The face inversion effect and evoked brain potentials:
Complete loss of configural information affects the N170

Ciro Civile (cc413@exeter.ac.uk)
School of Psychology, College of Life and Environmental Sciences,
University of Exeter, UK.

Heike Elchlepp (H.Elchlepp@exeter.ac.uk)
School of Psychology, College of Life and Environmental Sciences,
University of Exeter, UK.

R. McLaren (R.P.McLaren@exeter.ac.uk)
School of Psychology, College of Life and Environmental Sciences,
University of Exeter, UK.

Aureliu Lavric (A.Lavric@exeter.ac.uk)
School of Psychology, College of Life and Environmental Sciences,
University of Exeter, UK.

I.P.L. McLaren (I.P.L.McLaren@exeter.ac.uk)
School of Psychology, College of Life and Environmental Sciences,
University of Exeter, UK.

Abstract

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. 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. Event-related potentials (ERPs) were recorded while subjects performed an Old/New recognition study on normal and scrambled faces presented in upright and inverted orientations. We obtained the standard result for normal faces: The electrophysiological activity corresponding to the N170 was larger and delayed for normal inverted faces as compared to normal upright ones. On the other hand, the ERPs for scrambled inverted faces were not significantly larger or delayed as compared to scrambled upright stimuli. These results, in combination, show how the effect of inversion on the N170 is reliably greater when the faces are normal compared to scrambled, which suggests the disruption of configural information affects the FIE.

Keywords: Face recognition; Face inversion effect; N170; First and second order relational information; Old/new recognition task

Introduction

Recognition of objects that are usually seen in one orientation is sometimes strongly impaired when the same objects are turned upside down, showing how intrinsically difficult it is to identify them. This has been found to be particularly the case for faces, leading to a phenomenon known as the face inversion effect (FIE). Thus, the fact that recognition of human faces is more impaired by inversion than is recognition for other stimuli has underlined how faces are, in some sense, special. Some of the first evidence for the FIE reported by Yin (1969) presented participants with upright or inverted pictures of faces, airplanes, houses, and other stimuli. Following the study phase, participants were then tested with stimuli in the same orientation in a recognition task paradigm. The results showed that when the stimuli were studied and tested in an upright orientation, faces were better recognized than other sets of stimuli. However, when the same stimuli were presented and tested in an inverted orientation, recognition for faces decreased more than was the case for the other classes of stimuli. Yin (1969, experiment 3) replicated this result in an experiment using line drawings of facial stimuli and period costumes, thus controlling for the effect of subtle shadow information in an inverted face as a potential explanation for the large effect of inversion. In this experiment faces were not the easiest stimuli to be recognized when presented in an upright orientation. Therefore, the large FIE could not be attributed to the overall difficulty in discriminating within a stimulus category. Yin interpreted his results in terms of a face-specific process.

Over the past two decades more behavioral evidence has emerged that challenges the assumption that facial stimuli are special, not the least of which is the demonstration presented by Diamond and Carey (1986) that the inversion effect on recognition memory can be as strong with pictures of dogs as with faces when the subjects are experts in the identification and assessment of specific dog breeds. Given that the only stimuli that result in a substantial inversion effect are the ones for which the subjects have the necessary expertise, this suggests that the FIE may not be due to the fact that facial stimuli are subject to special processing because they are facial in nature, but instead that there are

other factors, such as expertise, which give rise to this effect. They distinguished between three types of information that can be used in recognition: isolated features, first-order relational features and second-order relational features. Isolated or local features are the independent constituent elements of an object. First-order information consists of spatial relations between constituent elements of an object, for example, the arrangement of the nose above the mouth. It is the first-order information that organizes a set of facial features into a face. Second-order information defines the relative size of these spatial relationships with regard to a base prototype. All faces tend to possess the same set of first-order relations, the essential manner in which faces differ from each other is captured by second-order relational information. These two kinds of relational information are both examples of configural information. Diamond and Carey suggested that large inversion effects will be obtained only if three conditions are met. Firstly, the members of the class of stimuli must share a configuration. Secondly, it must be possible to individuate the members of the class through second-order information. Finally, observers must have the expertise to exploit such second-order information. They proposed that the elements that distinguish faces lie on a continuum from isolated/local to second-order relational. Thus, recognition of members within the class differs from other types of recognition in its reliance on second-order relational features and in requiring expertise to use these features.

Searcy and Bartlett (1996) and Leder and Bruce (1998) have provided very clear evidence on the effect of disrupting configural information by inversion. In one of their experiments, Searcy and Bartlett (1996) made faces grotesque by either changing local elements, such as blackening teeth, blurring the pupils, or by changing the facial configuration. When shown in an inverted orientation, faces that were distorted through configural changes seemed to be more similar to the normal version, while the "locally distorted face" still looked grotesque. Thus, configural changes did not survive the inversion process as well as local ones. In another experiment, Leder and Bruce (1998) distorted faces so as to be more distinctive, either changing local features by giving them darker lips, bushier eye brows, etc. or by changing configural information to give a shorter mouth to nose spatial relation, etc. Distinctiveness impressions caused by distorted configural information disappeared when faces were presented in an inverted orientation compared to both upright faces and faces distorted in their local aspects. These results all provide evidence for the powerful effect that relational information has in the processing of upright faces relative to inverted faces. But there is still a question as to what precisely is the difficulty caused by any disruption of configural information consequent on inversion. The suggestion from some theories of perceptual learning (e.g. McLaren, 1997) is that expertise for faces can act directly on configural information, and confers the ability to make better use of it by effectively reducing the salience of first order relational information (which is also configural but shared by most faces), leaving second order relational information relatively salient which aids discrimination. Thus, once configural information in upright faces has been disrupted (or at least our ability to make use of it), 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 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. This improvement is lost when the stimuli are presented in an inverted orientation (McLaren, 1997). Recently, Civile et al., (2011) provided some evidence that disrupting second order relational information by inverting (rotating by 180^0) the eyes and the mouth, producing Thatcherised faces, whilst leaving other types of information (first order and local) intact reduces, even if it does not entirely eliminate, the FIE. However, in that same study they proposed that the FIE was still present for Thatcherised baseline stimuli (but significantly smaller than for normal faces) because Thatcherised faces still had some second-order information which had not been disrupted by the manipulation. Thus, in a second experiment they created a set of faces with all the second-order information disrupted. To do this they scrambled the faces by shuffling at random each of the features within a face. The effect of this was, in part, the expected one in that any inversion effect for the scrambled faces disappeared. The new finding was that performance for scrambled faces, whether in an upright or inverted orientation, was now below not only that for upright normal faces but also below that obtained for inverted normal faces. A possible explanation for this finding was that using scrambled faces may have affected both first and second order relational structure. In particular, when the ears were moved inside the face and replaced with other features, the typical shape of every face was changed to the point where it was no longer easily recognizable as a face.

In this present study, we aimed to replicate behaviorally those results obtained by Civile et al., (2011), but this time we used a slightly different design. Participants were presented with two old/new recognition tasks, one including male faces and another female faces. All together the sample of faces seen in this experiment was more than double that used in the Civile et al., (2011) study. This was done so that we could measure event-related potentials (ERPs) recording subjects' neural activity while performing the tasks. There have been previous ERPs studies that have compared the presentation of normal upright faces and normal inverted faces. Rossion et al., (1999) recorded neural activity in a delayed-matching task. A larger amplitude and delayed activity on the N170 was found for inverted faces compared to upright faces suggesting that inversion may slow down and increase difficulty in face processing.

Following the ERP literature on the N170 (de Haan *et al.*, 2002; Eimer, 2000; Tanaka & Curran, 2001;Rossion *et al.*, 2002) we predicted a larger inversion effect on the N170 for normal faces compared to scrambled faces which suffer from disrupted configural information. We expected to obtain significantly larger and delayed N170 amplitudes for normal inverted faces compared to normal upright faces. This follows from the assumption that inversion effects the expertise needed to exploit configural information, and that the N170 depends on the ability to make use of this information. Thus, this difference is expected to be significantly larger than the one between the amplitudes for scrambled upright and inverted faces as the influence of expertise here will be minimal. We also looked for neural activity correlates to the disadvantage that scrambled faces have compared to normal inverted 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, scrambled upright and scrambled inverted which were used in a counterbalanced fashion across participants so that each face was equally often used in each condition of the experiment.Six facial features were used for scrambling i.e. the mouth, nose, two ears and the two eyes (including eyebrows). Scrambling was done by selecting at random one feature of the face and moving it to the forehead (chosen because this is the widest space inside the face and so can accommodate any feature). Following this, a second feature was selected and moved to the space left empty by the first feature, and so on until all the six facial features had been moved. 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.
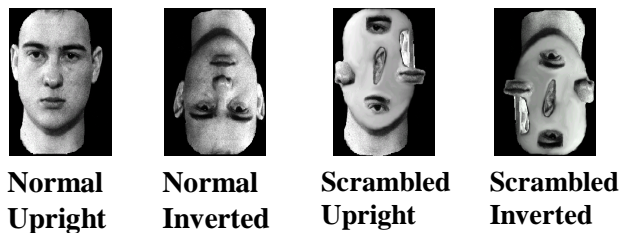

| **Normal Upright** | **Normal Inverted** | **Scrambled Upright** | **Scrambled Inverted** |

Figure 1; Examples of stimuli used in the experiment showing the four different facial conditions. 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

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

Procedure

The experiment consisted of an initial 'study phase' followed by an 'old/new recognition phase' using only male faces, and then 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, 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 the "familiar"(designated as type 1) faces for that participant because they were presented again later on in the old/new recognition task. The face types were: Normal Inverted faces (1NI); Normal Upright faces (1NU); Scrambled Inverted faces (1SI) and Scrambled Upright faces (1SU). 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 and split into the same four face sub-types as in the study phase. During this old/new recognition task participants indicated whether or not they had seen the male face during the study phase by pressing the '.' key If they recognized the face or to press 'x' if they did not. Each face never appeared as more than one face sub-type at a time during 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 split 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 male faces. The second part of the experiment followed 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	Part. Group1	Part. Group2	Part. Group3	Part. Group4	Part. Group5	Part. Group6	Part. Group7	Part. Group8
1(1NI)	Set1	Set4	Set3	Set2	Set5	Set8	Set7	Set6
2(1NU)	Set2	Set1	Set4	Set3	Set6	Set5	Set8	Set7
3(1SI)	Set3	Set2	Set1	Set4	Set7	Set6	Set5	Set8
4(1SU)	Set4	Set3	Set2	Set1	Set8	Set7	Set6	Set5
5(2NI)	Set5	Set8	Set7	Set6	Set1	Set4	Set3	Set2
6(2NU)	Set6	Set5	Set8	Set7	Set2	Set1	Set4	Set3
7(2SI)	Set7	Set6	Set5	Set8	Set3	Set2	Set1	Set4
8(2SU)	Set8	Set7	Set6	Set5	Set4	Set3	Set2	Set1

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 male and female faces.

EEG Apparatus

The EEG was sampled continuously during study and recognition phases at 500 Hz with a bandpass of 0.016-100 Hz, the reference at Cz and the ground at AFz using 64 Ag/AgCl active 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 24 participants contributed to the signal detection d' analysis. Responses for male and female faces were collapsed and transformed into d' measures. A significant interaction was found between face type and orientation, $F(1,23) =20.77$, p<.01.Figure 2 shows the results for the mean d' obtained for each face type. A planned comparison was used to examine whether or not there was a significant inversion effect for normal facial stimuli. This gave a highly significant advantage $F(1,23) =34.37$, p<.001, for normal upright faces vs. normal

inverted faces, and another planned comparison revealed no significant effect of inversion for scrambled upright vs. scrambled inverted faces, $F(1,23) =0.026$, p=ns. The effect of face type on the recognition of upright faces was also analyzed. Normal upright faces were recognized significantly better than scrambled upright faces $F(1,23) =56.75$, p<.001, but there was no significant difference in the recognition of normal inverted faces and scrambled inverted faces. Finally, scrambled upright were recognized significantly above chance, $F(1,23) = 19.63$, p<.01, as were scrambled inverted faces, $F(1,23) = 28.04$, p<.01.
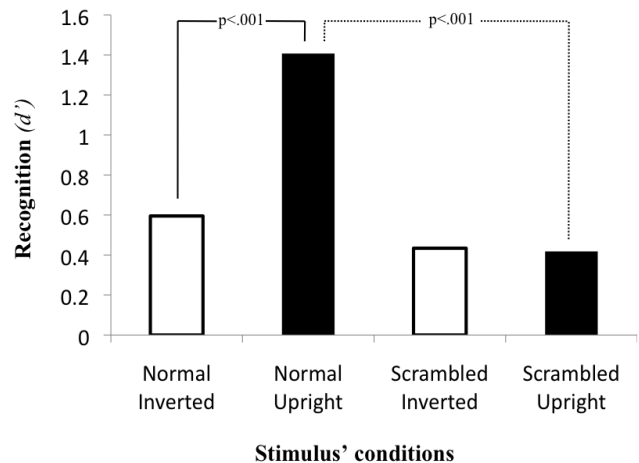
Figure 2; Behavioral results from old/new recognition task. The X-axis shows the four different stimulus' conditions, whereas the Y-axis shows the d' means for each of the four facial conditions.

N170 analysis

N170 latency and amplitude analyses were run in electrode PO8 which was the electrode 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)

Latency analysis: The Face Type by Orientation interaction was significant, i.e. the effect of face inversion on N170 latencies was reliably larger when faces were Normal compared to Scrambled, $F(1,23) = 7.79$, p < .05. In particular, the face inversion effect was highly reliable for Normal faces, $F(1,23) =24.54$, p<.001, with N170 latencies peaking 10 ms earlier for upright faces (at 175 ms) compared to inverted faces (186 ms). For scrambled faces, peaks for inverted faces were delayed compared to upright faces by less than 1 ms failing to reach significance, $F(1,23) =0.18$, p=ns. Latencies of upright faces peaked earlier (by 5 ms) when faces were Normal compared to Scrambled. This difference was reliable, $F(1,23) =5.36$, p <.05.

Peak amplitude analysis: The difference in peak amplitudes between upright and inverted faces was larger when faces were Normal (-0.61μV) than when they were Scrambled (0.18μV), but this was only marginally reliable,

F(1,23) =3.13, p<.1.The effect of inversion neared significance for Normal faces, F(1,23) =3.28, p<.1, with more negative amplitudes for inverted (-1.56μV) compared to upright (-0.94.μV) faces. For scrambled faces, the inversion effect did not approach significance F(1,23) =.075 p=ns. The effect of Face Type was not reliable for upright faces, F(1,23) =0.30, p=ns. Amplitudes for inverted faces were significantly larger when the faces were Normal compared to Scrambled (-0.711 μV) F(1,23) =4.23, p<.05.

Old/new recognition task (see Figure 4)

Latency analysis: A significant Orientation by Face Type interaction was found F(1,23) = 6.45, p<.025. A significant inversion effect was observed for normal faces F(1,23) =37.34, p<.001,with N170 latencies peaking 9 ms earlier for upright faces (at 167 ms) compared to inverted faces (178 ms). A trend towards significance was found for the inversion effect related to scrambled faces F(1,23) =2.51, p=.13with N170 latencies peaking at nearly 4 ms earlier for upright Scrambled faces (at 176.3 ms) compared to inverted (179.90 ms). A final comparison revealed a significant effect for upright normal stimuli compared to scrambled upright stimuli F(1,23) =9.06, p<.01.

Peak amplitude analysis: No reliable Orientation by Face Type interaction was found. Means show a near significant inversion effect for Normal faces, with more negative amplitudes for inverted (-1.815μV) vs. upright (-1.200μV), F(1,23) = 3.67, p=.06. No reliable difference was found for scrambled faces amplitudes F(1,23) = 0.79, p=ns. No significant effect was found for upright normal stimuli compared to upright scrambled ones, F(1,23) = 1.03, p=ns. However a significant effect was found for normal inverted faces compared to scrambled inverted (-1.216 μV) , F(1,23) = 5.91, p<.05.
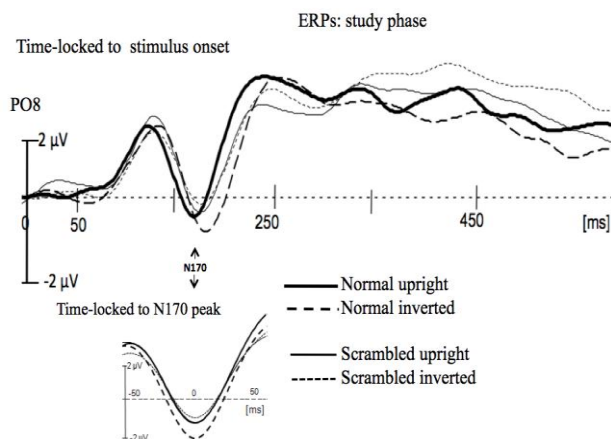

Figure.3. The X-axis shows the elapsed time after a stimulus was presented, whereas the Y-axis shows the amplitudes (μV) of the electrophysiological reactions in the study phase of the experiment. The insert in this figure is the ERP time-locked to the N170 peak, as identified in individual subjects.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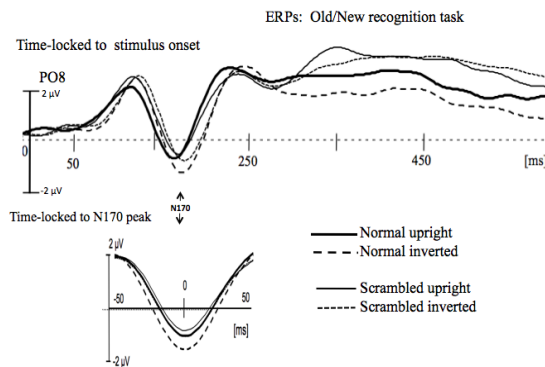

Figure.4.The X-axis shows the elapsed time after a stimulus was presented. The Y-axis shows the amplitudes (μV) of the electrophysiological reactions in the old/new recognition phase of the experiment. The insert in this figure is the ERP time-locked to the N170 peak, as identified in individual subjects during the old/new recognition task.

Discussion

On the behavioral side, and in agreement with the literature, we have obtained a strong inversion effect for normal faces. This has been eliminated entirely with scrambled faces. We have clear evidence here that configural information does indeed play an important role in driving the inversion effect for faces. Analyses on both the amplitude and latency of the N170 indicate a numerically larger inversion effect for normal faces than for scrambled faces. Running the same planned comparisons on the ERP data as for the behavioral data produces a very similar pattern of results, i.e. a strong inversion effect for the normal faces, and no inversion effect for scrambled faces, and a difference in N170 latencies between the upright normal and scrambled faces. The new finding here is that the scrambled stimuli (both upright and inverted) elicit a very similar N170 to one elicited by normal upright stimuli.

General Discussion

From the behavioral results of this study we have confirmed we can obtain a significant inversion effect with normal faces that can be eliminated entirely by disrupting both sources of configural information in the scrambled faces. This is consistent with our hypothesis that participants when presented with scrambled faces in an upright orientation would have no applicable expertise for those upright faces. Thus, when the same scrambled faces are presented in an inverted orientation, participants would not suffer any loss of expertise, as there was none to start with. Hence, we do not observe any inversion effect with scrambled faces. This supports the idea that the inversion effect observed with normal faces can at least in part be

explained by our ability to exploit configural information for categories of stimuli that possess both the necessary structure and are sufficiently familiar. If this structure is disrupted, then so is the inversion effect.

The ERP results provide neural correlates of our behavioral findings. In particular, 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 of the N170 gave a larger inversion effect for normal faces than for scrambled faces, and this result was highly significant for the latencies. Running the same planned comparisons on the ERP data as used for the behavioral data produces a very similar pattern of results, i.e. a strong inversion effect for the normal faces, none for the scrambled faces. However, If we study the waveforms that are time-locked to stimulus onset, then the new finding here is that both upright and inverted scrambled stimuli elicited a similar N170 to that for normal upright stimuli. This presents us with something of a mismatch with the behavioral patterns of results. According to the literature on face inversion and the N170, the ability to use configural information facilitates face processing, and this is supported by our behavioral results. The loss of configural information on inversion could have resulted in a selective amplification of the neural activity linked to faces because of an increase in difficulty due to a decrease in expertise for those faces presented in an inverted orientation (de Haan *et al*., 2002; Eimer, 2000; Tanaka & Curran, 2001;Rossion *et al*., 2002). In favor of this hypothesis is the correspondence between the behavioral data for the effects of inversion on normal faces and N170 for normal faces. This can also explain the lack of an inversion effect for the scrambled faces. Participants do not have expertise for these latter stimuli, thus the level of difficulty in processing them whether upright or inverted is the same leading to a similar N170 for both. However, according to this hypothesis we should have expected to obtain a larger and delayed N170 for scrambled faces compared to the N170 for normal upright faces and we did not. Instead, they are more similar to the N170 for normal upright faces.

Our results do agree with ERP studies using normal upright faces and familiar objects such as shoes or houses or chairs, in which it was found that the N170 elicited for these objects was more similar to that for normal upright faces. We can contrast this with the result obtained by Rossion *et al*(2000), which compared the N170 elicited by a novel class of stimuli called Greebles which shared a common configuration to that obtained with faces and found it to be more like the N170 to inverted faces. This may suggest that our study may suffer from a lack of a correct baseline. Our scrambled stimuli were constructed by shuffling at random each of the features presented within a face. If our normal faces could be represented by a prototype, this was not the case for our scrambled faces, which instead varied a great deal in configuration because of the many different ways we shuffled the features within the face. It may be that our results show that participants perceived those scrambled stimuli as many different types of object rather than as a set of new stimuli that could be represented by a prototype and shared a new configuration.

Conclusion

In conclusion further research will be needed to evaluate the full implications of our results, but our data clearly suggest that there is a role for both first and second order structure in face recognition, that we argue can be understood in terms of experience-based expertise. And we have also shown that the elimination of the FIE can be correlated with a reduction of differences in neural activity in the N170.

Acknowledgments

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