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The upside-down self: One's own face recognition is affected by inversion

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Abstract

One's own face is recognized more efficiently than any other face, although the neural mechanisms underlying this phenomenon remain poorly understood. Considering the extensive visual experience that we have with our own face, some authors have proposed that self-face recognition involves a more analytical perceptual strategy (i.e., based on face features) than other familiar faces, which are commonly processed holistically (i.e., as a whole). However, this hypothesis has not yet been tested with brain activity data. In the present study, we employed an inversion paradigm combined with event-related potential (ERP) recordings to investigate whether the self-face is processed more analytically. Sixteen healthy participants were asked to identify their own face and a familiar face regardless of its orientation, which could either be upright or inverted. ERP analysis revealed an enhanced amplitude and a delayed latency for the N170 component when faces were presented in an inverted orientation. Critically, both the self and a familiar face were equally vulnerable to the inversion effect, suggesting that the self-face is not processed more analytically than a familiar face. In addition, we replicated the recent finding that the attention-related P200 component is a specific neural index of self-face recognition. Overall, our results suggest that the advantage for self-face processing might be better explained by the engagement of self-related attentional mechanisms than by the use of a more analytical visuoperceptual strategy.

KEYWORDS
ERPs, inversion effect, N170, P200, self-face, self-processing

1 | INTRODUCTION

One's own face is a remarkable self-referential stimulus that has attracted considerable research interest in recent years. It is well established that the self-face is processed more efficiently in comparison with other familiar faces (Keyes & Brady, 2010; Keyes et al., 2010),

being recognized faster and more accurately in a variety of different contexts (Sui & Humphreys, 2013; Tong & Nakayama, 1999). Whilst this behavioral advantage has generally been associated with perceptual experience, recent research points to attention as the key neural mechanism underlying this phenomenon (Alzueta et al., 2019, 2020).

Familiar faces are usually processed holistically, as a whole (Tanaka & Gordon, 2011). In contrast, self-face recognition has been suggested to involve a more analytical processing style, which has been attributed to our extensive visual experience with our own face throughout the lifespan (Keyes & Brady, 2010; Tong & Nakayama, 1999). Thus, whilst the recognition of facial identity is predominantly holistic, self-face might undergo a more analytic process aimed at daily grooming routines and the detection of facial details (Brédart, 2003; Fuentes et al., 2013; Keyes & Brady, 2010). Indeed, some facial features, such as the eyes, are processed in more detail when perceiving one's own face in comparison with other familiar and unfamiliar faces (Hills, 2018). Under this view, self-face is presumably rich not only in global but also in local facial information, which would in turn facilitate its recognition (Keyes & Brady, 2010).

The notion that the self-face engages a more analytical processing style has received support from behavioral studies using inverted faces. In general, face inversion results in an inability to perceive the face as a whole (Van Belle et al., 2010; Freire et al., 2000), forcing us to use a more analytical approach to extract its identity—although some studies have also found inversion to disrupt facial features to some extent (McKone & Yovel, 2009; Yovel, 2009). In other words, inversion mostly disrupt the holistic processing of a face leading to a less optimal featural-based perceptual strategy (Rossion & Gauthier, 2002; Valentine, 1988), which ultimately impairs face recognition (e.g., response times are delayed). A striking finding to emerge from some studies is that the self-recognition advantage remains, at least partially, when the self-face is presented in an inverted position (Keenan et al., 1999; Keyes, 2012; Keyes & Brady, 2010). Considering that isolated facial characteristics (e.g., the eyes) are usually not disturbed by inversion (Itier et al., 2007; Kloth et al., 2013; Rhodes, 1993; but see McKone & Yovel, 2009; Yovel, 2009), self-face resistance to inversion might indicate the engagement of a more analytical strategy focused on processing individual facial features. As argued by Keyes and Brady (2010), the additional use of local facial cues when processing one's own face could provide an explanation for why the self-recognition advantage persists even when the face is inverted.

An additional body of evidence supporting the idea that the self-face is processed more analytically comes from some event-related potential (ERP) studies reporting an enhanced N170 amplitude for the self-face in comparison with other familiar faces (Caharel et al., 2002; Geng et al., 2012; Keyes et al., 2010). The N170 component is a face-sensitive ERP which reflects the pre-categorical structural encoding of faces, namely the processing of individual facial features that takes place before the face is recognized (Bentin & Deouell, 2000; Eimer, 2000a). Moreover, the N170 component exhibits higher amplitudes when isolated facial features—such as the eyes—are presented instead of the whole face (Itier et al., 2007; Kloth et al., 2013). Thus, the enhanced N170 for the self-face could be taken to indicate that the analytical processing of facial features is critical for the recognition of one's own face. However, more recently, the supposed modulation of N170 by the self-face has been questioned, given the lack of replicability of this effect (Alzueta et al., 2019). By comparing the self-face and faces with different levels of familiarity, Alzueta et al. (2019) showed that the N170 component is not sensitive to the self-face. Instead, P200, a later ERP component linked to attention processes (e.g., Alorda et al., 2007; Carretié et al., 2001, 2004; Delplanque et al., 2004) emerged as a more reliable and specific index of self-face recognition (Alzueta et al., 2019; Estudillo, 2017). In light of this new information, the self-face advantage might be better explained by the action of attentional rather than perceptual mechanisms. As a matter of fact, the self-advantage is not restricted to face perception, but more generally observed when processing self-related information, from one's own name (Yang et al., 2013) to geometrical figures artificially associated with the self (Sui et al., 2012, 2013). In addition, several studies have evidenced the involvement of specific attentional mechanisms while processing self-related information (Alzueta et al., 2020; Humphreys & Sui, 2016; Sui & Gu, 2017; Sui & Humphreys, 2017; Tacikowski & Nowicka, 2010). Therefore, the advantage in recognition observed for the self-face might be just a consequence about how our attentional system prioritizes the personally relevant information (Ota & Nakano, 2021; Sui & Rotshtein, 2019; Woźniak et al., 2018).

In sum, some previous research findings support the view that the self-face advantage is boosted by an enhanced analytical style of processing. However, the available evidence is scarce and inconclusive. On the one hand, the modulation of N170 by the self-face is still a matter of debate (Alzueta et al., 2019; Estudillo, 2017). On the other hand, the alleged resistance of the self-face to inversion has only been found at the behavioral level (Keenan et al., 1999; Keyes, 2012; Keyes & Brady, 2010). More direct evidence could be obtained by investigating brain activity in response to self-face inversion. Although other tasks (e.g., part-whole task) have also been used to promote analytical face processing, inversion has been proved to be the best in predicting face recognition abilities (Rezlescu et al., 2017). Further, it is able to disturb holistic processing in a more naturalistic way, and its effects on the N170 component are well replicated. In particular, the analytical processing induced by face inversion produces an increase in both the amplitude and latency of the N170 component (Eimer, 2000b; Rossion, 2014; Sagiv & Bentin, 2001), which is known as the inversion effect. Surprisingly, although the modulation of N170 by face inversion is a very

well-established phenomenon, it has not been applied to investigate how one's own face is processed by the brain in comparison with other familiar faces.

Hence, we sought to determine if the self-face is processed more analytically than other familiar faces by investigating the neural response to inverted faces. To achieve this aim, we used a facial recognition task consisting of two levels of identity (Self and Familiar face) and two face orientations (Upright and Inverted position), as well as an EEG system to record the participants' brain response. Based on the findings of previous behavioral studies, it can be hypothesized that the self-face would be less affected by inversion in comparison with other familiar faces at both behavioral and neural levels. Thus, we expect to find the classical inversion effect (i.e., an increase in recognition response times, as well as enhanced amplitude and delayed latency of N170) for the familiar face—as inversion would disrupt holistic processing giving rise to an analytical perceptual strategy. In contrast, the self-face will show an attenuated (or even absent) inversion effect, which would support the view that one's own face is generally processed more analytically.

2 | METHOD

2.1 | Participants

Nineteen undergraduate and graduate students from the Universidad Autónoma de Madrid (Mean age: 22.5 ± 3.9 years, mean ± SD; 7 males) participated in this study. All of them had normal or corrected to normal vision and were right-handed, according to the Edinburgh Laterality Questionnaire (Oldfield, 1971). The data of three participants were discarded during data analysis due to low quality of the EEG recording and/or poor performance (i.e., low signal-to-noise ratio and less than 70% of artefact-free and correctly-responded trials); thus, the final sample was composed of 16 participants (mean age 22.2 ± 3.8 years; 5 males). The study was approved by the Ethics Committee of the Universidad Autónoma de Madrid and carried out in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants prior to initiating the experiment. Their participation was completely voluntary, and they were informed of their right to withdraw from the study at any time.

2.2 | Stimuli

The stimuli consisted of photographs of faces with two levels of identity and two orientations. The levels of identity were *Self*, i.e., the participant's own face, and *Familiar*, i.e., the face of a classmate with whom the participants had been

in regular contact for at least one year. Orientation levels were *Upright*, if the face was presented in a regular orientation, and *Inverted*, if it was downward. The stimuli were obtained following a procedure similar to that described by Alzueta et al. (2019). We took photographs of each participant (Canon EOS 500D) under controlled lighting conditions (Neewer®), using a gray background to naturally eliminate external features (Figure 1a). Each participant was photographed showing a neutral expression and articulating several speech sounds, but controlling the facial expression so that it was emotionally neutral. Images were flipped vertically downward to create the inverted version of each face stimulus. A total of 15 different photographs were selected for each participant in order to increase variability in stimulation (Figure 1b).

The images were edited in Adobe Photoshop®, centered to avoid eye movements during stimulation, and converted to grayscale. Each photograph had 247 × 350 pixels, corresponding to a visual angle of 6.8° × 9.4° at a constant viewing distance of 50 cm. All images were matched in terms of contrast, luminance, and spatial frequency using the SHINE toolbox (Willenbockel et al., 2010). In addition, in order to control for the use of different facial stimuli in each experimental condition, the participant's own face was not only used for the *Self* condition, but also for the *Familiar* condition when his/her classmate participated in the experiment. Facial images were saved in the original orientation for the *Upright* condition, and upside-down for the *Inverted* condition. For the *Self* condition, the picture was further rotated to obtain a mirrored version, which is the orientation to which people are most accustomed (Brédart, 2003). Examples of the stimuli used in the four experimental conditions can be seen in Figure 1a,b.
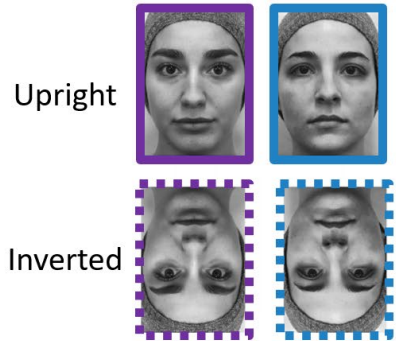
2.3 | Experimental procedure

The participants completed a facial recognition task. They were instructed to identify and classify the images, independently of their orientation, as either "me" (*Self*-face) or a "friend" (*Familiar* face). They were asked to respond as quickly as possible by pressing a key assigned to each condition, which was randomized for each participant.

The experimental task was run with Psychtoolbox (Brainard & Vision, 1997). This task consisted of the sequential and random presentation of the different facial images (15 images × 2 identity conditions × 2 orientations) with a fixed duration of 1,000 ms. During the inter-stimulus interval, a fixation cross was displayed at the center of the screen for a variable time ranging from 800 to 1,200 ms (see Figure 1c). A total of 420 trials (105 trials per condition) were presented, distributed across five blocks (four blocks of 86 trials and the last one with 76 trials). Each block was followed by a brief

(a) Participant's face

(b) Self Familiar
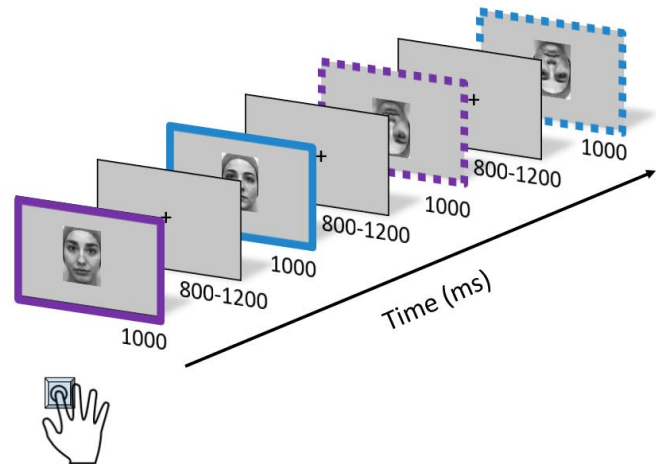
Upright

Inverted

(c)

FIGURE 1 Experimental stimuli and procedure. (a) Examples of different variants of a facial stimulus in one condition. (b) Examples of face stimuli from the four experimental conditions (*Self-Upright*, *Familiar-Upright*, *Self-Inverted*, *Familiar-Inverted*). (c) Random sequential presentation of the face stimuli during the recognition task

self-paced break in order to avoid fatigue. Overall, the task lasted approximately 15 min.

The experiment was conducted in a light and sound controlled environment. The participants were comfortably seated and positioned at a distance of 50 cm from the screen (1,336 × 768 pixels). They were requested to remain relaxed throughout the task and asked to refrain from eye-blinking as far as possible, particularly during the presentation of the images.

2.4 | Recording of the EEG signal

An ActiveTwo BioSemi system (128 EEG + 4 EOG channels) was used to record brain activity. The data were digitized at a sampling rate of 512 Hz and filtered online with a 100 Hz low-pass filter. EEG signals at each active electrode were recorded with respect to a common mode sense active electrode and a Driven Right Leg passive electrode, replacing the ground electrode. The offsets of active electrodes were kept below 25–30 mV.

2.5 | Analysis of the EEG signal

2.5.1 | Pre-processing

EEG data analysis was conducted using Fieldtrip (Oostenveld et al., 2011) and run on Matlab (R2015a, MathWorks). The

EEG signal was first filtered below 40 Hz by applying a two-pass fourth-order Butterworth filter, after which it was re-referenced to the average of all channels, as recommended for ERP analysis when having a high electrode density (Lei & Liao, 2017).

Subsequently, the continuous EEG signal was segmented into epochs from −500 ms to 1,000 ms. Noisy channels were linearly interpolated using the activity of neighboring electrodes. Trials contaminated with blinks or other artefacts such as movements or muscular activity, were visually identified and removed. In addition, trials with incorrect responses were also excluded from the analysis. Only participants with more than 70% of artefact-free and correctly responded trials per condition were included in the analysis. Hence, the number of analyzed trials for each condition was as follows: 84.1 ± 12.1 (mean $\pm$ SD) in the *Self-Upright* condition, 84.3 ± 18.8 in the *Familiar-Upright*, 79.1 ± 17.2 in the *Self-Inverted* condition, and 73.1 ± 13.4 in the *Familiar-Inverted* condition.

2.5.2 | ERP analysis

ERPs were calculated separately for each condition and participant. First, we applied baseline correction using a 500-ms interval prior to stimulus presentation. Then, in order to select the regions and electrodes of interest, we calculated the average for all conditions and participants (Kriegeskorte et al., 2009). The following two regions of interest were extracted from the topographic distribution of ERP components: right

occipito-temporal (ROT) and left occipito-temporal (LOT). To compare our results with those of previous related studies, we followed the same approach as that described by Alzueta et al. (2019); that is, those electrodes showing the greatest activity at the mean latency of each ERP component were selected for statistical analysis. Electrodes chosen for each region of interest and time window are displayed in Table 1.

In order to assess the inversion effect, we extracted the amplitude and latency of the main ERP components (i.e., N170 and P200) for each participant and experimental condition individually. These were extracted from a ± 10-ms time window around the individual maximum peak for each condition.

2.6 | Statistical analysis

2.6.1 | Analyses of variance

Behavioral data were statistically tested by means of two-way repeated measures analyses of variance (ANOVAs). Specifically, we studied the effects of face identity (*Self*, *Familiar*) and orientation (*Upright*, *Inverted*) on both hit rate and recognition response times.

We then tested the effects of face identity *(Self, Familiar)*, orientation *(Upright, Inverted)* and region of interest *(LOT, ROT)* on the amplitude and latency of ERP components by applying three-way repeated measures ANOVAs.

The Greenhouse-Geisser correction for non-sphericity was applied when required, and Bonferroni corrected post-hoc pairwise comparisons were conducted to identify specific differences between conditions. We used the partial eta-square η_p^2 method and calculated the bias-corrected Cohen's d (Cumming, 2013) to estimate effect sizes. Statistical analyses were conducted using the SPSS 15.0 software package (SPSS, 15.0).

Additionally, we computed Bayes factors for N170 amplitude and latency. The aim of Bayesian analysis is to assess the strength of the evidence in favor of the null hypothesis. A Bayes factor (BF10) of less than 1/3 indicates that there is substantial evidence supporting the null hypothesis over the alternative hypothesis (Jeffreys, 1939; see also Dienes, 2014). The BF10 was calculated employing JASP 0.11.1 (JASP Team, 2019). Priors were obtained from standardized effect sizes (Cohen's d) calculated from previous results; specifically, the alternative hypothesis (H1) was modeled based on a

previous study which analyzed the effect on N170 amplitude and latency when inverting intact faces compared with isolated eye regions (Kloth et al., 2013). We selected this previous evidence, given that, as explained in the Introduction, the face stimuli employed by these authors should resemble those used in the present study with respect to the required degree of analytical processing. We assumed that the minimal deployment of an analytical strategy for the intact face would be comparable to that of the familiar face in the present study, whilst the recognition of the isolated eye region would demand a much higher degree of analytical processing, as we had expected for the self-face in our study. Hence, the amplitude and latency differences in N170 reported in the cited study served as expected effect sizes—and, thus, informed priors—for determining the model of the H1 in our Bayesian analysis.

Hence, H1 was specified using a Cauchy distribution centered on zero and with scale factors defined by the respective previous effect sizes. Given that the cited results did not allow for fully determining the results expected in our study (due to the stimuli not being identical), the Cauchy distribution was selected to describe the H1 model. This would allow for observing effects in either direction, with large effect sizes (larger than those found in the cited work) being less plausible than smaller effects sizes (albeit still possible). For obtaining the scale factors, Cohen's d, denoting effect sizes of the amplitude and latency differences between intact faces and isolated eye regions, were computed from *t*-values reported in Kloth et al. (2013). The data of the right and left hemisphere of the present N170 results were averaged for this analysis to allow for comparison with those of the previous study (in which an average was reported).

3 | RESULTS

3.1 | Behavioral results

Performance on the facial recognition task was generally good (hit rate mean ± *SD* across all conditions 87.3 ± 4.8%). Experimental conditions did not differ in hit rate (Figure 2). More specifically, a repeated measures ANOVA revealed no significant effect of either face identity ($F_{(1, 15)} = 0.199$; $p = .662$, $\eta_p^2 = 0.013$) or orientation ($F_{(1, 15)} = 2.979$; $p = .105$, $\eta_p^2 = 0.166$). Similarly, no significant interaction was found between identity and orientation ($F_{(1, 15)} = 3.062$; $p = .207$, $\eta_p^2 = 0.104$).

TABLE 1 Time windows and regions of interest

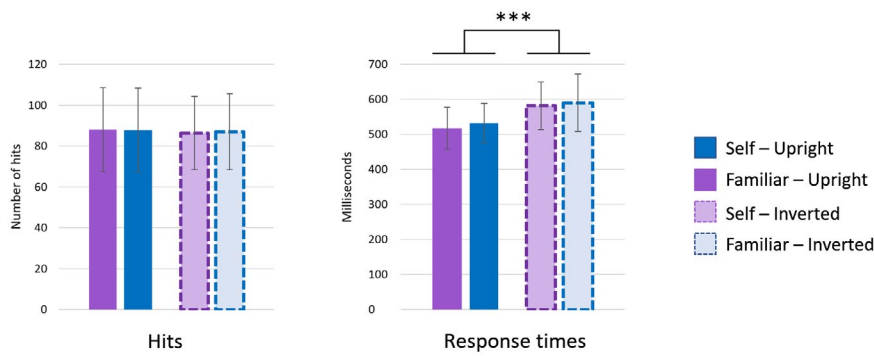| ERP component	Time window	Region of interest	
		ROT	LOT
N170	151–171 ms	TP8, P8, P10, PO10, PO12	TP7, P7, P9, PO9, PO11
P200	207–227 ms	POO6, PO8, PO10, O2, I2	POO5, PO7, PO9, O1, I1

TABLE 2 N170 and P200 amplitudes and latencies

| | LOT | | | | ROT | | | |
| | Upright | | Inverted | | Upright | | Inverted | |
	Self	Familiar	Self	Familiar	Self	Familiar	Self	Familiar
N170 amplitude								
Mean	−3.608	−3.235	−6.201	−5.975	−2.676	−2.608	−6.120	−6.264
SD	4.055	3.869	5.28	5.153	4.11	3.847	4.277	4.453
P200 amplitude								
Mean	2.874	3.699	3.052	3.744	4.492	5.971	4.208	4.831
SD	3.751	3.185	3.825	4.304	3.511	3.223	3.145	3.339
N170 latency								
Mean	157	155	166	165	158	157	166	167
SD	13	14	11	10	13	14	11	10
P200 latency								
Mean	203	203	225	225	211	218	230	227
SD	18	16	19	21	17	15	14	11

Note: Mean and *SD* amplitudes (microvolts) and latencies (milliseconds) of N170 and P200 components for each region of interest (LOT, left occipito-temporal; ROT, right occipito-temporal), face identity (Self and Familiar), and orientation (Upright and Inverted).

In contrast, the statistical analysis revealed a significant main effect of face orientation for recognition response times ($F_{(1, 15)} = 92.104$; $p < .001$, $\eta_p^2 = 0.860$), indicating that response times were significantly slower when identifying faces in the inverted position (586 ± 75 ms) in comparison with the upright position (525 ± 60 ms) (Figure 2). Moreover, neither face identity ($F_{(1, 15)} = 2.355$; $p = .146$, $\eta_p^2 = 0.136$) nor the interaction identity × orientation ($F_{(1, 15)} = 0.343$; $p = .567$, $\eta_p^2 = 0.022$) were significant. These results indicate the existence of an inversion effect at the behavioral level, in particular on response times, regardless of face identity.

3.2 | ERP results

Descriptive statistics (mean and *SD*) of ERP components' (N170 and P200) amplitudes and latencies for the different regions of interest and experimental conditions are detailed in Table 2.

3.2.1 | N170 component

As in the case of the behavioral data, particularly recognition response times, our ERP analysis revealed that N170 is only modulated by face inversion, but not by face identity. A three-way ANOVA revealed a significant main effect of face orientation for the amplitude of the N170 component ($F_{(1, 15)} = 73.044$, $p < .001$, $\eta_p^2 = 0.830$). As shown in Figure 3, the amplitude of N170 for inverted faces was significantly higher in comparison with upright faces for both self and familiar faces in either occipito-temporal region. However, there was no significant effect of face identity ($F_{(1, 15)} = 0.354$, $p = .561$, $\eta_p^2 = 0.023$). Similarly, neither region of interest ($F_{(1, 15)} = 0.504$, $p = .488$, $\eta_p^2 = 0.033$), nor any of the interactions reached significance ($F_{(1, 15)} < 1.599$, $p > .05$).

Latency analysis revealed that face inversion induced a delay in the N170 component. As in the case of the previous results, face orientation was the only factor that modulated the latency of N170 ($F_{(1, 15)} = 55.555$, $p < .001$, $\eta_p^2 = 0.787$).
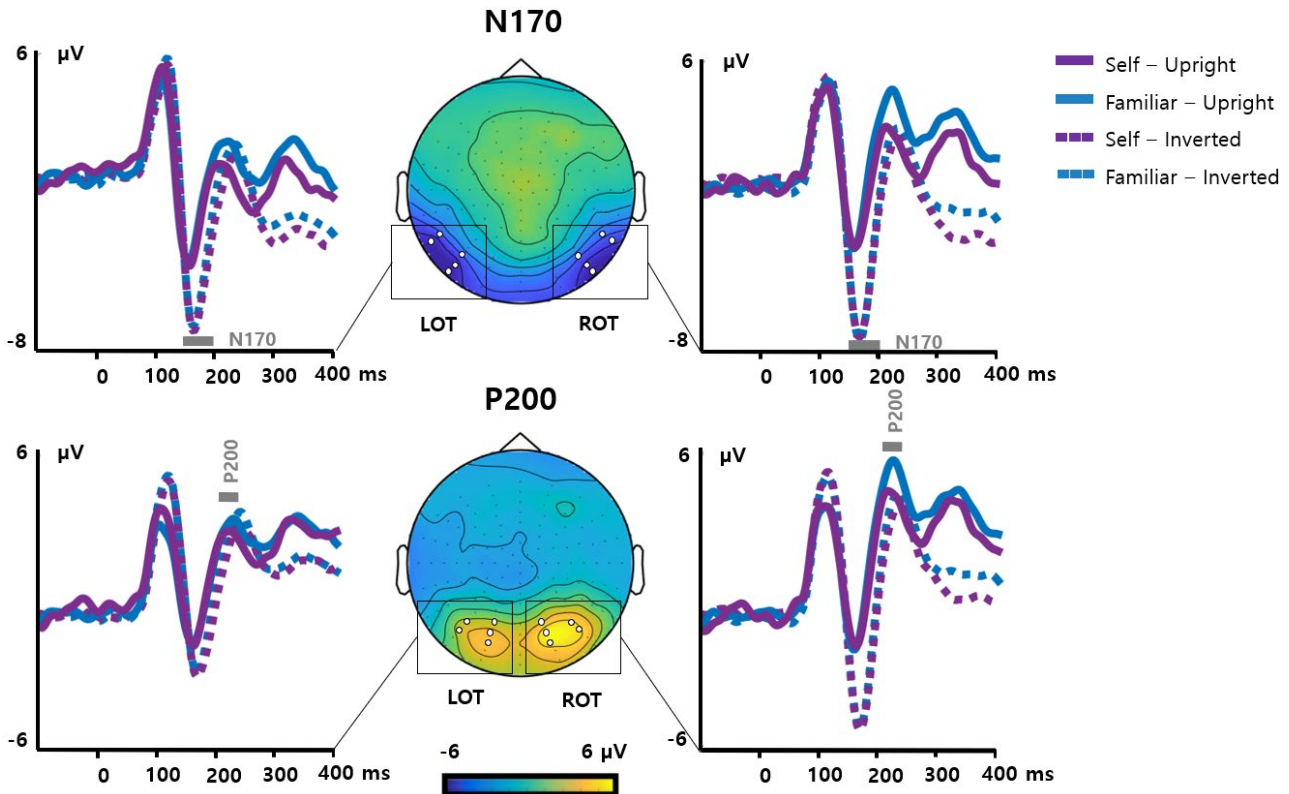
FIGURE 3 ERPs and topographies for N170 and P200 components. N170 and P200 topographies are shown in the middle panel. The left and right-hand panels show the ERP grand-averages for each condition (*Self-Upright*, *Familiar-Upright*, *Self-Inverted*, and *Familiar-Inverted*), extracted from the most representative electrodes of the right (ROT) and left (LOT) occipito-temporal regions

As can be observed in Figure 3, the N170 latency was significantly slower for inverted than upright faces for both self and familiar faces in the two regions of interest. A significant, though marginal, interaction between face identity and region of interest ($F_{(1, 15)} = 4.733$, $p = .046$, $\eta_p^2 = 0.240$) was also found. However, subsequent post-hoc analysis showed no significant differences between self and familiar faces in any of the two regions of interest (ROT: *Self* vs *Familiar*: $t_{(15)} = 0.146$, $p = .886$, 95% CI [−0.001, −0.001], $d = 0.036$) (LOT: *Self* vs *Familiar*: $t_{(15)} = 1.928$, $p = .073$, 95% CI [−0.001, −0.004], $d = 0.482$).

Finally, in order to confirm that N170 amplitude and latency in response to inversion were, in fact, not modulated by face identity, we computed BF10 for both measures. Employing the priors that were estimated based on the mean difference (i.e., the t-values) for amplitude (scale factor = 0.803) and latency (scale factor = 1.223), our BF10 provided moderate evidence in favor of the null hypothesis of no difference between the *Self-Inverted* and the *Familiar-Inverted* faces for both N170 amplitude and latency (BF10 = 0.232 and BF10 = 0.175, respectively). To sum up, the Bayesian analysis on the N170 component provided additional support for the finding that the self-face is not more resistant to inversion, but rather that it is affected by inversion to the same extent as other familiar faces.

3.2.2 | P200 component

Given that the N170 component did not show any sign of being modulated by face identity, we conducted the same analyses on the subsequent P200 component, which has recently been demonstrated to be sensitive to the self-face (Alzueta et al., 2019; Keyes et al., 2010). Indeed, amplitude analysis revealed the existence of a self-face effect on P200, replicating previous findings. In particular, the three-way ANOVA revealed a significant main effect of facial identity ($F_{(1, 15)} = 12.116$, $p = .003$, $\eta_p^2 = 0.447$), as well as a significant main effect of region of interest ($F_{(1, 15)} = 9.587$, $p = .007$, $\eta_p^2 = 0.390$). As shown in Figure 3, P200 amplitude was significantly lower for the self-face in comparison with a familiar face, and significantly greater in the ROT in comparison with the LOT region. However, unlike the N170 results, the main effect of face orientation did not reach significance ($F_{(1, 15)} = 0.611$, $p = .447$, $\eta_p^2 = 0.039$). None of the interactions resulted significant.

Similar to the results obtained for N170, the latency of the P200 component showed a significant effect of face orientation ($F_{(1, 15)} = 38.840$, $p < .001$, $\eta_p^2 = 0.721$), whilst both the effect of face identity ($F_{(1, 15)} = 1.431$, $p = .250$, $\eta_p^2 = 0.087$) and region of interest ($F_{(1, 15)} = 3.549$, $p = .079$, $\eta_p^2 = 0.191$) failed to reach significance. No single interactions

were significant, although the interaction between face orientation and identity approached statistical significance ($F_{(1, 15)} = 4,390$, $p = .054$, $\eta_p^2 = 0.226$). However, differences between conditions might best be explained by a triple interaction between identity, orientation, and region of interest ($F_{(1, 15)} = 4.976$, $p = .041$, $\eta_p^2 = 0.249$). As with the case of our P200 amplitude results, subsequent post-hoc analyses revealed a shorter P200 latency for the self in comparison with the familiar face in the ROT region, but only when the face was presented in the upright position (*Self-Upright* vs *Familiar-Upright:* $t_{(15)} = -3.136$, $p = .007$, 95% CI [-0.012, -0.002], $d = 0.627$), and not when the faces were inverted (*Self-Inverted* vs *Familiar-Inverted*: $t_{(15)} = 1.193$, $p = .251$, 95% CI [-0.002, -0.007], $d = 0.239$). In contrast, these effects were not observed in the LOT sensors ($t_{(15)} < 0.245$, $p > .810$).

4 | DISCUSSION

The purpose of the present study was to test whether the self-face truly benefits from a more analytical form of processing when compared with other familiar faces. To this end, we investigated the behavioral and neural responses to the self and familiar faces when presented in both upright and inverted orientations. Our results showed that, contrary to what might be expected, self and familiar faces are equally vulnerable to the inversion effect. In both cases, the amplitude of N170 was enhanced and its latency delayed when the face was inverted, in line with the delays observed in the responses to the recognition task. In addition, our results replicated the finding that the P200, an attention-related component, is the earliest neural index of self-face processing.

4.1 | N170 and the inversion effect

The effect of inversion on the N170 component is well-documented (De Lissa et al., 2014; Eimer, 2000a; Sadeh & Yovel, 2010; Parketny et al., 2015). However, to date, no ERP studies have investigated how inversion disrupts self-face processing compared with other familiar faces. This is somewhat striking, since the presumable modulation of N170 by the self-face has been closely linked to its processing advantage in terms of distinctiveness and recognition (Geng et al., 2012; Keyes et al., 2010). Therefore, the importance of the results reported here is twofold. First, these findings indicate that the N170 component is not modulated by the self-face, and second, they demonstrate that the self-face is equally as vulnerable to inversion as any other familiar face, as we will discuss in detail in the following paragraphs.

The finding that N170 is not modulated by the self-face is compatible with the strong body of evidence suggesting

that this component is insensitive to facial identity (Bentin & Deouell, 2000; Bentin et al., 1996; Eimer, 2000b). In line with this possibility, recent research has found that this component is not a reliable neural index of self-recognition (Alzueta et al., 2019; Estudillo, 2017). This contrasts with earlier studies showing increases in N170 amplitude for self-face processing (Geng et al., 2012; Keyes et al., 2010), though these contradictory results could be explained by methodological differences. For instance, Geng et al. (2012) used a rather broad time window to analyze the N170 component (140–240 ms), and thus included not only the N170 but also the P200 component, which we have demonstrated to be highly sensitive to the self-face. Moreover, in the study by Keyes et al. (2010), participants had to focus on facial features to perform the experimental task, which might have boosted the use of an analytical strategy. This might explain why the self-face showed an enhanced N170, since this component usually shows higher amplitudes when processing facial features in comparison with the face as a whole (Itier et al., 2007; Kloth et al., 2013).

The second main finding to emerge from our study is that the self-face is affected by inversion. This is consistent with recent evidence showing that the self-face exhibits the inversion effect on N170, similar to what can be observed for unknown faces (Ritter et al., 2020). Here, we have additionally controlled for familiarity, demonstrating that the self-face is no more resistant to inversion than other familiar faces. As inversion mainly disrupts holistic processing (Rossion & Gauthier, 2002; Valentine, 1988; but see McKone & Yovel, 2009; Yovel, 2009), our findings support the notion that a predominant holistic processing strategy would be the most efficient for extracting the identity from a face (Richler et al., 2011). Our results, confirmed by Bayesian analyses, run counter to the initial hypothesis that the self-face would be processed more analytically, as expected on the basis of the results reported in previous behavioral studies. Moreover, it is important to note that our conclusions are based on direct neural evidence of the self-face inversion effect, whereas most previous research is based on indirect behavioral methods.

For example, Keyes and Brady (2010) used an interhemispheric cooperation task, in which they presented three facial identities (self, friend, and stranger) in two different positions (upright and inverted) in either one or both hemifields. They demonstrated that self and familiar face recognition benefit from the simultaneous processing of faces by both hemispheres. Crucially, only the self-face partially maintained this recognition advantage when the faces were presented in an inverted position. These results led the authors to conclude that self-face recognition is more resistant to inversion than other faces due to a neural bilateral representation of self-faces (Kircher et al., 2001; Sugiura et al., 2005; Taylor et al., 2009). Future research using brain imaging methods

could help to disentangle the nature of this "bilateral" representation of the own face. On the one hand, such research might reveal the joint processing of global and local facial features as a consequence of the extensive perceptual experience with our own-face, accumulated over many years (Devue & Brédart, 2011; Keyes & Brady, 2010). But on the other hand, evidence might be found to indicate the engagement of specific attentional mechanisms related to the self, the so-called Self-Attention Network. As postulated by Humphreys and Sui (2016), this extensive network includes frontal, parietal and temporal regions of both hemispheres and is particularly active during self-processing.

In a later study, Keyes (2012) used a recognition task with faces in both upright and inverted positions in order to investigate the phenomenon of categorical perception. Morphed faces were artificially created by a combination of different identities, either familiar (i.e., self or a friend) or unknown. Categorical perception takes place when a face is perceived as belonging to one or another identity and generally occurs for known identities (i.e., familiar faces), which suggests that robust facial representations and holistic processing are both important factors for observing this phenomenon (Beale & Keil, 1995). Keyes' study showed that whilst inversion usually eliminates categorical perception effects due to the disruption of holistic processing, this phenomenon remained intact for the self-face. This finding was attributed to the analytical processing of the self-face and the importance of local as well as global information in self-face recognition. However, it is important to note that categorical perception effects have also been reported for unfamiliar and newly learned faces (Campanella et al., 2003; Levin & Beale, 2000), with representations that are not as robust as those of familiar faces. Therefore, given that the mechanisms underlying categorical perception are not yet well understood, we cannot ascertain whether the observed resistance of the self-face to inversion is the result of holistic or analytical processing.

4.2 | P200 and the distinctive processing of the self-face

Aside from the N170 component, we also observed an inversion effect in the P200 latency for both self and familiar faces. The P200 component has been linked to the encoding of the spatial relationship between facial characteristics (Latinus & Taylor, 2006; Schweinberger & Neumann, 2016), which could explain why this component is modulated by face orientation. Nevertheless, the observed effect might simply be the consequence of the N170 delay for inverted faces that might have, in turn, delayed the subsequent P200 component.

Beyond the inversion effect, our results replicated the recent finding that P200 is the earliest neural index of self-face recognition (Alzueta et al., 2019). In particular, the present results revealed a lower amplitude and shorter latency of the P200 component for the self-face in the upright orientation compared with a familiar face. Differences between self and familiar faces were evident in ROT areas, which are often active during facial processing (Alzueta et al., 2020; Iidaka, 2014) and might thereby facilitate self-face recognition. Although the effects of self-face processing on P200 have been observed in a number of previous studies (e.g., Caharel et al., 2007; Estudillo et al., 2018; Keyes et al., 2010; Parketny et al., 2015; Tanaka et al., 2006), they have often been overlooked. Indeed, only recently have some authors highlighted the importance of the P200 component for self-face processing (Alzueta et al., 2019; Estudillo, 2017).

The P200 component has been associated with the spatial configuration of the face, reflecting face typicality or distinctiveness (Schweinberger & Neumann, 2016). Critically, other-race faces (i.e., non-typical faces) have been found to elicit smaller P200 amplitudes compared to own-race faces (Stahl et al., 2010). Under this view, the modulation of P200 observed in the present study might be explained by a greater distinctiveness of the self-face. However, this "distinctiveness" could either be purely perceptual or driven by attention. Critically, the temporo-occipital P200 component has also been proposed to be involved in the implementation of attentional mechanisms—i.e., selective attention to certain stimulus features—(e.g., Alorda et al., 2007; Chen et al., 2011; Delplanque et al., 2004; see also Schupp et al., 2003). In agreement with previous reports, our results showing a reduced and faster P200 component for the self-face suggest that there is minimal involvement of cognitive resources at an early stage, possibly mediated by attention (Alzueta et al., 2019). Indeed, one's own face needs less cognitive resources to be recognized (Geng et al., 2012; Sui & Humphreys, 2013), and induces a sustained attentional engagement as indexed by the desynchronization of alpha-band oscillations (Alzueta et al., 2020). Furthermore, there is increasing evidence that self-face processing recruits a specific Attention Network (see Humphreys & Sui, 2016; Sui & Gu, 2017), the role of which is to make the cognitive system prioritize self-related stimuli (Sui & Rotshtein, 2019). Finally, recent findings (Ota & Nakano, 2021; Wójcik et al., 2019) show the subliminal presentation of the self-face automatically captures attention pointing out to the involvement of early bottom-up neural mechanisms during its processing. Taken together, these findings suggest that the modulation of the P200 component reflects the involvement of early attentional mechanisms (bottom-up) during self-processing and thus the self-face processing advantage could be explained by the action of attentional rather than purely perceptual mechanisms.

5 | CONCLUSIONS

To our knowledge, this is the first attempt to investigate brain activity in response to self-face inversion while controlling for face familiarity. Our results show that, at both a behavioral and neural level, one's own face is as vulnerable to inversion as other familiar faces, which lead us to refute the assumption that the self-face is processed more analytically. In addition, we provide further evidence to suggest that the self-face processing advantage might result from the involvement of attentional mechanisms specific to the self, rather than the use of a different perceptual strategy. Our findings have important implications for understanding how the self-face is processed by the brain and suggest that the key element of such processing could be linked to social relevance rather than accumulated visual experience.

AUTHOR CONTRIBUTIONS
Elisabet Alzueta: Conceptualization; Formal analysis; Investigation; Methodology; Visualization; Writing-original draft. **Dominique Kessel:** Formal analysis; Funding acquisition; Writing-review & editing. **Almudena Capilla:** Data curation; Funding acquisition; Methodology; Resources; Software; Supervision; Writing-review & editing.

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