience with exemplars of a category that can be represented by a prototype (and so have second order relational structure as a result of their variation about that prototype) leads to an increased ability to discriminate between members of that category (McLaren, Leevers and Mackintosh, 1994). This improvement is lost when the stimuli are presented in an inverted orientation (McLaren, 1997). Thus,the results from these studies taken together support the view that experience with stimuli may have a role in driving the specialization of processes subserving learning and memory.

This view receives support from event-related potentials (ERPs) studies such as Rossion, Gauthier, Goffaux, Tarr and Crommelinck (2002) who have shown that it is possible to obtain an electrophysiological inversion effect for an experimental non-face stimulus class called 'Greebles' once participants are trained in recognizing them. Rossion *et al.* (2002) trained participants with a three-phase experiment in which there was first, a baseline phase, where ERPs were recorded from responses to face and Greeble presentations in both upright and inverted orientations. Following this, there was a training phase using only upright Greebles. Finally, during the last phase of the experiment ERPs were measured using new faces and new Greebles presented in both upright and inverted orientations. ERPs prior to the training phase revealed the inversion effect to be larger for faces than for Greebles. Following training with upright Greebles, the N170 (negative deflection occurring between 150-200 ms) latencies for the upright faces and Greebles were similar. The ERPs for inverted faces remained roughly constant before and after the training phase with Greebles, but ERPs to Greebles showed a significant training effect, in that there was an increased delay and increased amplitude for inverted Greebles as compared with Greebles presented in an upright orientation. In conclusion, although the inversion effect for faces was larger in both experimental sessions, the inversion effect for Greebles increased with increasing expertise with that category of stimuli. Furthermore, Tanaka and Curran (2001) investigated the neural basis of object expertise while recording the brain activity of experts when categorizing images of common dogs and birds. Results showed that the magnitude of the N170 was larger when the participants categorized objects in the domain in which they were expert than when they categorized objects in the domain in which they were novices. Finally, de Haan, Pascalis & Johnson (2002) investigated the inversion effect and the link to expertise using human and monkey faces, as the latter have a similar configuration of features to human faces. These two categories of stimuli were presented to participants in both upright and inverted orientations. Results revealed thatthe N170 amplitude evoked by upright faces was smaller than for other stimuli, and the amplitudes for monkey faces both upright and inverted, and inverted human faces did not differ significantly from one another. Thus, inversion increased the amplitude and latency for human faces but not for monkey faces. The same experiment conducted on 6-month-old infants produced a component with similar morphology to the N170. However, this infant component differed from the N170, both because it peaked 100 ms later and it was not affected by inversion. Thus, for adults the orientation of faces played a role in determining the N170 (Eimer, 2000), but for infants the influence of orientation appeared only at later processing stages. This absence of an inversion effect in the infant ERPs is consistent with the idea that adults develop expertise for face processing, including both species and orientation, as a consequence of experience with that stimulus category (de Haan *et al*., 2002). These results also suggest that ERP inversion effects are tied to expertise with a suitable category, rather than to the category of faces per se.

EXPERIMENT

In this study we investigated the link between second-order relational structure and the face inversion effect suggested by Diamond and Carey (1986).The argument is that the improvement brought about by our expertise with faces is lost on inversion because this disrupts the ability to exploit second order relational information, leading to a strong inversion effect.In the behavioral part of this study, we aimed to demonstrate the typical strong inversion effect for normal face stimuli (for which we have expertise), and for comparison purposes ran a condition using what are known as Thatcherised face stimuli (see Fig. 1 for examples). These latter stimuli serve as our experimental manipulation in the sense that they suffer from somewhat disrupted second order-relational information (even when upright) caused by the 180º rotation of the eyes and the mouth, which should reduce at least some of the effect of expertise in the upright orientation. Another useful characteristic of these stimuli is that they are still faces, and are well matched for complexity with the normal faces. We also investigated the electrophysiological responses to normal faces in comparison with the responses obtained to Thatcherised faces and predicted that the N170 would correlate with our behavioral results. That is, the N170 for upright normal faces was expected to be different from that obtained in our other conditions. We expected to observe larger and delayed N170 amplitudes for inverted normal faces, as well as for upright and inverted Thatcherised faces, by analogy with the results of de Haan *et al*. (2002). This follows from the assumption that the disrupted second order relational information in Thatcherised faces in part reduces the effect of expertise in the same way that inversion also reduces its impact, and that the N170 depends, at leastin part, on the effect of expertise. Hence we expect the effect of expertise to only be evident for normal upright faces, and to manifest as a smaller amplitude and latency, leading to a large inversion effect (in the ERPs) for normal faces but not for Thatcherised faces.

Materials

The study used 320 images in total, half female and half male. These were photographs of faces of former students at the University of Cambridge. The faces were standardized in grey scale format using Adobe Photoshop. A program called Gimp 2.6 was used to manipulate the 320 stimuli. Any given face stimulus was prepared in four different versions i.e. normal upright, normal inverted, Thatcherised upright and Thatcherised inverted, which were used in a counterbalanced fashion across participants so that each face was equally often used in each condition of the experiment. For the Thatcherised faces, each of the eyes and the mouth were flipped about the horizontal axis. Examples of the stimuli used are given in Figure 1. The experiment was run using E-prime software Version 1.1 installed on a PC computer.

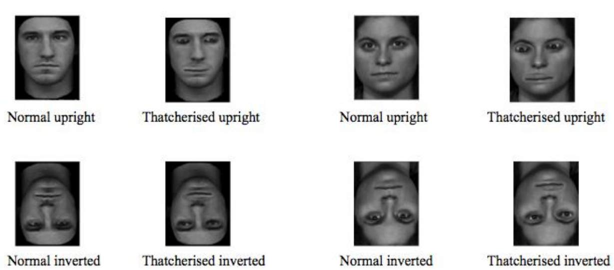

Figure 1; Examples of stimuli used in the experiment showing the four different conditions for male and female faces. The dimensions of the stimuli were 5.63cm x 7.84cm. The stimuli were presented at a resolution of 1280 x 960 . Participants sat 1m away from the screen on which the images were presented.

Participants

32 undergraduates and postgraduates at the University of Exeter took part in the experiment.

Procedure

The experiment consisted of a ‘study phase’ and an ‘old/new recognition phase’ using only male faces, followed by another ‘study phase’ and ‘old/new recognition phase’, but this time using only female facial stimuli. After the instructions, the first part of the experiment involved participants looking at 80 male faces (presented one at a time in random order).The participants saw a fixation cross in the centre of the screen that was presented for 500 ms. This was followed by a black screen for 500 ms and then by a facial stimulus that was presented for 3000ms. Then the fixation cross and the black screen were repeated, and another face presented, until all stimuli had been seen.These faces will be termed “familiar”(designated as type 1) faces for that participant because they will be presented again later on in the old/new recognition task. The face types during the study phase were: Normal Inverted faces (1NI); Normal Upright faces (1NU); Thatcherised Inverted faces (1TI) and Thatcherised Upright faces (1TU). Following the study phase, after further instructions, there was an old/new recognition task in which participants were shown (in random order) the 80 male faces they had already seen (i.e. the familiar faces) intermixed with a further 80 unseen male faces which were designated as type 2 (novel) and split into the same four face sub-types as the familiar set.During this old/new recognition task participants indicated whether or not they had seen the male face onscreen during the study phase by pressing the ‘.’ key If they recognized the face or by pressing ‘x’ if they did not. Each facial stimulus had a unique identifying number, to make sure that individual faces never appeared in more than one face type at a time during the experiment. To simplify their use in the experiment, the facial stimuli available were divided into sets of 20giving 8 sets of stimuli, and each participant group was shown a different combination of the 160 facial stimuli rotated over the 8 sets as shown in Table 1. Because there were 160 male faces to consider (80 in the study phase and 80 in the recognition task), four participant breaks were incorporated. These allowed participants to rest their eyes after they had viewed 40 faces. The second part of the experimentfollowed the same procedure as that used in the first part of the experiment. The only difference this time was that participants saw female faces.

Face Type	Participant Group 1	Participant Group 2	Participant Group 3	Participant Group 4	Participant Group 5	Participant Group 6	Participant Group 7	Participant Group 8
1 (1NI)	Set 1	Set 4	Set 3	Set 2	Set 5	Set 8	Set 7	Set 6
2(1NU)	Set 2	Set 1	Set 4	Set 3	Set 6	Set 5	Set 8	Set 7
3(1TI)	Set 3	Set 2	Set 1	Set 4	Set 7	Set 6	Set 5	Set 8
4(1TU)	Set 4	Set 3	Set 2	Set 1	Set 8	Set 7	Set 6	Set 5
5(2NI)	Set 5	Set 8	Set 7	Set 6	Set 1	Set 4	Set 3	Set 2
6(2NU)	Set 6	Set 5	Set 8	Set 7	Set 2	Set 1	Set 4	Set 3
7(2TI)	Set 7	Set 6	Set 5	Set 8	Set 3	Set 2	Set 1	Set 4
8(2TU)	Set 8	Set 7	Set 6	Set 5	Set 4	Set 3	Set 2	Set 1

Table.1. Combinations of facial stimuli presented to each participant group. The same face set combinations were used in the first and second half of the experiment for the maleand female faces.

EEG Apparatus

The EEG was sampled continuously during both the study and test phases at 500 Hz with a bandpass of 0.016-100 Hz, the reference at Cz and the ground at AFz using 64 Ag/AgClactive electrodes and BrainAmp amplifiers. There were 61 electrodes on the scalp in an extended 10-20 configuration and one on each earlobe. Their impedances were kept below 10 kΩ. The EEG was filtered offline with a 20 Hz low-pass filter (24 dB/oct) and re-referenced to the linked ears.

EEG Analysis

Peak amplitudes of the N170 in study and recognition phases were examined for differences between the experimental conditions. To improve the estimates of N170 amplitude and latency given the relatively small number of ERP segments in each condition (leading to a low signal-to-noise ratio), N170 extraction was aided by linear decomposition of the EEG by means of Independent Component Analysis (ICA, Bell &Sejnowski, 1995). ICA was run separately for each subject using all scalp channels and the entire dataset. For analyses of the recognition phase, segments associated with incorrect responses were discarded (there were no responses in the study phase). The remaining EEG segments were averaged for every participant and experimental condition. In each subject, we identified ICA components that: (1) showed a deflection (peak) in the N170 time-range (at 150-200 ms following stimulus onset), and (2) had a scalp distribution containing an occipital-temporal negativity characteristic of N170 (the scalp distributions of components are the columns of the inverted unmixing matrix). This resulted in 1-4 ICA components corresponding to the N170 identified in most subjects (mean 2.6; SD 1) - these were back-transformed into the EEG electrode space (by multiplying the components with the inverted unmixing matrix that had the columns corresponding to other components set to zero) and submitted to statistical analysis of N170 peak amplitude and latency.

Results

Behavioral Results

The data from all 32 participants contributed to the signal detection *d'* analysis. Responses for male and female faces were collapsed and transformed into *d'*measures. There was a significant interaction between face type and orientation, F(1,31) = 8.30, p<.01. This reflected the fact that the inversion effect in the normal faces was significantly greater than that in the Thatcherised faces. Figure 2 shows the results for the mean *d'* obtained for each face type. A planned comparison gave a highly significant advantage F(1,31) = 29.99, p<.001 , for normal upright faces vs. normal inverted faces, and another planned comparison showed a similar (although smaller) inversion effect for Thatcherised upright vs. Thatcherised inverted faces, F(1,31) =6.24, p<.025. To further investigate this result, the effect of face type on the recognition of upright faces was also analyzed. Normal upright faces were recognized significantly better than Thatcherised upright faces F(1,31) =13.71, p<.01, but there was no significant difference in the recognition of normal inverted faces and Thatcherised inverted faces. Thus, it would seem that the reduction in the inversion effect for Thatcherised faces is more due to the impact that Thatcherisation has on the upright faces rather than on the inverted ones.

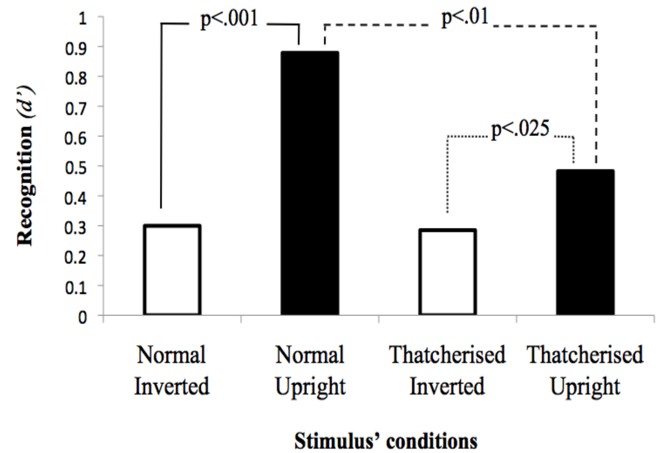

Figure 2;Resultsfor the old/new recognition task. The X axis shows the four different stimulus' conditions, the Y axis shows the mean *d'* for each condition.

N170 analysis

Three participants had to be excluded because ICA did not find any components containing the N170 (nor was there an N170 visible in the original ERP). N170 latency and amplitude analyses were run in electrode PO8 which was the one showing most of the activity during our experiment. We attempted to run the same analyses on the N170 data as on the *d'* behavioral data considered earlier to facilitate comparison.

Study phase *(see Figure 3)*

<u>*Latency analysis:*</u>The Orientation x Face Type interaction, i.e. the effect of inversion on N170 latencies,was reliably larger when faces were Normal compared to Thatcherised, F(1,28) = 4.73, p< .05. In particular, the effect was highly reliable for Normal faces, F(1,28) =21.19, p<.01, with N170 latencies peaking 9 ms earlier for upright faces (at 165 ms) compared to inverted faces (174 ms). For Thatcherised faces, peaks for inverted faces were delayed compared to upright faces by 3 ms. This delay did not reach significance, F(1,28) = 1.54, p=ns. Latencies of upright faces peaked earlier (by 4 ms) when faces were Normal compared to Thatcherised. This difference was only marginally reliable, F(1,28) =3.24, p =.082.

<u>*Peak amplitude analysis*</u>: The difference in peak amplitudes between upright and inverted faces was significantly larger when faces were Normal (-0.46μV) than when they were Thatcherised (0.002μV), F(1,28) =4.18,

p=.05.The effect of inversion was reliable for Normal faces, F(1,28) =7.06, p<.025, with more negative amplitudes for inverted (-0.513μV) compared to upright (-0.046μV) faces. For Thatcherised faces the inversion effect did not approach significance F(1,28) =.0001 p=ns. The effect of Face Type was marginally reliable for upright faces, F(1,28) =3.82, p=.06, with more negative amplitudes for Thatcherised (-0.451μV) compared to Normal (-0.046μV) faces.

Old/new recognition task *(see Figure 4)*

Latency analysis:No significant Orientation by Face Type interaction was found. A significant inversion effect was obtained for normal faces F(1,28) =16.36, p<.01with N170 latencies peaking 5 ms earlier for upright faces (at 163 ms) compared to inverted faces (168 ms). A reduced but still significant inversion effect was found for Thatcherised faces F(1,28) =6.62, p<.025with N170 latencies peaking at nearly 5 ms earlier for upright Thatcherised faces (at 165.31 ms) compared to inverted (169.72 ms). A planned comparison revealed a trend towards significance for upright normal stimuli compared to Thatcherised upright ones F(1,28) = 2.27, p=.15.

Peak amplitude analysis: As for latencies, no reliable Orientation by Face Type interaction was found. Means show a trend towards significance for Normal faces, with more negative amplitudes for inverted (-0.73μV) vs. upright (-0.39μV), F(1,28)=2.50, p=.13. For Thatcherised faces amplitudes arereliably more negative when they are inverted (-0.91μV) vs. upright (-0.54μV), F(1,28) = 4.59, p<.05.

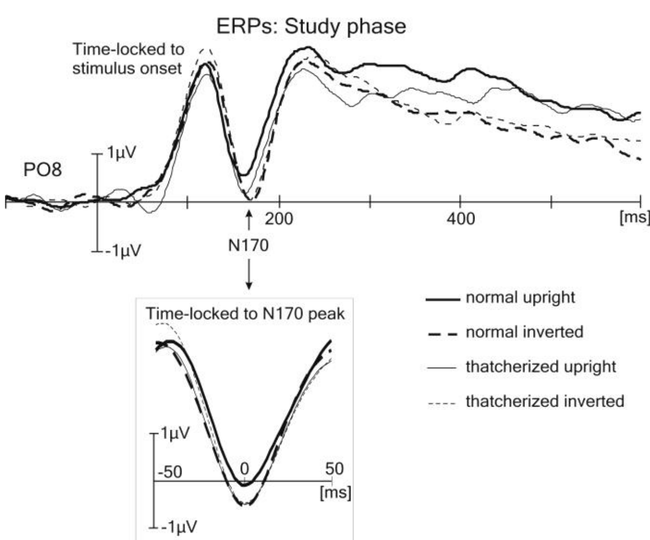

Figure.3. The X axis shows the elapsed time after a stimuluswas presented, whereas the Y axis shows the amplitudes (μV) of the electrophysiological reactions in the study phase of the experiment. The insert in this figure is the ERP time-locked to the N170 peak, as identified in individual subjects. The time-scale of the inserts is stretched relative to the main stimulus-locked ERPs, the amplitude scale is the same in the insert as in the mainfigure.

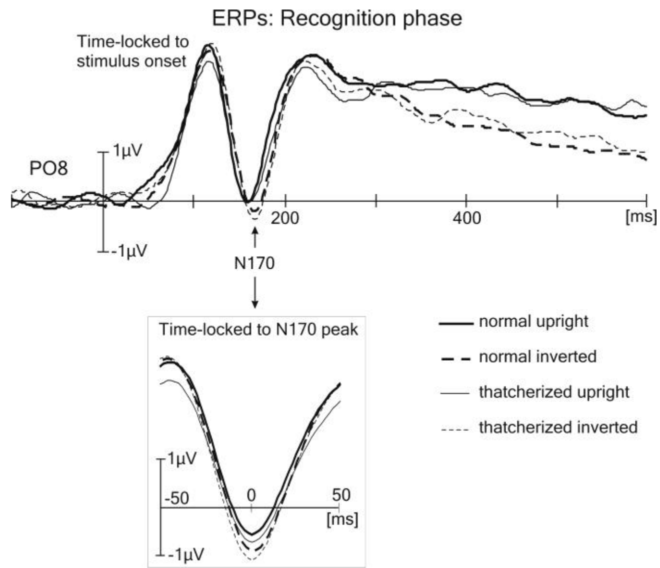

Figure.4.The X axis shows the elapsed time after a stimulus was presented. The Y axis shows the amplitudes (μV) of the electrophysiological reactions in the old/new recognition phase of the experiment.

Discussion

This study has, in essence, confirmed our predictions. On the behavioral side we have obtained a strong inversion effect for normal faces and a reduced one for Thatcherised faces. The ERP results provide the sought after correlates of our behavioral findings in the study phase where participants were only asked to look at the faces and try to memorize them. Analyses on both the amplitude and latency show a larger inversion effect onthe N170 for normal faces than for Thatcherised faces. Running the same planned comparisons on the ERP data as for thebehavioral data produces a very similar pattern of results, i.e. a strong inversion effect for the normal faces, a greatly reduced effect for the Thatcherised faces, and a difference in N170 amplitude between the upright normal and Thatcherised faces but not between the two face types when inverted.

General Discussion

The behavioral results of this study show that we have obtained a significant inversion effect with normal faces, and have demonstrated that it is significantly larger than the inversion effect obtained with Thatcherised faces. To some extent, then, we have confirmed the basic face inversion finding. We have some evidence here that second order relational information plays a role in driving the inversion effect for faces. The most straightforward explanation of the difference in performance to the two face types when upright is that the Thatcherised faces have lost some (but not all) of the benefit of our expertise in dealing with second order structure.Because the Thatcherised faces are still essentially faces, then the application of our expertise with normal faces may lead to positively unhelpful results for upright Thatcherised faces, in that the changed features stand out and command processing. Because these features are not those best suited to individuate faces, i.e. our processing is being dominated to a greater extent by what is common to Thatcherised faces (because they are surprising) rather than what would aid us in discriminating between them, performance for upright Thatcherised faces would be expected to be worse than for normal upright faces. The lack of any difference in recognition performance between normal and Thatcherised faces when inverted can be explained by arguing that in these circumstances second order relational information is not in play, and the two types of face are otherwise equated in terms of features and other factors (e.g. overall shape of the face).

The results from the ERPs bolster our interpretation of the effects we obtained in the behavioral results. As we predicted, the N170 to upright normal faces was different to that of our other stimuli, an effect that we can now argue reflects in part the high degree of expertise participants had for them. One of our findings is that this difference was a great deal clearer in the study phase of our experiment than in the test phase. This is not an entirely unexpected result. Firstly, if the modulation of the N170 reflects an effect of expertise, then this should occur when simply perceiving the stimulus – the effect is not tied to having to do anything in particular, except perhaps attend to the stimulus. Secondly, as a result of the study phase, the Thatcherised stimuli will start to become familiar, in particular the Thatcherised upright faces will tend to become progressively more equivalent to normal upright faces. Thus, any effect in the study phase will be a relatively pure comparison of the two stimulus types, one highly familiar, the other novel (at least in part); but in the test phase this distinction, and the effects that flow from it, will be attenuated by participants' increasing familiarity with the Thatcherised stimuli.If we study the waveforms that are time-locked to stimulus onset then the pattern at the N170 exactly corresponds to that observed in the behavioral data. As we predicted, upright normal faces occur earlier and with smaller amplitude in the N170, upright Thatcherised faces are somewhat later and have greater amplitude, and both the inverted face types are slightly later still and have slightly greater amplitude than upright Thatcherised faces. We suggest that the N170 isindexing, at least in part, the effect of expertise with the stimulus category. Inversion of the faces increases the amplitude of the N170 and delays its onset in agreement with a number of other studies which have found a greater delay and larger amplitude for the inverted stimulus (Rossion*et al*, 2002; Tanaka and Curran, 2001; de Haan *etal*, 2002). We notethat the FIE for our Thatcherised stimuli is still significant, suggesting that simply disrupting second order information does not completely eliminate the FIE. A possible explanation for this is that by rotating the eyes and the mouth we have not disrupted all the second order information in a face. Thus, our baseline stimuli still have some second order information which participants may have expertise for. Another explanation could be that not only second order information is involved in the FIE but there may be an important role for other types of information. Perhaps by disrupting both first and second order configural information we would be able to eliminate the FIE entirely. Our claims about the magnitude of the inversion effect are secure, but we cannot tell if performance in all our conditions is still benefiting from the effects of expertise (all the stimuli are, after all, recognizable as faces). One obvious way in which this might happen is by virtue of all the face types containing standard facial features that have not been themselves changed apart from a rotation or reflection. Another would be to appeal to the basic envelope of the stimuli remaining unchanged under Thatcherisation and inversion. Clearly it would be unwise to assume that all effects of expertise disappear under inversion, Thatcherisation or a combination of the two manipulations. What we can conclude, however, is that Thatcherisation interacts with stimulus inversion in a way that strongly suggests that experience with these stimuli helps us to better exploit that information.

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