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Changing face contours reduces the inversion effect and overall recognition performance

Siobhan McCourt, I.P.L. McLaren, Ciro Civile*

School of Psychology, College of Life and Environmental Sciences, University of Exeter, UK

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ABSTRACT

This paper investigates how manipulating the face contour would systematically influence the face inversion effect (i.e., better recognition performance for upright vs inverted upside-down faces) and overall face recognition. Experiment 1 (n=144) addressed the question of whether manipulating the face contour would affect the inversion effect for scrambled faces which have disrupted configural information. Our results revealed that blurring the face contour significantly reduced the inversion effect by means of impaired performance for upright scrambled faces. Experiment 2a (n=144) and Experiment 2b (n=144) examined how either blurring the contour or replacing it with a new contour would influence the inversion effect for normal faces. These results confirmed a reduction of the inversion effect mainly due to impaired performance for upright faces. A reduction in overall recognition performance was also recorded for normal faces with a manipulated contour. Experiment 3 (n=144) manipulated the contour of New Thatcherized faces which suffer from partial configural information disruption. The results revealed no influence on the inversion effect but a significant reduction in overall recognition performance. Taken together, our results suggest that face contour information can have an impact in influencing both the inversion effect and overall recognition performance.

Face recognition is a skill that most people rarely think about, but it is fundamental to successful social interaction. When someone enters our office or approaches us on the street, we look to their face to determine who they are, and we can usually instantly recognize the person. Although face recognition feels effortless, recognizing a face is hard because all faces are physically quite similar to one another; facial features are in the same location in everyone, with two eyes above a nose above a mouth. In addition, we see them from many different viewpoints, at a range of distances and under variable lighting conditions. The challenge posed by face recognition can be hard to appreciate because we are so good at making use of the information in faces seen in their usual upright orientation, but it becomes much more apparent when faces are turned upside down. Hence, the mechanisms underpinning the processes underlying face recognition skills are an important and sometimes contentious area of debate and have been since the discovery of the face inversion effect by Yin (1969).

The face inversion effect is the name given to the phenomenon in which recognition of faces is affected more greatly by inversion than recognition of non-face stimuli. Yin tested faces against other mono-oriented stimuli (e.g., houses, planes, men in motion) in a variety of paradigms and found that both memory and recognition performance declined when stimuli were inverted and that this decline was disproportionately greater for faces. This inversion manipulation has been used extensively throughout the literature as an index of face recognition. This disparity between faces and non-face stimuli when inverted was initially attributed to some specific neural mechanism that is unique to face recognition which is disrupted by inversion (Scapinello and Yarmey, 1970; Valentine and Bruce, 1986; Haxby et al., 2000; Yovel and Kanwisher, 2005). Yin (1969) did not explain what this mechanism might be but noted that for most stimuli participants reported trying to pick specific features of the image to remember but for faces they tended to try to remember a general impression of the image, something that they struggled to do when it was inverted.

This face specific mechanisms interpretation has been challenged, in the first instance by Diamond and Carey (1986) who proposed an alternative explanation based on expertise with prototype-defined categories. They discovered that an inversion effect equivalent to that for faces can be found for dog images when the participants were dog breeders. They proposed that there are different types of information, each with distinct roles in recognition processing. First-order relational information refers to the average spatial arrangements among the main features within a face/object (e.g., within a face the nose above the mouth and so on). Second-order relational information refers to the small variations of these spatial arrangements for each exemplar compared to the prototype face/object. Both are configural information and are different from featural information which refers to each feature taken in isolation.

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* Corresponding author.
E-mail address: c.civile@exeter.ac.uk (C. Civile).

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Based on this Diamond and Carey (1986) proposed that it is our considerable expertise in using the configural information provided by upright faces that allows us to recognise them so successfully and that the use of this expertise is disrupted when the faces are inverted, resulting in the observed decline in recognition performance.

Support for the expertise account of face recognition indexed by the inversion effect came from the work conducted using artificial sets of stimuli which participants were trained to recognize. One example of this is the work by Gauthier and Tarr (1997) using sets of novel artificial stimuli constructed so as to share some constraints with faces i.e., Greebles. The authors revealed that when participants had been trained with a Greeble configuration, the recognition of a Greebles' part was easier if presented within the familiar configuration compared to when presented in isolation or within a modified configuration. However, this advantage in recognition was lost when the stimuli were presented upside-down. In a similar vein, McLaren (1997), McLaren and Civile (2011), Civile et al. (2014a), (2016a) and (2021a) using non-mono-orientated categories of checkerboards demonstrated that a robust inversion effect can be obtained after the participants were pre-exposed to the checkerboards. Importantly, the inversion effect was only obtained when checkerboards were drawn from a prototype-defined familiar category (i.e., they shared a configuration), whereas no inversion effect was obtained when the checkerboards were drawn from a category that was not represented by a prototype (i.e., they did not share a configuration). Taken all together, these findings provided additional support to the account first proposed by Diamond and Carey (1986) and more specifically for the idea that expertise for configural information is a key factor determining our face recognition skills.

In addition to the debate on the nature of face recognition mechanisms, another debate that emerged was that on the face inversion effect itself and the specific source of visual/perceptual information involved in this phenomenon. Several authors have manipulated face stimuli or object/pattern stimuli to systematically investigate the role that configural information and featural information have in the inversion effect. Leder and Bruce (1998) used face stimuli that had been rated as average in distinctiveness and manipulated them to increase their distinctiveness by altering either the featural or configural information. They found that featural and configural manipulations both resulted in higher perceptions of distinctiveness for the upright faces compared to the originals, but that the apparent distinctiveness of faces with the configural manipulation was reduced significantly more than those with the featural manipulation when faces were inverted. Tanaka and Sengco (1997) (see also Tanaka and Farah 1993) altered the second-order relational information of face stimuli by either moving the eyes closer together or farther apart. Participants were tested on recognition of facial features (e.g., eyes, nose, mouth) in isolation (presented without the surrounding of the face), new configurations (presented in a face with different eye spacing from the study phase), and old configurations (presented in a face with same eye spacing as in the study phase). It was found that participants recognized features best when presented in the old configuration. Importantly, participants were not sensitive to any configural disruption on inversion. The authors proposed that disruption to second-order configural information impacts our ability to recognise individual features in upright but not inverted faces, thereby affecting the inversion effect. Interestingly, Tanaka and Farah (1991) used sets of dot patterns, some of which shared a configuration and some which did not. For those that did not share a configuration discrimination between exemplars was achieved through first-order configural information, while for those that did share a configuration discrimination between exemplars relied on second-order configural information. Participants were trained to identify these dot patterns during a study phase and were later asked to identify them in either their upright or inverted orientation during a test phase. The findings showed that inversion did not have a different impact depending on whether the dot pattern shared a spatial configuration, indicating that second-order information is not more greatly affected by inversion than first-order information, and both may contribute to the face inversion effect

Featural information has also been shown to be important to the process of face recognition. A plethora of research was considered in a meta-analysis conducted by McKone and Yovel (2009), in which they aimed to assess the hypothesis that perception based on local features would show little or no inversion effect and found this to be unsupported by the evidence they evaluated. Their results indicated that in addition to configural information, the orientation of the individual features could also contribute to the inversion effect and in fact they posit that the contribution from featural information can be just a great as that from configural information. For instance, Rakover and Teucher (1997) showed that it was possible to record a robust inversion effect for facial features presented in isolation suggesting that configural information is not necessary to obtain this effect. This position was also supported by Civile et al. (2014a)'s work using altered face stimuli to manipulate the types of information available to participants. The authors created a set of scrambled faces designed to disrupt both first and second order configural information, in each case one of the features was moved to the forehead and the others were moved in sequence to take the place of the last. They used an old/new recognition task common in the face recognition literature in which participants were asked to memorise a set of faces during a study phase and then shown those same faces along with a new set in a recognition phase and asked to identify which had been in the original set and which were new. It was discovered that while disruption to both types of configural information through scrambling reduced recognition performance (compared to normal faces), it was not sufficient to significantly reduce the inversion effect. A follow up experiment was conducted to investigate a potential causal role of the individual features in the inversion effect. This involved the creation of new stimuli called “50% Feature-Inverted and Scrambled Faces”. These were based on the scrambled faces previously described, but, in addition, half of the features in the face (one eye, one ear and either the nose or mouth) were also inverted. This configuration means that no matter the overall orientation of the stimuli, half of the features are always inverted. The same old/new recognition task was used, and it was found that with both configural and single feature orientation information manipulated in this way, the inversion effect was eliminated. This pattern of results suggested that the orientation of facial features in isolation is also relevant when studying the causes of the inversion effect.

In subsequent work Civile et al. (2016a) first replicated the findings from Civile et al. (2014a) and then they investigated further whether second-order relational information is required to produce the face inversion effect while controlling for single feature orientation information. Using the previous technique of inverting half of the features in a face, they created a set of “new Thatcherized” faces. In the original version of the ‘Thatcher Illusion’ subjects were presented with inverted upside-down images (posters) of the British PM Margaret Thatcher. One image was the unaltered “normal” face of Margaret Thatcher, the other one had been manipulated by rotating the both the eyes and the mouth by 180° from their usual orientation. Subjects found it hard to detect any differences between the normal and the manipulated faces when inverted. However, when the two images were rotated and presented upright, the subjects rapidly detected that the two faces were different and that one looked incredibly bizarre (Thompson, 1980). Since this discovery the Thatcher manipulation (i.e., rotating the eyes and the mouth by 180°) has become one of the most used in the literature to investigate the impact that the inversion effect has on face recognition. This is because this manipulation alters the featural and second-order relational information while maintaining the first-order relational information relatively unaltered. However, having both eyes inverted may present an issue given that the eyes have been shown to be highly salient in face recognition (Ellis et al., 1979; Haig, 1984; Hosie et al., 1988). Civile et al. (2016a) revised the Thatcher manipulation to control for this, by inverting just one of the eyes, along with one of the ears and either the nose or mouth. The set of New Thatcherized faces created were based on normal i.e., non- scrambled faces, meaning that first-order relational information remained relatively unaltered while second-order relational information was disrupted, and single feature orientation information was controlled for. The results from a series of studies using an old/new recognition task confirmed a significantly reduced inversion effect (compared to normal faces) for New Thatcherized faces but did not eliminate the effect. Overall, the results from Civile et al. (2014a) and Civile et al. (2016a) indicated that both featural and first-order relational information play a causal role in the inversion effect

There are two key findings from the work conducted by Civile et al. (2014a) and Civile et al. (2016a). Firstly, the full disruption of the configural information provided by the main facial features (through the scrambling manipulation) does not significantly affect the robustness of the inversion effect. Secondly, the inversion effect is eliminated only when, in addition to the scrambling manipulation, half of the main facial features are also turned upside-down. In the current paper we conducted a series of large studies where we aimed to extend our understanding of the role of different information in determining the face inversion effect and face recognition performance in general. Specifically, to our knowledge no study has directly investigated the effects that manipulating the face contour would have on the inversion effect. As a starting point for our investigation, we selected the robust inversion effect found for scrambled faces in Civile et al. (2014a) and Civile et al. (2016a) and we compared it with the effect obtained for the same set of scrambled faces with a contour blurring manipulation (Experiment 1). We then expanded our investigation to normal faces for which the contour has been either blurred (Experiment 2a) or replaced with a novel contour (Experiment 2b) and finally to New Thatcherized faces (Civile et al., 2016a) with a novel contour (Experiment 3). Overall, the results from our studies reveal that the face contour contribute to the inversion effect and has a role in determining overall recognition performance.

Experiment 1

Methods

Subjects

Overall, 144 naïve participants (89 female, 55 male; Mean age = 21.7, age range = 16-57, $SD = 6.39$) took part in Experiment 1. 72 of these were students at the University of Exeter who participated for course credit, and 72 we recruited through the third-party recruitment service Prolific and received monetary compensation adhering to the fair pay policies of Prolific Academic. Analyses with *Recruitment* as a factor (University or Prolific) showed no main effect ($F[1, 142] = 0.262$, $p = 0.60$, $\eta^2_p < 0.01$) and it did not interact significantly with any other factors in the study (max. $F[1, 142] = 2.57$, $p = 0.11$, $\eta^2_p = 0.018$). The sample size was determined from previous studies utilising the same scrambled faces (from the same prototype categories), counterbalancing of the participant conditions and stimuli, and behavioural paradigm (Civile et al., 2018b, 2014a, 2016a, 2011).

Materials

The experiment used 128 face images that were standardized to a greyscale colour on a black background. The original face images were selected from the Psychological Image Collection at Stirling open database, (http://pics.stir.ac.uk). Only male faces were used to enable the hair to be cropped on each image without cropping the ears. This is because males tend to have shorter hair with ears visible whereas females often have longer hair covering the ears, making this feature rather variable. All faces had a neutral emotional expression.

The experiment used two sets of scrambled faces created from the original set of stimuli. The set of scrambled faces with regular face contour was the same as that in Civile et al. (2014a) and Civile et al. (2016a). These were constructed to conform to a prototype-defined category, that is a particular configuration, but not to the regular one that participants would be familiar with. Overall, four prototype-defined categories of scrambled faces were constructed. Within each category, six main facial features (mouth, nose, two ears and two eyes including eyebrows) were used to create the scrambled face exemplars. The scrambling manipulation consisted of selecting at random one of the facial features and moving it to the forehead which is the widest space within the face that can accommodate any feature. A second facial feature was then selected and moved to the space left empty by the first one and so on until all six features had been moved. Within the same category of scrambled faces all the exemplars shared the same new configuration (e.g., it was the mouth that was moved first, the nose second etc.,), but they varied in the facial features as they were taken from different original faces.

The other set of faces used in the experiment consisted of the same four categories of scrambled faces described above with the exception that the contour of the faces was manipulated by blurring the edges that defined the outline of the faces (see Fig. 1).

Participants were presented with scrambled faces with the normal and blurred outline drawn from one category alone (randomly assigned). The four categories of scrambled faces were counterbalanced across participant groups. For each participant, each face identity was shown in only one condition (i.e., scrambled normal-contour upright, or scrambled normal-contour inverted, or scrambled blurred-contour upright, or scrambled blurred-contour inverted). Across participant groups each face identity was shown in each of the four conditions (i.e. they were counterbalanced) to ensure our results were not due to the particular faces employed in a condition.

Procedure

The behavioural task used was an old/new recognition task with normal and no-contour faces presented intermixed. 64 faces were presented one at a time in random order for 3 s, with a 1 s fixation cue in between. These faces were evenly split between normal and blurred-contour, and upright and inverted faces (16 upright normal-contour, 16 inverted normal-contour, 16 upright blurred-contour, 16 inverted blurred-contour). Participants were not required to respond during this phase but were instructed to try to memorise as many of the faces as possible. Following this, participants were shown 128 faces, also presented one at a time and in random order. These were the 64 faces previous shown in the study phase and 64 novel faces which were also split equally between normal and blurred-contour and upright and inverted. They were instructed to respond by pressing “x” or “.” to indicate whether they had seen the faces during the study phase. Participants had 3 s to respond before they were timed out and the next trial began. Images stayed on the screen for the whole 3 s duration of the trial. Response keys were counterbalanced across participants (Civile et al., 2014a, 2016a).

Data analysis

In agreement with previous related studies (Civile et al., 2014a, 2016a, 2014b), for all four experiments reported on this paper the primary measure used in our analyses was a d-prime (d’) sensitivity measure (Stanislaw and Todorov, 1999). This was calculated from the accuracy data obtained during the old/new recognition task. This is because old/new recognition tasks, typically used in the inversion effect literature, are yes/no tasks involving signal and noise trials. This approach assumes that responses are based on the value that a decision variable achieves in each trial. If this is sufficiently high, participants respond yes otherwise they would respond no (Macmillan and Creelman, 2005).

The d’ measure considers both the hit rate (H) and the false alarm rate (F), making it a more useful measure than the number of correct responses alone. H is calculated by extracting the proportion of trials to which the answer is YES and the participants responded YES. F is calculated by extracting the proportion of trials to which the answer is YES and the participants responded NO. The statistic d’ is a measure of this

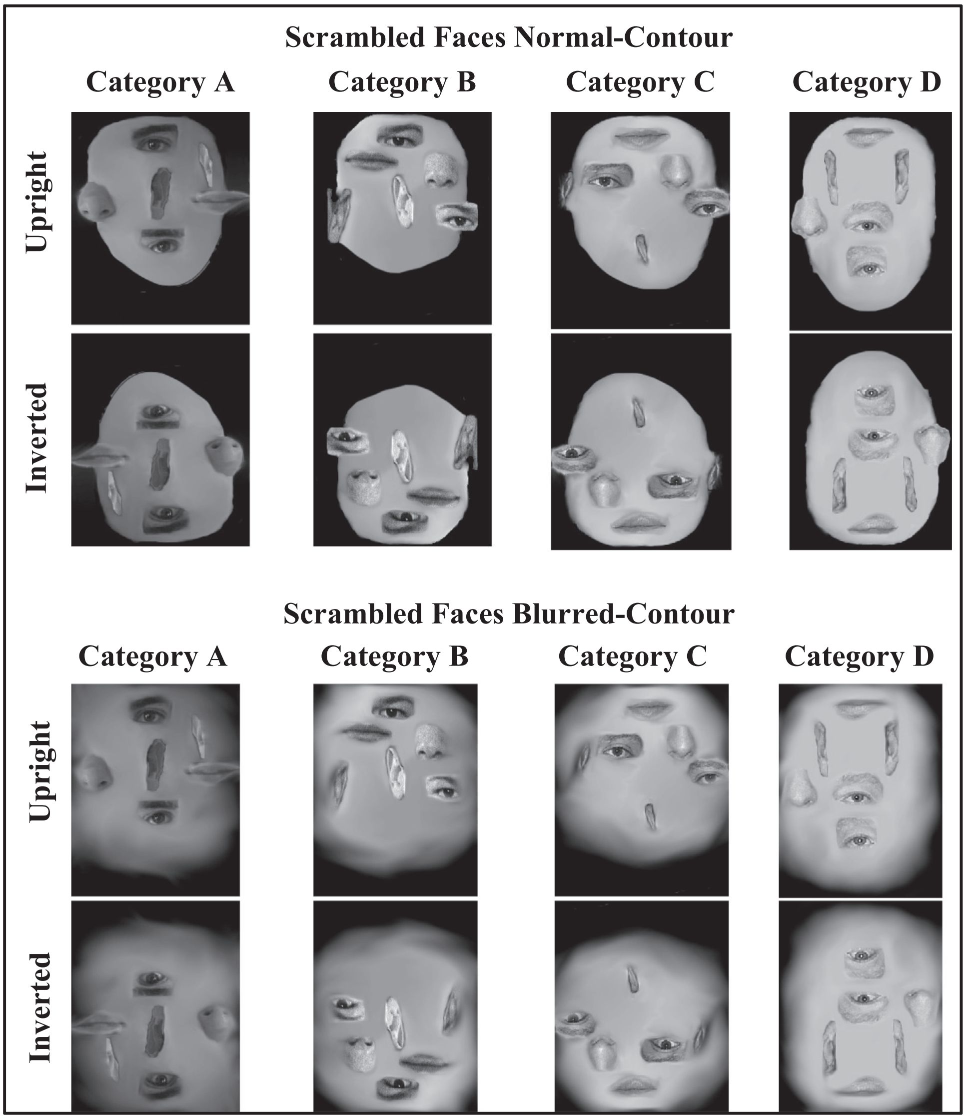

Fig. 1. Examples of stimuli used in Experiment 1 showing one stimulus from each category, upright and inverted. Each exemplar from a given category has the same featural configuration. Thus, for example, each face drawn from Category B had the nose, mouth, and the other four main facial features in the same locations as shown.

difference; it is the distance between the means of the signal + noise and noise alone distributions. Thus, d' is the difference between the z transforms of the two rates: [d' = z(H) - z(F)]. To give an example, in all the experiments here reported, 16 trials were presented in every condition. Let us take the performance for participant 1 in Experiment 1. They responded accurately to 13 out 16 trials for the 'old' (i.e., seen in the study/learning phase) upright scrambled faces with normal-contour. The proportion [13/16] would give us H. They then responded accurately to 5 out 16 trials for the 'new' (i.e., not seen in the study/learning phase) for upright scrambled faces with normal-contour. To extract the F the calculation [(16-5)/16] was applied. Once that H and F were extracted d' was calculated by applying z(H) - z(F) giving a d' of 0.39 for upright scrambled faces with normal-contour. A higher d' value indicates better sensitivity, maximising the H rate and minimising the FA rate.

The p-values reported in all four experiments are all two-tailed, and we report the F or t value along with measures of effect size (η^2_p). For each experiment we have also reported the full statistical analyses for performance on chance level (d' of 0 = 50% chance) in response to each stimulus' conditions as well as overall recognition performance.

Furthermore, following the suggestions from Reviewer 1, we conducted a series of additional analyses where for each experiment the participants with an overall recognition performance lower than chance were excluded from the statistical analyses. The results from these analyses and related figures are reported in the Supplemental Material document.

For completeness, we analysed the reaction time data for the four experiments to check for any speed-accuracy trade-off. No effects of speed-accuracy trade-off were found. These analyses are not reported because they do not contribute anything to the interpretation of our results.

Experiment 1: results

A 2 × 2 within subjects ANOVA was conducted with the factors *Face Type* (scrambled normal-contour, scrambled blurred-contour) x *Orientation* (upright, inverted), this revealed a significant main effect of *Orientation* (with upright better), $F(1, 143) = 17.28$, $p < 0.001$, $\eta^2_p = 0.108$ indicating that overall a robust inversion effect was found. No significant main effect for *Face Type* was found, $F(1, 143) = 0.63$, $p = 0.425$, $\eta^2_p < 0.01$ indicating that there was no difference in overall recognition performance (upright and inverted stimuli averaged together) between the scrambled faces with a normal contour and those without a blurred contour. Critically, a significant overall interaction (*Face Type x Orientation*) was found, $F(1, 143) = 4.41$, $p = 0.037$, $\eta^2_p = 0.030$ was found indicating that the inversion effect for one of the two face types was found to be significantly larger than for the other one. Hence, two paired-sampled

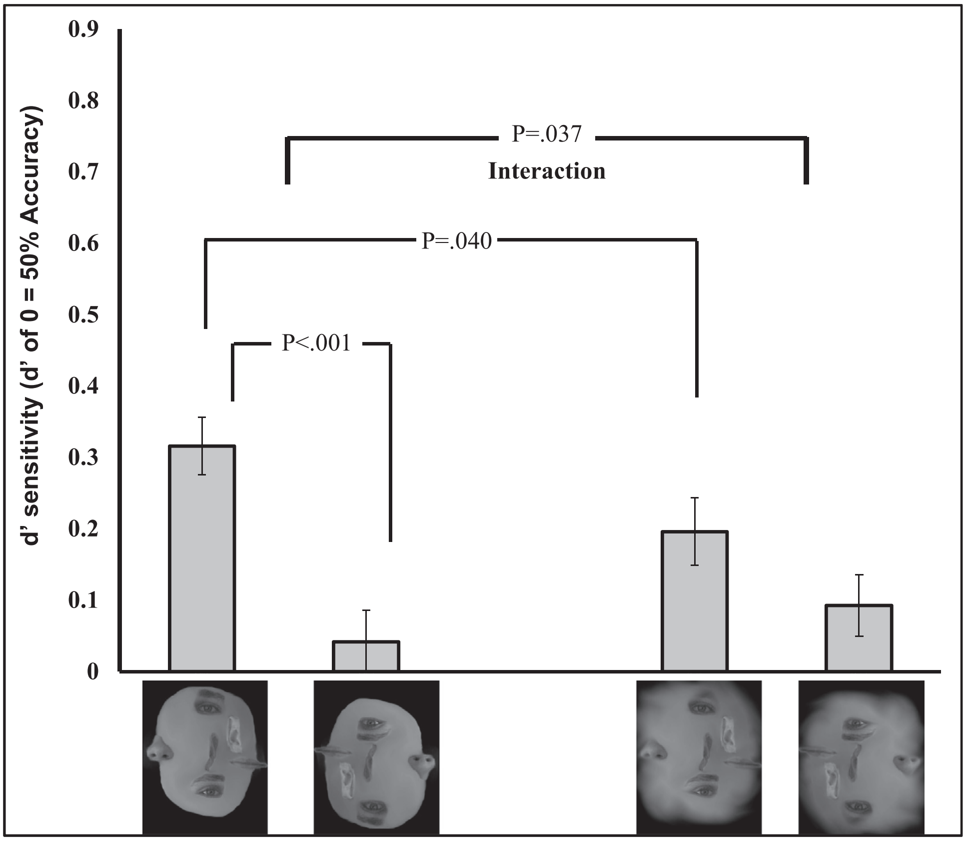

Fig. 2. Graph reporting the inversion effect results from Experiment 1. The x-axis shows the stimulus condition, and the y-axis shows d' sensitivity. The error bars show the SE of the mean. A significant inversion effect was found for scrambled normal-contour faces but not for scrambled blurred-contour faces.

t-tests were conducted for each face type to compare performance for upright and inverted faces i.e., the inversion effect. These revealed a large inversion effect for scrambled normal-contour faces with performance for upright faces (*M* =0.31 *SD* =0.48) significantly better than that for inverted faces (*M* = 0.04 *SD* = 0.53), *t*(143) = 4.71, $p < 0.001$, $\eta^2_p = 0.036$. For the scrambled blurred-contour faces there was a numerical difference between upright faces (*M* = 0.19 *SD* = 0.57) and inverted faces (*M* = 0.09 *SD* = 0.51), but no independently significant inversion effect was found, *t*(143) = 1.62, p = 0.107, $\eta^2_p = 0.239$. We therefore interpret the significant interaction in the 2 × 2 ANOVA as being the result of a reduced inversion effect in the scrambled blurred-contour faces (see Fig. 2).

In agreement with previous studies (Civile et al., 2014a, 2016a), we directly compared performance for upright scrambled normal-contour faces with that for upright scrambled blurred-contour faces and compared performance for inverted scrambled faces normal-contour with inverted scrambled blurred-contour faces. These are particularly important comparisons because the stimulus sets are counterbalanced across participants such that each upright or inverted face shown in the scrambled normal-contour condition for a given participant will equally often serve as an upright or inverted face in the scrambled blurred-contour condition as well. Performance for upright scrambled normal-contour faces was significantly higher than that for scrambled blurred-contour faces, *t*(143) = 2.07, p = 0.040, $\eta^2_p = 0.029$. No significant difference was found between inverted scrambled normal-contour and inverted scrambled blurred-contour faces, *t*(143) = 0.846, p = 0.399, $\eta^2_p < 0.01$. This suggests that the difference in the inversion effects is mostly (but not exclusively) due to a difference in performance to upright faces.

We also analysed recognition performance against chance (d' of 0) for each stimulus condition. Performance for upright scrambled normal-contour faces was significantly above chance, *t*(143) = 7.45, $p < 0.001$, $\eta^2_p = 0.44$, as well as that for upright scrambled blurred-contour faces, *t*(143) = 3.93, $p < 0.001$, $\eta^2_p = 0.18$. There was a similar trend for inverted blurred-contour scrambled faces, *t*(143) = 1.95, p =0.052, $\eta^2_p = 0.05$. Performance for inverted normal-contour scrambled faces was not significantly above chance, *t*(143) = 0.75, p =0.453, $\eta^2_p < 0.01$. Overall performance across all the four conditions was significantly above chance, *t*(143) = 6.17, $p < 0.001$, $\eta^2_p = 0.35$.

Discussion

These results in part confirm the findings of Civile et al. (2014a) and Civile et al. (2016a) that a robust inversion effect can be found for scrambled face stimuli derived from prototype-defined categories when the individual feature orientation information is unaltered providing further evidence that familiar configural information is not always necessary to obtain a significant inversion effect. Importantly, they also indicate that manipulation of the face contour, results in the inversion effect for scrambled faces being significantly reduced. Based on this we suggest that the face contour, when there is disruption of the familiar configural information by means of the scrambling manipulation, can contribute to the inversion effect. The next step in our investigation was to assess the extent to which face contour disruption alone is sufficient to reduce the inversion effect on normal faces. Hence, in Experiment 2a the inversion effect for normal faces was compared with that for the same set of faces with their contour manipulated using the same blurring manipulation as in Experiment 1.

Experiment 2a

Methods

Subjects

As with Experiment 1 there were 144 naïve participants (98 female, 46 male; Mean age=23.1, age range=18–55, SD=7.04) of which 72 were recruited through the University of Exeter and received course credit for

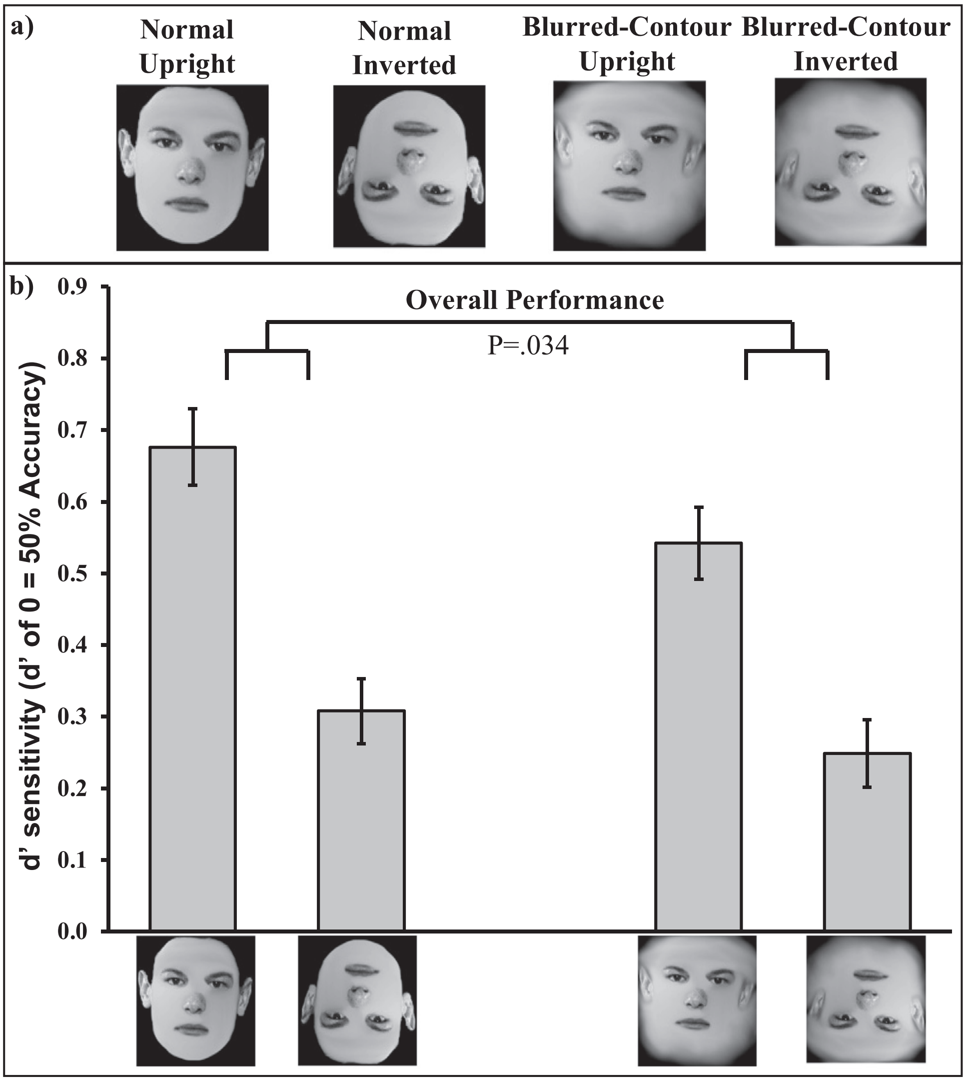

Fig. 3. *Panel a* shows Examples of the stimuli used in Experiment 2a. Examples of each stimulus type are shown with normal contour and blurred contour faces shown in both the upright and inverted orientation. *Panel b* illustrates a graph reporting the results from Experiment 2a. The x-axis shows the stimulus condition, and the y-axis shows d' sensitivity. The error bars show the SE of the mean.

their participation and 72 were recruited through the online platform Prolific and were compensated in accordance with Prolific Academic's fair pay policies. Analyses with *Recruitment* as a factor (University or Prolific) showed no main effect ($F[1, 142] = 1.59$, $p = 0.22$, $\eta^2_p = 0.01$) and it did not interact significantly with any other factors in the study (max. $F[1, 142] = 2.82$, $p = 0.10$, $\eta^2_p = 0.02$).

Materials

The experiment used 128 face images that were standardized to a greyscale colour on a black background. The original face images were selected from the Psychological Image Collection at Stirling open database, (http://pics.stir.ac.uk). In this experiment we also used two sets of faces. One set of faces were the same normal faces as those used in Civile et al. (2014a) and Civile et al. (2016a). These were male faces looking straight ahead with a neutral expression. Their hair and neck were cropped leaving only the features and outline of the face. All faces were also smoothed to the same extent as the sets of scrambled faces used in Experiment 1 to control for any effect of this manipulation. The other set of faces used in the experiment consisted of the same normal faces described above with the exception that the contour of the faces was manipulated by blurring the edges that define the outline of the faces (see Fig. 3a).

For each participant each face identity was shown in only one condition (i.e., normal-contour upright or normal-contour inverted or normal blurred-contour upright or normal blurred-contour inverted). Across participants groups each face identity was shown in each of the four conditions.

Procedure

The behavioural task used was the same as that used in Experiment 1.

Results

A 2 × 2 within-subjects ANOVA was conducted using as factors *Face Type* (normal contour, blurred-contour) x *Orientation* (upright, inverted) which revealed a significant main effect of Orientation, $F(1, 143) = 48.65$, $p < .001$, $\eta^2_p = 0.25$, indicating an overall robust inversion effect (upright better than inverted). A significant main effect of Face Type, $F(1, 143) = 4.57$, $p = 0.034$, $\eta^2_p = 0.03$, was found showing that overall recognition performance for normal faces with the contour (M = 0.49, SD=0.46) was significantly higher than that for normal faces with blurred-contour (M=0.39, SD=0.45). Critically, no significant interaction (Face Type x Orientation) was found this time, $F(1, 143) = 0.90$, $p = 0.34$, $\eta^2_p < 0.01$, indicating that both sets of faces showed a robust inversion effect, although numerically the inversion effect for normal faces with blurred-contour (M = 0.29, SD = 0.74) was smaller than the one found for normal faces with normal contour (M = 0.37, SD = 0.74) (see Fig. 3b).

Finally, performance for upright normal-contour faces, $t(143) = 12.63$, $p < 0.001$, $\eta^2_p = 0.53$, upright blurred-contour faces, $t(143) = 6.78$, $p < 0.001$, $\eta^2_p = 0.24$, inverted normal-contour faces, $t(143) = 10.79$, $p < 0.001$, $\eta^2_p = 0.45$, and inverted blurred-contour faces, $t(143) = 5.26$, $p < 0.001$, $\eta^2_p = 0.16$, was significantly above chance. Overall performance across all the four conditions was significantly above chance, $t(143) = 14.38$, $p < 0.001$, $\eta^2_p = 0.59$.

Discussion

The results from Experiment 2a suggest that disruption of face contour alone is not sufficient to significantly reduce the inversion effect although a numerical reduction is found for the normal faces with blurred-contour. However, our manipulation is having a significant effect on overall recognition performance resulting in the significant decrease in performance when the outline is disrupted. One possibility is that the blurring manipulation not only affects the outline of the faces but also degrades the image overall, which may have contributed to the reduction in overall recognition performance in Experiment 2a. In addition, the blurring removes any sense of "objecthood" the image has and make it not only less face-like but also less like any recognisable stimulus. To address these issues, we designed a new manipulation that we tested in for Experiments 2b that would maintain the integrity of the normal face images and the information that makes them distinct from one another while still eliminating the characteristic face outline. Thus, Experiment 2b was a replication of Experiment 2a however this time we designed a face manipulation that would replace the typical normal face outline with a novel face outline instead of removing it entirely.

Experiment 2b

Methods

Subjects

In line with the previous experiments 144 participants were tested (72 female, 70 male; 2 prefer not to say; mean age = 26.1, age range = 18–71, SD = 8.69). In this experiment all participants were recruited through Prolific and were compensated in accordance with Prolific Academic's fair pay policies.

Materials

Experiment 2b used two sets of stimuli. One set was the same normal faces with contour from Experiment 2a. The other set of stimuli started with the same set of normal faces used in Experiment 2a, however, in this instance instead of blurring the outline of these faces to alter the contour, we instead created a new spiked outline. Each face had 8 spikes added to the outside of the face spaced evenly around the outline. The existing spatial relationships of the features for each face were used to create the new ones with the distance from the centre of the face to the original outline being measured and used to determine the length of a given spike i.e., if the distance from the centre of the nose to the top of the forehead on the original face was 0.4 cm, then the distance from the forehead to the tip of the spike was also made 0.4 cm. Hence, the new contour similarly to a 'normal' contour would vary from face to face based on the spatial relationships between the facial features and the original contour. The bottom of the spikes was brought down to a point slightly above the original outline to prevent an effect similar to the Kanizsa triangle illusion (Kanizsa, 1955) in which the facial outline is in a sense generated by bottom points of the spikes. The new spike outline was then smoothed and blended with the existing face to create a seamless image. Once again images were standardised to greyscale on a black background (Fig. 4a). In this way we were able to maintain some of the information from the outline that made the faces distinct from one another, whilst still eliminating the usual face outline that has been theorised to elicit holistic processing.

For each participant each face identity was shown in only one condition (i.e., normal-contour upright or normal-contour inverted or normal new-contour upright or normal new-contour inverted). Across participants groups each face identity was shown in each of the four conditions.

Procedure

This was the same as for the previous experiments.

Results

A 2 × 2 within-subjects ANOVA using as factors *Face Type* (normal contour, new-contour) x *Orientation* (upright, inverted) revealed a significant main effect of Orientation, $F(1, 143) = 42.00$, $p < 0.001$, $\eta^2_p = 0.23$ indicating that overall a robust inversion effect was found. In this experiment as well we found a significant main effect of Face Type, $F(1, 143) = 7.45$, $p = 0.006$, $\eta^2_p = 0.05$, showing how overall recognition performance for normal faces with the normal contour (M = 0.56, SD=0.48) was significantly larger than that for normal faces with the new-contour (M=0.40, SD=0.40). Critically, no significant interaction (Face Type x Orientation) was found, $F(1, 143) = 2.57$, $p = 0.11$, $\eta^2_p = 0.02$, indicating how both sets of faces showed a robust inversion effect even though the inversion effect for normal faces with new-contour (M = 0.28, SD = 0.74) was numerically smaller than the one found for normal faces with normal contour (M = 0.42, SD = 0.92) (see Fig. 4b).

Finally, performance for upright normal-contour faces, $t(143) = 11.69$, $p < 0.001$, $\eta^2_p = 0.49$, upright new-contour faces, $t(143) = 11.42$, $p < 0.001$, $\eta^2_p = 0.47$, inverted normal-contour faces, $t(143) = 6.44$, $p < 0.001$, $\eta^2_p = 0.22$, and inverted new-contour faces, $t(143) = 6.51$, $p < 0.001$, $\eta^2_p = 0.23$, was significantly above chance. Overall performance across all the four conditions was significantly above chance, $t(143) = 13.68$, $p < 0.001$, $\eta^2_p = 0.56$.

Additional analyses Experiment 2a and 2b together

Due to the same procedures being used and the similar results obtained across Experiment 2a and 2b we decided to conduct an additional set of analyses aiming to examine the influence of using the blurred-contour vs the new-contour manipulation on the inversion effect and overall performance for normal faces.

A 2 × 2 × 2 ANOVA was conducted with the within-subjects factors *Face Type* (normal normal-contour, normal blurred/new-contour) x *Orientation* (upright, inverted), and the between-subjects factor *Experiment* (Experiment 2a, Experiment 2b).

No significant main effect of *Experiment* was found, $F(1, 286) = 0.803$, $p = 0.371$, $\eta^2_p < .01$, nor any significant interaction for *Experiment x Face Type,* $F(1, 286) = 0.009$, $p = 0.924$, $\eta^2_p < 0.01$, or for *Experiment x Orientation,* $F(1, 286) = 0.037$, $p = 0.848$, $\eta^2_p < 0.01$. And, no significant three-way interaction was found, $F(1, 286) = 0.042$, $p = 0.683$, $\eta^2_p < .01$. Overall, we have no evidence to suggest that adopting the blurred-contour vs new-contour manipulation would induce different effects.

Coming back to the overall ANOVA, we found a significant main effect of *Orientation* (with upright better), $F(1, 286) = 92.65$, $p < 0.001$, $\eta^2_p = 0.245$ and a significant main effect for *Face Type,* $F(1, 286) = 12.85$, $p < 0.001$, $\eta^2_p = 0.043$ with higher overall recognition performance for normal faces with a normal contour (M = 0.52, SD = 0.51) vs normal faces with blurred/new contour (M = 0.41, SD = 0.44).

Critically, a significant interaction was found between, *Face Type* and *Orientation,* $F(1, 286) = 3.95$, $p = 0.047$, $\eta^2_p = 0.014$. Paired-sampled *t*-tests revealed a large inversion effect for normal faces ($M = 0.40$, $SD = 0.83$), $t(287) = 5.50$, $p < 0.001$, $\eta^2_p = 0.192$ and a significantly reduced one for the blurred/new-contour normal faces ($M = 0.28$, $SD = 0.74$), $t(287) = 4.52$, $p < 0.001$, $\eta^2_p = 0.130$ (see Fig. 5).

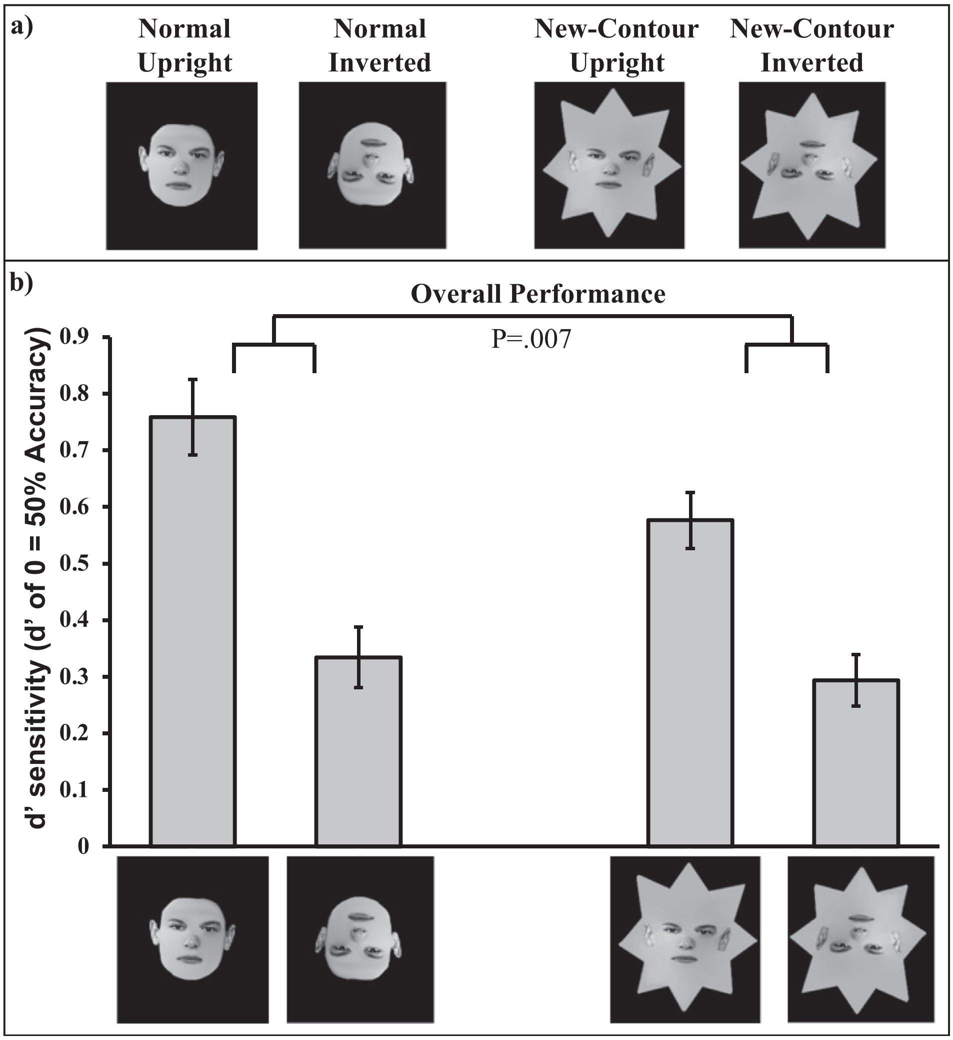

Fig. 4. *Panel a* shows examples of the stimuli used in Experiment 2b. Examples of each stimulus type are shown with normal contour and spiked contour faces shown in both the upright and inverted orientation. *Panel b* illustrates a graph reporting the results from Experiment 2b. The x-axis shows the stimulus condition, and the y-axis shows d' sensitivity. The error bars show the SE of the mean.

In agreement with previous studies (Civile et al., 2014a, 2016a), and our Experiment 1, to determine what leads the reduction of the inversion effect we directly compared performance for upright normal faces with normal-contour (*M* =0.73, *SD* =0.71) with that for upright normal faces with blurred/new-contour (*M* = 0.56, *SD* = 0.59), which revealed a significant difference, *t*(287) = 14.17, p < 0.001, $\eta^2_p = 0.04$. No significant difference was found between inverted normal faces with a normal contour (*M* = 0.32, *SD* = 0.59) vs blurred/new-contour (*M* = 0.27, *SD* = 0.55), *t*(287) = 1.54, p = 0.215, $\eta^2_p < 0.01$. This suggests that in this case, and in agreement with Experiment 1, the difference in the inversion effects is mostly (but not exclusively) due to a difference in performance to upright faces.

Additional Bayesian Factor analyses

We conducted a Bayes Factor analysis on the difference between the d' values for upright and inverted faces (i.e., the inversion effect) comparing normal faces with normal contour vs normal faces with blurred/new-contour (thus capturing the 2 × 2 interaction) for the additional analysis where Experiment 2a and 2b data were pooled together. We adopted the procedure outlined by Dienes (2011), using as a prior the interaction from Experiment 1, setting the standard deviation of p (population value | theory) to the mean of the differences in the inversion effect between normal vs no-contour scrambled faces (0.17). We used the standard error (0.05) and mean difference (0.12) between normal-contour and blurred/new-contour normal faces from Experiment 2a and 2b together. We assumed a one-tailed distribution for our theory and a mean of 0. This produced a Bayes factor of 7.89 which confirms that we can be confident (greater than 3, for the conventional cut-offs see Dienes 2011, Jeffreys 1961) that these results are in line with those of Experiment 1, showing that the reduction of the inversion effect when the face contour is manipulated is a reliable finding.

Similarly, we also conducted a Bayes Factor analysis using as a prior the mean difference between upright scrambled faces (normal-contour vs no-contour) in Experiment 1 (0.12). We then used the standard error (0.04) and mean difference (0.16) between upright normal faces (normal contour vs blurred/new-contour) in Experiment 2a and 2b together. This produced a Bayes factor of 845. 15 which is strong evidence (greater than 10, for the conventional cut-offs see Dienes 2011, Jeffreys 1961) that these results are in line with those of Experiment 1, indicating that when the face contour is manipulated recognition for upright faces (either scrambled or normal) is reduced.

Discussion

These results from Experiment 2b are consistent with Experiment 2a, showing that for normal faces, changing the outline affects overall recognition performance and only numerically the inversion effect. However, from the analysis conducted on the pooled data from both experiments (2a and 2b) the inversion effect is significantly reduced when the outline of the faces is manipulated (either by the blurring manipulation or

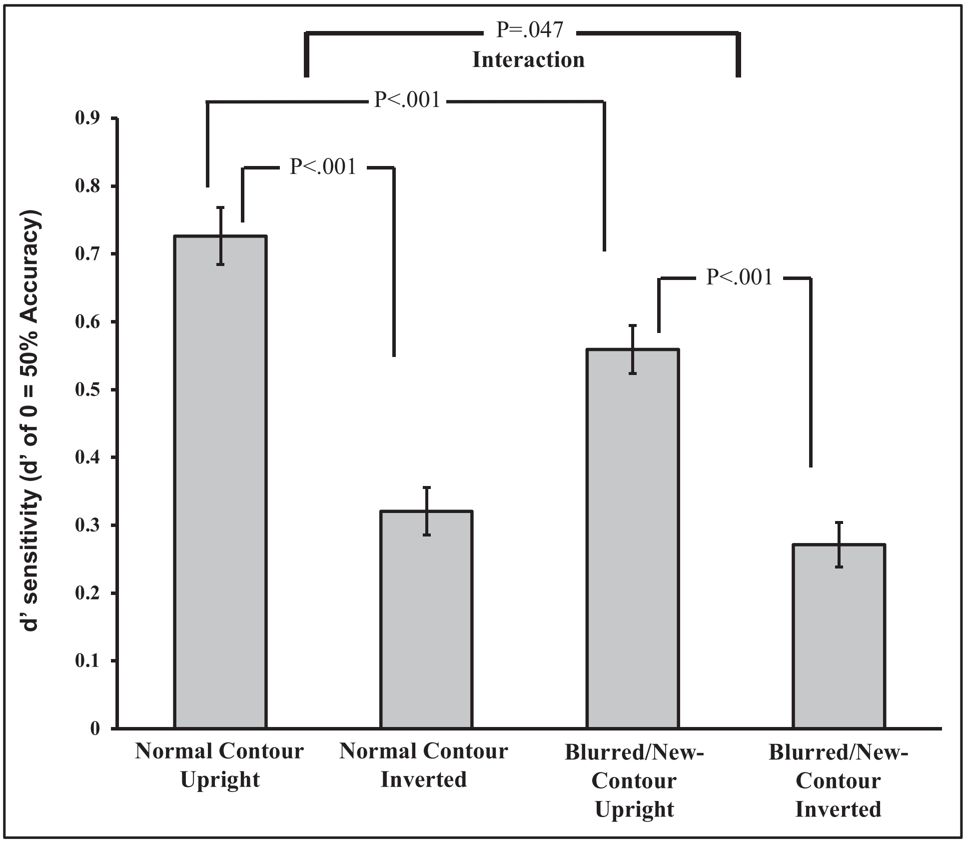

Fig. 5. Illustrates a graph reporting the results from Experiment 2a and 2b put together. The x-axis shows the stimulus condition, and the y-axis shows d' sensitivity. The error bars show the SE of the mean.

replacing it with a novel outline). This reduction would seem to be due mainly by impaired performance for upright faces with the manipulated outline. This claim is also consistent with the results of the Bayesian factor analysis which show that the reduced inversion effect and impaired performance for upright faces are in line with the results from Experiment 1. The additional analysis also confirmed that overall recognition performance is affected by the manipulations of the face outline. In our final study we extended the new-contour manipulation to the set of New Thatcherized faces previously established by Civile et al. (2016a). The aim this time was to investigate whether the contour manipulation would affect the inversion effect and recognition performance in a set of faces where orientation of the individual features is controlled for (three features upright and three features inverted) and the first-order relational information is relatively unaltered. However, second-order relational information will be somewhat affected by rotation of some of the individual features through 180°. Note that Civile et al. (2016b) found that for New Thatcherized faces the inversion effect was still significant though reduced in size.

Experiment 3

Methods

Subjects

144 naïve participants (70 female, 74 male; mean age = 30.4, age range = 18–64, SD = 10.42) were again recruited through Prolific and compensated in accordance with Prolific Academic's fair pay policies.

Materials

The experiment used 128 face images that were standardized to a greyscale colour on a black background. As the previous experiments reported on this paper, the original face images were selected from the Psychological Image Collection at Stirling open database, (http://pics.stir.ac.uk). Only male faces were used so to enable the hair to be cropped on each image without cropping the ears. All faces had a neutral emotional expression.

We constructed two sets of New Thatcherized faces from the original set of stimuli. The set of New Thatcherized faces with regular face contour was the same as that in Civile et al. (2016a). The specific manipulation used to Thatcherize the faces involved rotating by 180° one eye (including eyebrow), one ear, and either the nose of the mouth of the same set of normal faces with a normal contour used in Experiment 2a and 2b. The features selected for rotation were counterbalanced so to create four categories of New Thatcherized faces. Faces drawn from the same category would share the same orientation of the features. The specific manipulation elaborated by Civile et al. (2016a) ensures that within each of the upright or inverted New Thatcherized faces the number of upright and inverted features is the same. The other set of faces used in the experiment consisted of the same four categories of New Thatcherized faces described above with the exception that the contour of the faces was replaced with the new spikey contour manipulation introduced by Experiment 2b (see Fig. 5a).

Participants were presented with New Thatcherized faces with normal and new contour from one category only (randomly assigned). The four categories of faces were counterbalanced across participants groups. For each participant each face identity was shown in only one condition. Across participants groups each face identity was shown in each of the four conditions.

Procedure

This was the same as for the previous experiments.

Results

A 2 × 2 within-subjects ANOVA using as factors *Face Type* (normal contour, new-contour) x *Orientation* (upright, inverted) revealed a

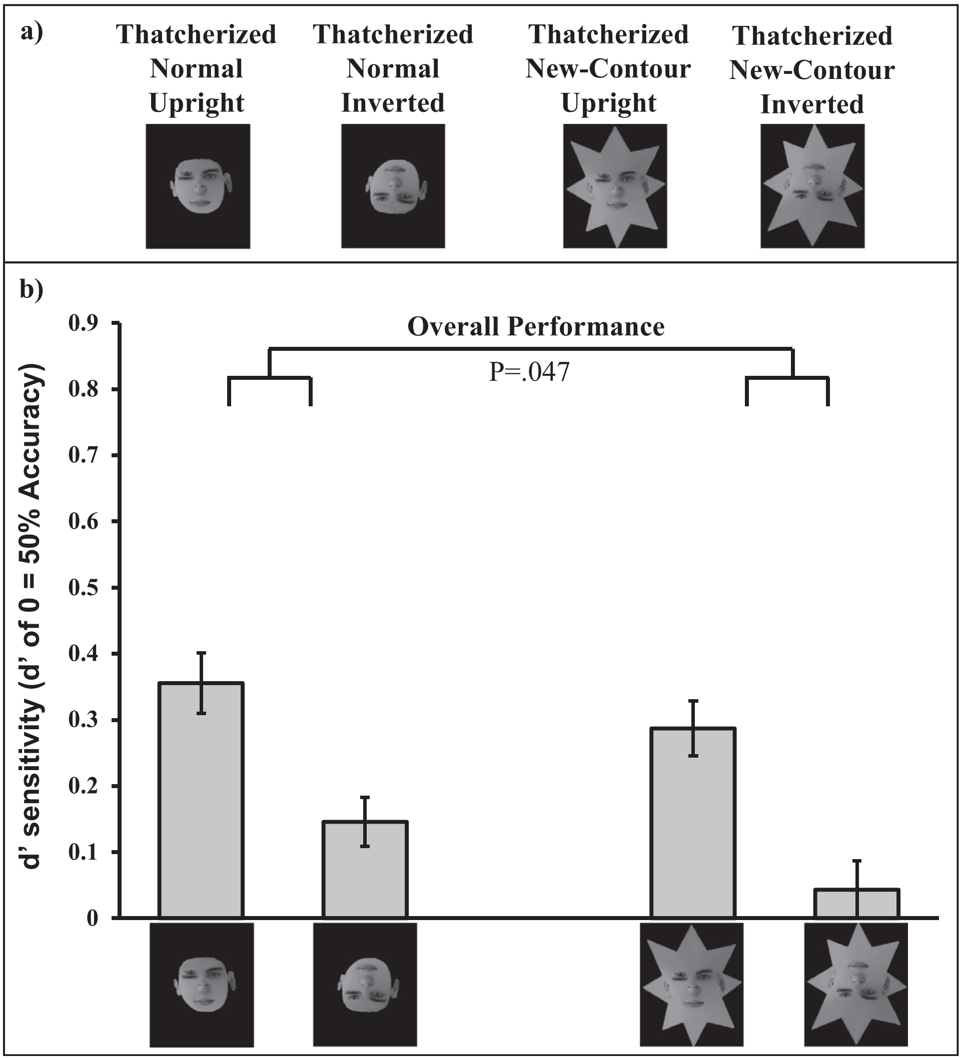

Fig. 6. *Panel a* shows examples of the stimuli used in Experiment 3. Examples of each Thatcherized stimulus type are shown with normal contour and spiked contour faces shown in both the upright and inverted orientation. *Panel b* illustrates a graph reporting the results from the overall recognition performance (upright and inverted faces averaged together) for each Face Type in Experiment 3. The x-axis shows the stimulus condition, and the y-axis shows d' sensitivity. The error bars show the SE of the mean.

significant main effect of Orientation (i.e., the inversion effect), $F(1, 143) = 32.51$, $p < 0.001$, $\eta^2_p = 0.185$. In agreement with Experiments 2a and 2b, in this case we also found a significant main effect of Face Type, $F(1, 143) = 3.98$, $p = 0.047$, $\eta^2_p = 0.027$, revealing greater overall recognition performance for New Thatcherized faces with a normal contour (M = 0.25, SD=0.36) vs that for New Thatcherized faces with the new spikey contour (M=0.17, SD=0.37). Furthermore, no significant interaction (Face Type x Orientation) was found, $F(1, 143) = 0.17$, $p = 0.68$, $\eta^2_p < 0.01$ indicating that both sets of faces showed a robust inversion effect although this time the inversion effect for the New Thatcherized faces with the new contour was actually numerically larger (M = 0.24, SD = 0.68) than that for the New Thatcherized faces with normal contour (M = 0.20, SD = 0.68) (see Fig. 6).

Finally, performance for upright normal contour faces, $t(143) = 7.82$, $p < 0.001$, $\eta^2_p = 0.30$, upright new-contour faces, $t(143) = 6.92$, $p < 0.001$, $\eta^2_p = 0.25$, and inverted normal contour faces, $t(143) = 3.97$, $p < 0.001$, $\eta^2_p = 0.09$. was significantly above chance. Performance for inverted new-contour faces, $t(143) = 1.01$, $p = 0.31$, $\eta^2_p < 0.01$, was not significantly above chance. Overall performance across all the four conditions was significantly above chance, $t(143) = 9.53$, $p < 0.001$, $\eta^2_p = 0.38$.

Bayesian Factor analyses Experiment 3

We also conducted a Bayesian factor analysis for the difference in overall performance between the New Thatcherized faces with normal contour and those with the new spikey contour, using as a prior (population value | theory) the difference in overall recognition performance between face types in Experiment 2a and 2b data pooled together (0.108). We assumed a one-tailed distribution for our theory and a mean of 0. We then used the standard error (0.04) and mean difference (0.09) between overall performance for normal-contour Thatcherized faces and new-contour new Thatcherized faces. This produced a Bayes factor of 6.3 which confirms that we can be confident (greater than 3, for the conventional cut-offs see Dienes 2011, Jeffrey 1961) that these results are in line with those of Experiment 2a and 2b, showing that the reduction in overall recognition performance when the face contour is manipulated is a reliable finding.

Discussion

The results from Experiment 3 reveal that manipulating the face contour does not affect the inversion effect for a set of face stimuli where the single feature orientation information is controlled for (i.e., three features always upright and three always inverted) and first-order relations are relatively unaltered. Importantly, we found a significantly reduced overall recognition performance for new-contour New Thatcherized faces vs normal contour ones, providing more support for the previous results from Experiment 2a and 2b. The Bayesian statistics indicate that this effect on overall performance is in line with that from Experiments 2a and 2b, showing it to be a reliable effect.

General discussion

We have reported the results from a series of large studies (overall n = 576) in which we systematically investigated the effects of manipulating the face contour on the inversion effect and recognition performance in general. Experiment 1 showed that the inversion effect for scrambled faces is significantly reduced when the face contour is manipulated by means of the blurring manipulation. The set of scrambled faces taken from Civile et al. (2014a) was devised to disrupt the usual familiar first and second-order relational information. Civile et al. (2014a) found that the inversion effect for scrambled faces was still highly significant suggesting that that configural information may not be the only source of information determining the effect. The fact that in our Experiment 1 we induced a significant reduction of the inversion effect for scrambled faces mainly due to impaired performance for upright faces suggests how the face contour is an important information that we rely on to recognising upright faces when the other familiar configural information has been disrupted by the scrambling manipulation. This finding directly extends Civile et al. (2014a) by showing how the inversion effect for scrambled faces can be reduced by either disrupting the single feature orientation information (i.e., rotating half of the features upside down, Civile et al. 2014a) or by blurring the face contour. More generally, our findings provide additional support to the literature showing that configural/relational information is not always necessary to obtain the inversion effect (McKone and Yovel, 2009)

The results from Experiment 2a and 2b together provide additional support to the idea that face contour influences the inversion effect. In this case the contour of normal faces was manipulated either by using the same blurring manipulation as for Experiment 1, or by replacing the contour with a novel one. The results from pooling together the data from Experiment 2a and 2b revealed that overall, both manipulations had been effective at reducing the inversion effect for normal faces. Additionally, in this case we also found that the reduction of the inversion effect was mainly due to impaired performance in recognising upright faces with a manipulated contour. The Bayes factor analyses confirm these two main findings across Experiments 1, 2a and 2b. The fact that only numerical differences were obtained in Experiment 2a and 2b taken individually, and the significant overall interaction (Face Type x Orientation) only emerges when the data from the two studies are pooled together, may suggest that the effects are not as robust as those recorded in Experiment 1. One may suggest that the seemingly smaller effect of face contour on normal faces could be because configural information is the main source of information (Maurer et al., 2002). Hence, when unaltered configural information is what contributes the most to face recognition. Thus, unless familiar configural information is disrupted, it would be harder to detect the impact of other source of information. However, as mentioned in our introduction, the exact impact of configural information on the inversion effect is still an open debate. For now, our results suggest that face contour information has an impact on the inversion effect, but future work should investigate the amplitude of this effect and how it is modulated across different manipulations.

Furthermore, the results from Experiment 2a and 2b let us see how manipulating the face contour affected overall recognition performance for normal faces. This is an interesting result that is confirmed in Experiment 3. Here, by using the sets of New Thatcherized faces created by Civile et al. (2016a), we examined whether manipulating the contour for these stimuli would reduce the inversion effect and affect overall performance. Importantly, these stimuli had single feature orientation information controlled for because half of the features were upright, and half inverted irrespective of whether the whole face was presented upright or inverted. Our results show that manipulating the contour of New Thatcherized faces does not affect the inversion effect for these stimuli. But a significant reduction is found in overall recognition performance in line with the results of Experiments 2a and 2b.

The fact that the contour manipulation did not affect the inversion effect for New Thatcherized faces extends previous work conducted by Civile et al. (2016a). The authors suggested that the inversion effect found for the New Thatcherized faces in their studies could be explained by holistic information. According to Hole et al. (1999), holistic information is elicited by anything that conforms to the basic plan of a normal face, and it is holistic processing that establishes that it is a face that is being shown. Hence, Civile et al. (2016a) suggested how first-order relational information, and the face contour, which were both relatively unaltered in New Thatcherized faces, would be used to engage holistic processing which in turn would confer some advantage in the recognition of normal upright faces leading to a significant inversion effect. Our results from Experiment 3 allow us to further characterise the role that first-order relational information has in determining the inversion effect, when the other sources of information have been manipulated (i.e., second order relational information, face contour information) or controlled for (i.e., single feature orientation information). The results from Experiment 3 also show a reduction in overall recognition performance for New Thatcherized faces with the changed contour. This result is line with that found in Experiment 2a and 2b, hence now we have evidence in support of the contour information affecting overall recognition performance. This result contributes to previous literature showing how in certain circumstances (although not tested directly) manipulating the contour would affect both upright and inverted faces but not necessarily the size of the inversion effect (e.g., Malcolm et al. 2004, Royer et al. 2017).

One issue that we have with the evidence collected from Experiment 2a, 2b and Experiment 3 in support of the contour affecting overall recognition performance is that Experiment 1 did not show this effect. A potential explanation for this is that the combination of a generally difficult recognition task and the specific nature of the scrambled faces may have contributed to suppress the effect of contour on overall performance. Hence, both inverted scrambled faces with blurred-contour and with normal contour were not recognized significantly above chance (although the latter showed a clear trend) which may indicate a floor effect. Thus, the potential effect that the contour manipulation could have had at reducing (even if just numerically) performance for inverted scrambled faces with blurred-contour could have been taken away by the fact that performance was already at floor for scrambled faces with normal contour. However, we notice that the results from the additional analyses (see Supplemental Material file) would confirm that in Experiment 1 no significant effect of blurring the contour was found on overall recognition performance. In that circumstance only participants showing above chance performance were included in the analyses ensuring high levels of performance in each condition including the inverted ones. The significant effect of disrupting the face contour on the inversion effect was confirmed as well as no significant difference between overall recognition performance for scrambled normal-contour vs scrambled blurred-contour faces. Importantly, also the results from Experiment 2a, 2b and 3 were confirmed by the additional analyses with the addition that this time in Experiment 2b, the inversion effect was significantly reduced by the contour manipulation even without pooling the data together with Experiment 2a. Future studies should directly investigate the effect of face contour alone or in combination with configural information on overall performance by for example adopting a delayed matching task of the kind used in the literature to ensure higher level of overall recognition performance (Farah et al., 1995; Busigny and Rossion, 2010; Civile et al., 2020a, 2021a).

At this point a consideration to make regards the specific results obtained from Experiment 2a and 2b together which were also confirmed also by the additional analyses (see Supplemental Material file). Specifically, the effect that manipulating the contour of normal faces had on reducing the size of the inversion effect. This effect would seem to resemble the effect that in recent has been often shown through applications of transcranial Direct Current Stimulation (tDCS) on the inversion effect for normal faces. A new line of research derived from the perceptual learning literature has revealed how a specific tDCS procedure can be used to modulate the inversion effect for faces and for artificial set of stimuli (i.e., checkerboards) as a comparison (Civile et al., 2021a, 2021b; Civile et al., 2020a, 2020b 2016a, 2018a, 2019a). It was found that a brief (10 min duration, at 1.5 mA intensity) anodal stimulation at the DLPFC would significantly reduce the inversion effect for normal faces vs sham tDCS control condition or anodal tDCS active control condition. Importantly, this reduction of the inversion effect was found to be due to performance for upright faces being reduced in the anodal tDCS condition. Hence, the same reduction was found for the checkerboard inversion effect (index of perceptual learning; see McLaren 1997, McLaren and Civile 2011, Civile et al. 2014a) when the same anodal tDCS procedure was used vs tDCS sham control. In this case as well the reduced inversion effect was due to performance for upright checkerboards being significantly affected. The similar effects of tDCS on the face and checkerboard inversion effect were used as evidence for the direct link between perceptual learning and face recognition mechanisms and were interpreted based on perceptual learning theories (McLaren et al., 1989; McLaren and Mackintosh, 2000; McLaren et al., 2012). Our results from Experiment 2a and 2b reported on this paper would seem to show a similar pattern of results where the reduction of the inversion effect is mainly due to reduced performance for upright normal faces with a manipulated contour. This could suggest how the nature of the contour influence on the inversion effect could relate to perceptual learning, and how a life-times expertise at seeing upright faces with a specific contour is then disrupted when that contour is manipulated thus causing a reduction in face recognition performance for upright faces. The same effect would not be detected for inverted faces as much, simply because we do not have the same level of expertise and so manipulating the contour has less influence on performance.

An alternative interpretation would have the face contour manipulation affecting the use of face-specific processing mechanisms instead. These processes would have to be assumed to be orientation-specific in nature, such that they are typically engaged to a greater extent by upright faces. Removal of the facial contour would then be hypothesised to reduce engagement with these processes thus reducing recognition. Clearly this would mostly affect upright faces, and so tend to both reduce overall performance and reduce the inversion effect if we allow some effect on inverted faces. At present, we cannot decide whether either (or both) of these interpretations are correct, and clearly more work is needed to clarify this point.

Overall, our results contribute to the general debate in the literature regarding the role of configural, holistic and featural information. Hence, we revealed how in addition to the established first and second-order configural information (Diamond and Carey, 1986; Maurer et al., 2002), and the single feature orientation information (Civile et al., 2014a, 2016a) there is also the face-contour information that in some instances contribute to the inversion effect and overall recognition performance. Interestingly, our results also complement those by Davidenko (2007) s study 4, on the inversion effect for face silhouettes. Specifically, the author demonstrated that it is possible to obtain a significant inversion effect for silhouetted face profiles created by reducing gray-scale photographs of face profiles to two-tone black and white images that were then cropped at the forehead, below the chin, and down the ear line. Both our results and Davidenko (2007) s results contribute to the finding that the shape of the face constitute an important source of information when recognising faces. Future research could investigate whether applying the scrambling manipulation would affect the inversion effect for silhouetted face profiles. But, perhaps more important would be to investigate if the role of the shape information in contributing to the inversion effect and overall recognition would also be found for sets of familiar prototype-defined objects.

A final consideration regards how our results can contribute to the literature on the inversion effect used as a cognitive measure of social issues. For instance, Hills et al. (2019) have shown how induced social stress by means of monitoring participants during the study phase, can cause a reduction of the face inversion effect as well as of overall face recognition performance. A similar effect was found in Civile et al. (2019b) when regular standardised faces were labelled as being of individuals with autism. Also, the literature on a robust phenomenon named the ‘other race effect’ has often been indexed by the difference in size of the inversion effect for own vs other races faces with latter being reduced due a decrease at recognizing upright other-race faces (Rhodes et al., 1989; Vizioli et al., 2010; Civile and McLaren, 2022). Finally, the objectification and social power literature have shown how the inversion effect can be reduced by priming individuals to feel powerful (e.g., Civile and Obhi 2016; Civile et al. 2016c using the inversion effect paradigm developed by Bernard et al. 2015). Taken all together, the findings from these very different topics reveal how a reduction of the inversion effect (and in some instances also overall performance) can be induced without directly manipulating the face stimuli, and this reduction resembles what we found in our studies by manipulating the face contour of the faces used. Future studies should investigate the mechanisms shared across these different areas that all lead to a reduction of the face inversion effect in a similar way.

In conclusion, we have found some evidence to demonstrate that the face contour affects the inversion effect in sets of scrambled and normal faces. Furthermore, we found that manipulating the face contour would lead to a reduction of overall performance for normal faces and for New Thatcherized faces. These findings contribute to the face recognition literature showing how the contour is also relevant in determining our ability to recognize that face.

Declaration of Competing Interest

The authors declare not conflict of interest.

CRediT authorship contribution statement

Siobhan McCourt: Conceptualization, Methodology, Data curation, Validation, Visualization, Formal analysis, Writing – original draft, Writing – review & editing. **I.P.L. McLaren:** Conceptualization, Methodology, Writing – review & editing. **Ciro Civile:** Conceptualization, Methodology, Visualization, Formal analysis, Writing – review & editing.

Data Availability

The datasets generated during the current study are not currently publicly available as a precaution so that other people will not use them to produce new publications. However, these datasets are available to reviewers from the corresponding author upon reasonable request. All the data will be publicly available upon acceptance on the UK Data Service ReShare at the following link [To be Added Upon Acceptance].

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.crbeha.2023.100115.

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