

Am I the same person across my life span? An event-related brain potentials study of the temporal perspective in self-identity

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Funding information

Ministerio de Ciencia, Innovación y Universidades, Grant/Award Number: FPU18/02223; Ministerio de Ciencia, Innovación y Universidades (MICINN, Programa Estatal de Investigación Científica y Técnica de Excelencia, Subprograma Estatal de Generación de Conocimiento Proyectos de I+D), Spain, Grant/Award Number: PSI2017-82357-P

Abstract

While self-identity recognition has been largely explored, less is known on how self-identity changes as a function of time. The present work aims to explore the influence of the temporal perspective on self-identity by studying event-related brain potentials (ERP) associated with face processing. To this purpose, participants had to perform a recognition task in two blocks with different task demands: (i) identity recognition (self, close-friend, unknown), and (ii) life stage recognition (adulthood -current-, adolescence, and childhood). The results showed that the N170 component was sensitive to changes in the global face configuration when comparing adulthood with other life stages. The N250 was the earliest neural marker discriminating self from other identities and may be related to a preferential deployment of attentional resources to recognize own face. The P3 was a robust index of self-specificity, reflecting stimulus categorization and presumably adding an emotional value. The results of interest emerged for the subsequent late positive complex (LPC). The larger amplitude for the LPC to the self-face was probably associated with further personal significance. The LPC, therefore, was able to distinguish the continuity of the self over time (i.e., between current self and past selves). Likewise, this component also could discriminate, at each life stage, the self-identity from other identities (e.g., between past self and past close-friend). This would confirm a remarkable role of the LPC reflecting higher self-relevance processes. Taken together, the neural representation of oneself (i.e., “I am myself”) seems to be stable and also updated across time.

KEYWORDS

current self, event-related potentials, past self, self-continuity, self-identity recognition

1 | INTRODUCTION

The unitary sense of self that exists across time is central to the human experience (Gallagher, 2000; Heatherton, Macrae, & Kelley, 2004). In this sense, the fundamental question on how humans understand and represent knowledge about themselves and others is attracting interest in social and

cognitive neuroscience (Berkman, Livingston, & Kahn, 2017; Humphreys & Sui, 2016; Northoff, 2017). The concept of *self-continuity* is often defined as perceived associations of one's current self with past and future selves (Löckenhoff & Rutt, 2017). Northoff (2016a, 2017) has denoted this concept as a *diachronic component* linked to the awareness of the continuity of a person across time (i.e., “I am I” despite physical

and physiological changes during the lifetime). In contrast, the sense of self in a particular moment in time corresponds to a *synchronic component* (Doering et al., 2012). Although research on the neural basis of self-recognition has focused on a particular moment in time (e.g., Alzueta, Melcón, Poch, & Capilla, 2019; Xu et al., 2017), less is known about the neural processes involved in how self-continuity assembles as a function of time (Morin, 2006; Northoff, 2017).

1.1 | Self-referential processing: How and when the access to self-identity occurs?

Visual self-recognition is a potential indicator of self-awareness, as well as a byproduct of a general capacity to collate representations (Suddendorf & Butler, 2013). The processing of self-related information, such as one's name or one's face, is faster and more accurate than other types of not self-related stimuli. This phenomenon is called the *self-reference effect* (SRE; Rogers, Kuiper, & Kirker, 1977). In the past 40 years, numerous studies have described the SRE in a range of tasks (for a review, see Sui & Humphreys, 2015). Previous reports have described the SRE as reflecting a better recall or recognition when the experimental materials refer to the self (Yaoi, Osaka, & Osaka, 2015). Recent studies have suggested that self-relevant stimuli are powerful cues for attention and decision making, as they can modulate performance in a relatively automatic manner, even subliminally (Geng, Zhang, Li, Tao, & Xu, 2012; Humphreys & Sui, 2016; Ma & Han, 2010; Muñoz et al., 2020).

An open question in the SRE research is how and when self-preferential access occurs. To address this question, the event-related brain potentials (ERP) technique allows a precise temporal analysis of brain processing. According to the models of face processing (Bruce & Young, 1986; Olivares, Iglesias, Saavedra, Trujillo-Barreto, & Valdés-Sosa, 2015; Schweinberger & Neumann, 2016), the N170 seems to be an early ERP component associated with face processing, related to holistic, low-level processing of the global properties of a face. Previous electrophysiological studies focusing on self-face recognition have reported an early dissociation between self-face and other faces, more specifically, a larger amplitude in the N170 amplitude has been described for the self-face compared to other faces (Geng et al., 2012; Keyes, Brady, Reilly, & Foxe, 2010). Since other studies have failed to report this dissociation, it has been proposed the subsequent N250 component as an index of self-preferential access, distinguishing particularly the self from familiar and unknown persons (Alzueta et al., 2019; Miyakoshi, Kanayama, Nomura, Iidaka, & Ohira, 2008). However, Tanaka, Curran, Porterfield, and Collins (2006) have suggested that the N250 indexes two types of face memories: the access to self-face recognition from long term memory, and to a newly acquired face representation that was learned during the experiment

(i.e., the participants generate a certain familiarization with an unknown face). Hence it remains unclear whether more early components such as the N170 or the N250 may reflect the self-bias over the familiarity effect in face processing (Butler, Mattingley, Cunnington, & Suddendorf, 2013; Gosling & Eimer, 2011; Keyes et al., 2010).

Other relevant components for the self-referential processing are the P3 and the late positive complex (LPC). The P3 (a positive component occurring around 300 ms after the stimulus onset) has been related to the categorization or evaluation of the stimulus according to task demands and reflect the engagement of higher-order cognitive functions (Johnson, 1986; Polich, 2007). The LPC seems to reflect a step further allocating attentional resources (Azizian & Polich, 2007) probably enhanced by personal semantics, which includes semantic memory, autobiographical facts, self-knowledge and episodic memory (Tanguay et al., 2018); and affective evaluation processes, detecting the motivational relevance of the stimulus (Cunningham, Espinet, DeYoung, & Zelazo, 2005). Both P3 and LPC have been associated with the retrieval of face memories including verbal and personal semantics, as well as with the attribution of meaningful information associated with a person (Gillihan & Farah, 2005; Johnson, 1986; Olivares et al., 2015; Renoult et al., 2016; Tanguay et al., 2018). Although previous research on self-face recognition has proposed the P3 as the most robust index for self-referential processing (Knyazev, 2013), the function of the LPC in this regard remains unsettled and might play a significant role due to the significance of the self-related stimuli.

1.2 | The temporal perspective in self-identity: the present study

The cognitive processes accounting for personal changes across the lifespan require the ability to discriminate between mental representations of the current and the past selves, unifying temporally discrete self-related instances into a coherent whole. This mental representation is involved to arrange a stable identity during late adolescence (McAdams, 2013). Increasing evidence from neuroimaging studies has highlighted that the access to the current and the past self-representation is supported by different cognitive processes, as well as underpinned by distinct anterior and posterior neural circuits. It seems that posterior regions (specially, the posterior cingulate cortex and the precuneus) are crucial for tracing the self into an autobiographical memory across a lifetime, whilst anterior regions (critically, ventromedial prefrontal cortex) support the current representation of self-referential content (D'Argembeau et al., 2008, 2010; Northoff, 2017). The *Cortical Midline Structures* (CMS) have been specifically involved in self-related processing (Northoff & Bermpohl, 2004). In particular, the CMS mediate

higher-order perceptual representation, encoding memory, and attributing reward value, saliency, and valence to self-related content (Berkman et al., 2017).

Previous research has observed a reduction of the SRE by reflecting on autobiographical memories (Jackson et al., 2019). Studies from social psychology have proposed that people tend to distance themselves from their past and regard it as “another person” due to personal changes across the lifespan, adopting a third-person perspective when recalling past behaviors or traits that differ with their current self-concept (Libby & Eibach, 2002; Proning & Ross, 2006). This idea of a certain distance due to personal changes as a result of time could convey lower amplitude in latter components of the ERP for the past self, compared to the current self. However, previous research remains inconclusive whether the past self and the past close-relative are processed similarly (D'Argembeau et al., 2008; Kotlewska & Nowicka, 2015). A similarity in this sense would suggest that personal knowledge is accessed to both self-related and his/her close-relative when contrasted to a stranger (Cloutier, Kelley, & Heatherton, 2011). However, given the specificity and relevance of the self in the brain processing, the past self should be differentiated from the past close-relative at some point in the neural processing. To our knowledge, this point has been scarcely treated in the literature.

Not many electrophysiological studies have addressed self-identity processing over time (Morin, 2006; Northoff, 2017). For instance, Butler et al. (2013) studied the neural processes related to self-recognition across the lifespan using photographs of dizygotic twins to control familiarity. They grouped the stimuli into 5–15 (more-distant past), 16–25 (less-distant past), and 26–45 (current self) years of age. Their main results showed that the self and the twin faces share very similar featural (P1), configurational (N170), and matching processes (P3), but it was specific for the self in latter components (N400). More specifically, the N400 amplitude was larger for both current and less-distant past self, compared to a more-distant past self. They interpreted this finding as a result of the retrieval of personal mnemonic information. In addition, no difference was found between the current and the less-distant past. More recently, Kotlewska and Nowicka (2015) investigated this topic using as stimuli the current “adulthood” self, past “childhood” self, current familiar “close-other,” current adult famous, and current adult unknown faces. Noteworthy, they reported no differences in the P3 component associated with the current and past selves, suggesting similarly engaged attentional resources as well as similar levels of semantic knowledge between the current and past selves. This contrasts with the study by Butler et al. (2013) commented above.

Overall, while a body of evidence has largely explored self-face recognition regardless of a time perspective, less is known about the time course of self-representation at both lower and higher levels of processing (early and late ERP components, respectively). Additionally, previous research

has suggested that the access to self-face representation may be also enhanced automatically (Geng et al., 2012; Ma & Han, 2010) or even when self-recognition is irrelevant to the task (Scott, Luciana, Wewerka, & Nelson, 2005; Sui, Zhu, & Han, 2006). Hence, this effect seems to be task-independent, and it is associated with early and later components, as recently proposed (Humphreys & Sui, 2016; Sui & Humphreys, 2015); in contrast, other faces seems to be more influenced by attentional modulations and thus dependent on task demands (Morgan, Klein, Boehm, Shapiro, & Linden, 2008; Ruz, Aranda, Sarmiento, & Sanabria, 2015).

The present study aims at characterizing the neural mechanisms underlying the effect of the temporal perspective (life stage) on the core-self (self-awareness, “I am I” despite physical changes). We designed a recognition task in which participants had to focus on different aspects of the stimuli in two different blocks: (i) identity recognition (self, close-friend -as a control for familiarity-, unknown), and (ii) life stage recognition (adulthood -current-, adolescence, and childhood). This design enabled us to test the results consistency with different attentional demands. In both blocks, the stimuli were the same: three photographs of the face of the participant, three of the face of a close-friend, and three of an unknown person (same gender). Of the three pictures of each identity, one was current, one related to adolescence, and one related to childhood. Based on the literature reviewed above, we expected: (i) larger late positivities to the self, compared to the others, whilst close-friend exhibiting an intermediate position or similar to the unknown condition (Miyakoshi, Kanayama, Iidaka, & Ohira, 2010; Miyakoshi et al., 2008; Xu et al., 2017); (ii) ERP modulations would be enhanced for the self across life stages, in particular, related to current self-faces (Apps, Tajadura-Jiménez, Turley, & Tsakiris, 2012; Butler et al., 2013); (iii) the past self should be differentiated from the past close-relative at some point in the neural processing; (iv) regarding early face processing, whereas the N170 modulations would be sensitive to facial structural changes, the N250 may be more responsive to facial identity and some degree of familiarity (Olivares et al., 2015); (v) along the different ERP components, the effect of self-face processing compared to other faces would be relatively task-independent (Humphreys & Sui, 2016), that is, despite asking participants to focus on different aspects of the stimuli in the different blocks.

2 | METHOD

2.1 | Participants

Twenty undergraduate and graduate students participated in the study ($M_{\text{age}} = 23.85$, $SD_{\text{age}} = 3.93$ years; 10 females). All participants reported normal or corrected-to-normal vision

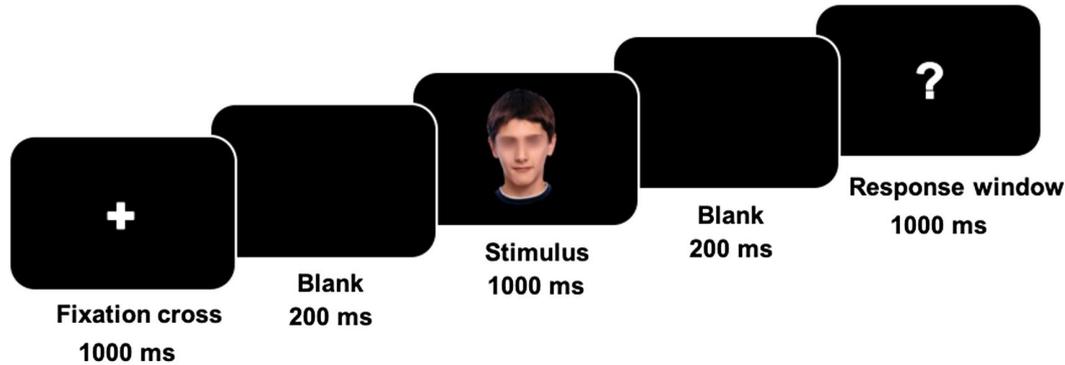


FIGURE 1 Schematic representation of the procedure. In the identity block, the participants had to judge if the face stimuli correspond to her/himself, her/his friend or an unknown person without being concerned about age. In the block of the life stages, the participants had to decide if the face stimulus corresponds to an infant, an adolescent or an adult, regardless of the identity

and had no history of neurological or cognitive disorders. They were right-handed with a handedness score mean of +86 (range: +63 to +100) according to the Edinburgh Handedness Inventory (Oldfield, 1971). Before the experiment, the participants gave their informed consent. The study was conducted following the Declaration of Helsinki of the World Medical Association and approved by the Ethics Committee of the faculty of psychology of the Complutense University.

2.2 | Stimuli

The materials contained a set of digitalized photographs from the faces of the participants and one of his/her close friends. Images showed neutral emotional expression and direct gaze. Two weeks before the experiment, the participants provided a set of digitalized high-quality photographs for each stage of life (childhood, adolescence, and adulthood) of themselves and one of their close-friends of the same gender. All participants included in the study stated informally a wide range of friendship since childhood (6–9 years old), and that the relationship was maintained several times a year to habitually or daily. All images were edited in Adobe Photoshop® (CS6), applying a black background. The luminance was equated across images as much as possible (self: $L = 80.85 \pm 1.46$, close-friend: $L = 77.89 \pm 1.34$, and unknown: $L = 77.89 \pm 1.34$). Differences were not significant ($F_{(2, 38)} = 2.683$, $p = .11$, $\eta_p^2 = .044$). The images were resized by setting a constant distance in the width of 145 pixels between pupils. All stimuli were framed within 450 pixels width and 600 pixels height.

The participants were presented with three different images of their own's face, close friend's face, and an unknown face corresponding to three life stages: adulthood, adolescence, and childhood. This represents a total of 27 images. To enhance the signal-to-noise ratio, each image

was repeated 10 times. The picture order was randomized. All were matched in age and gender. The unknown condition was obtained from the close-friend condition of previous participants, thereby each participant viewed a different unknown person. At the end of the experiment, all participants confirmed that they did not know the face identity of the unknown face.

2.3 | Procedure

The experiment was conducted using Presentation® software (Neurobehavioral Systems, Inc.). Participants were seated in an isolated room approximately 70 cm in front of an LCD screen of $1,024 \times 768$ pixels. A typical trial started with a fixation cross for 500 ms presented centrally on the screen in white with a black background, followed by a blank for 200 ms (see Figure 1). The stimuli, randomly presented, appeared for 1,000 ms followed by a blank for 200 ms, and finally, the response interval was 1,000 ms. The participants provided their responses by pressing one of the three buttons. The sequence of the buttons was counterbalanced between the index, middle, and ring fingers of the right hand. The experiment was divided into two blocks: in the identity block, the participants were asked to press a button to discriminate the identity of the face image (self, close-friend, unknown). In the life stage block, they were asked to identify the face's stage of life (adulthood, adolescence, and childhood). The block order was counterbalanced across subjects. Overall, 540 stimuli were presented to the participants (27 photos \times 10 presentations \times 2 blocks). Since previous studies have found a shorter reaction time response for the self-face recognition (e.g., Geng et al., 2012; Ma & Han, 2010), and executing the motor response at the very moment of recognizing the stimuli may introduce some motor artifact in the ERP, we established a delay for executing the response after a 200-ms blank following the offset of the stimulus (see Figure 1).

2.4 | EEG recordings and analysis

Continuous EEG was registered using 59 scalp electrodes (actiCap; Brain Products, Gilching, Germany) according to the international 10–20 system. EEG data were recorded by a BrainAmp DC amplifier (Brain Products, Gilching, Germany) at a sampling rate of 250 Hz with a band-pass from 0.01 to 100 Hz. During recording, all scalp electrodes plus left mastoid were all referenced to the right mastoid; they were re-referenced off-line to the average of the right and left mastoids. The ground electrode was located at AFz. The impedance of all electrodes was kept below 5 k Ω . Eye movements and blinks were monitored by means of two vertical (VEOG) and two horizontal (HEOG) electrodes placed above and below the left eye and on the outer canthus of both eyes, respectively.

EEG data were analyzed with the software Brain Vision Analyzer[®] and EEGLAB v14.1 (Delorme et al., 2011; <http://www.sccn.ucsd.edu/eeGLAB>) as a toolbox of MATLAB R2017b (MathWorks, Natick, MA, USA). Raw data were filtered off-line with a band-pass of 0.10–40 Hz and then segmented into 1,200 ms epochs starting 200 ms prior to the stimulus onset. The baseline correction was applied from –200 to 0 ms. Both incorrect or omitted responses were excluded from the analyses, as well as trials with transient noise. Typical artifacts (e.g., eye movements or muscle activity) were corrected through infomax independent component analysis (ICA, Bell & Sejnowski, 1995). This analysis decomposed individual EEG data into 64 independent components (ICs) each characterized by a fixed scalp map of the spatial projection of the component to each channel, as well as a time course of activation in each trial. From the overall ICs, we applied a semi-automated procedure described by Chaumon, Bishop, and Busch (2015). This procedure assists with statistical criteria to select artifact ICs due to eye movements, muscle contractions, line noise or electrode misconnections. After selecting the artifact ICs, they were dropped out from the EEG data from all electrodes. All EEG processing steps agree with the guidelines and recommendations described by Keil et al. (2014).

After artifacts rejection, the mean of segments for each condition was: self (86.55 ± 3.23); close-friend (86.00 ± 4.45); unknown (87.15 ± 2.97); childhood (84.25 ± 6.13); adolescence (81.45 ± 8.21); adulthood (84.00 ± 5.93). Comparing the overall segments between the identity block (259.7) and life stage block (249.7) revealed a significant difference ($t_{(19)} = 2.574, p < .05$). Overall, the mean rejection rate of segments of all epochs was 21.67% on the identity block and 23.12% on the life stage block. With regard to ERP measurement, separate average ERPs were calculated as a function of each face condition, and relative to a 200 ms prestimulus baseline.

For statistical analyses, the mean amplitudes for P3 and LPC were measured in specific clusters of electrodes in the

following scalp regions of interest (ROIs): anterior (AF3, AF4, Fz, F1, F2, F3, F4), middle (FCz, FC1, FC2, FC3, FC4, Cz, C1, C2, C3, C4), and posterior (CPz, CP1, CP2, CP3, CP4, Pz, P1, P2, P3, P4). The clustering was selected according to the visual inspection of the topographic distribution of the ERP effects (see Figure 3), and in accordance with previous ERP studies that have found a frontocentral distribution of relevant ERP differences, even if these components exhibit a main centro-parietal distribution (e.g., Geng et al., 2012; Sui et al., 2006; Woźniak, Kourtis, & Knoblich, 2018). Both N170 and N250 were measured at bilateral occipitotemporal sites (PO7 and PO8), as they showed the largest ERP effects at these sites, and in agreement with previous studies (e.g., Gosling & Eimer, 2011; Navajas, Nitka, & Quiroga, 2017). Since the N170 is usually measured using average reference (e.g., Geng et al., 2012; Nemrodov, Niemeier, Mok, & Nestor, 2016) and our linked mastoids reference could have attenuated its amplitude (Joyce & Rossion, 2005), the data were re-referenced offline to the average of all scalp channels for the statistical analyses of this component. Time windows were selected following a visual inspection of the main ERP effects, and based on the existing literature, namely: N170 (150–200 ms); N250 (250–300 ms); P3 (300–400 ms); LPC (450–600 ms). Amplitudes were analyzed using repeated-measures analysis of variance (ANOVA). The factorial design for the P3 and LPC components was $2 \times 3 \times 3 \times 3$ with “block” (two levels: focusing on identity recognition, focusing on life stage recognition), “identity” (three levels: self, friend, unknown), “life stage” (three levels: adulthood, adolescence, childhood) and “topographic distribution” (anterior, middle, posterior) as within-subject factors.¹ For N170 and N250 components, analyzed at PO7 and PO8 separately, the design was $2 \times 3 \times 3$ (Block \times Identity \times Life stage). The Greenhouse and Geisser (1959) procedure was used in the cases of infringing the sphericity assumption. Mean and 95% Confidence Intervals were reported. For all analyses, the alpha level was .05, moreover, partial eta-squared (η_p^2) is presented as a measure of statistical power, and *posthoc* tests were corrected through the Bonferroni method. The data used for the statistical analyses are available in the Open Science Framework (OSF) online repository (<https://osf.io/9hfd5/>).

3 | RESULTS

3.1 | Behavioral results

The overall percentage of participants' performance was as follows (mean \pm SD): hits rates (identity: $99.03\% \pm 1.25\%$; life stage: $92.5\% \pm 6.28\%$), misclassifications (identity:

¹The results did not change when including Block order as a between-subject factor.

0.87% \pm 1.23%; life stage: 7.25% \pm 6.31%), omissions (identity: 0.09% \pm 0.16%; life stage: 0.24% \pm 0.28%). The overall contrast corresponding to misclassifications between identity (2.3% \pm 3.33%) and life stage (17.05% \pm 3.81%) revealed a significant difference ($t_{(19)} = 4.713$, $p < .001$). As the response interval started 1,200 ms after the presentation of the stimulus, reaction times were considered uninformative and therefore were not measured.

3.2 | Electrophysiological results

Figures 2 and 3 depict the average waveforms across all conditions for the identity and the life stage effects. Figure 4 illustrates the mean differences and the 95% confidence intervals of the effect sizes for the identity and the life stages effects. Figure 5 shows a bar graph representing the interaction effects between identity and life stage. A visual inspection of the ERPs (Figure 2, and Figure 3) and the topographic maps (Figure 3) revealed differential modulations of the ERP across conditions. Additionally, as shown in the topographic distribution of Figure 3, it seems that the largest differences between the experimental conditions along the later components (i.e., P3 and LPC) follow a frontocentral distribution.

3.2.1 | N170 component

As can be seen in Table 1, the repeated-measures ANOVA of the N170 amplitude indicated that there were no significant differences for the main effects of block or identity at PO8 or PO7; but it was significant for the main effect of life stage at PO7 and PO8, also showing higher size effect at PO7 electrode than PO8 electrode. Pairwise comparisons indicated that the amplitude of the N170 measured at PO7 electrode to adulthood was significantly larger compared to adolescence ($p = .020$), and to childhood ($p = .006$), while no differences were found comparing adolescence with childhood.

Likewise, the following interactions were not significant at PO8 or PO7, namely: Block \times Identity, Block \times Life stage, Identity \times Life stage, and Block \times Identity \times Life stage.

3.2.2 | N250 component

The repeated-measures analysis of the N250 amplitude was nonsignificant for the main effect and interaction effects involving the block factor at PO8 and PO7 electrodes. The analysis of the N250 component showed a main effect for identity, indicating a higher size effect at the PO8 electrode than the PO7 electrode. Follow-up comparisons at the PO8 electrode revealed that the N250 amplitude was significantly larger for the self than for the close-friend and compared to the unknown; however, the difference between close-friend and unknown was nonsignificant. There was found a significant main effect for the life stage, which was associated with a higher size effect more remarkable at the PO8 electrode than the PO7 electrode. *Posthoc* analyses at the PO8 electrode showed significantly larger amplitude to adulthood compared to adolescence and to childhood, as well as a larger amplitude to adolescence compared to childhood. No significant effects were found for the interaction between Identity \times Life stage at PO8 electrode or PO7 electrode.

3.2.3 | P3 component

The repeated-measures analysis on the P3 amplitude was nonsignificant for the main effect and interaction effects related to the block factor. The P3 amplitude revealed a significant main effect of identity. Particularly, the mean amplitude for the self was significantly larger than for the unknown ($p < .001$); and for the close-friend ($p = .012$). The comparison between close-friend and unknown conditions was also statistically significant ($p = .020$). Moreover, a significant main effect for the life stage was found, being the mean

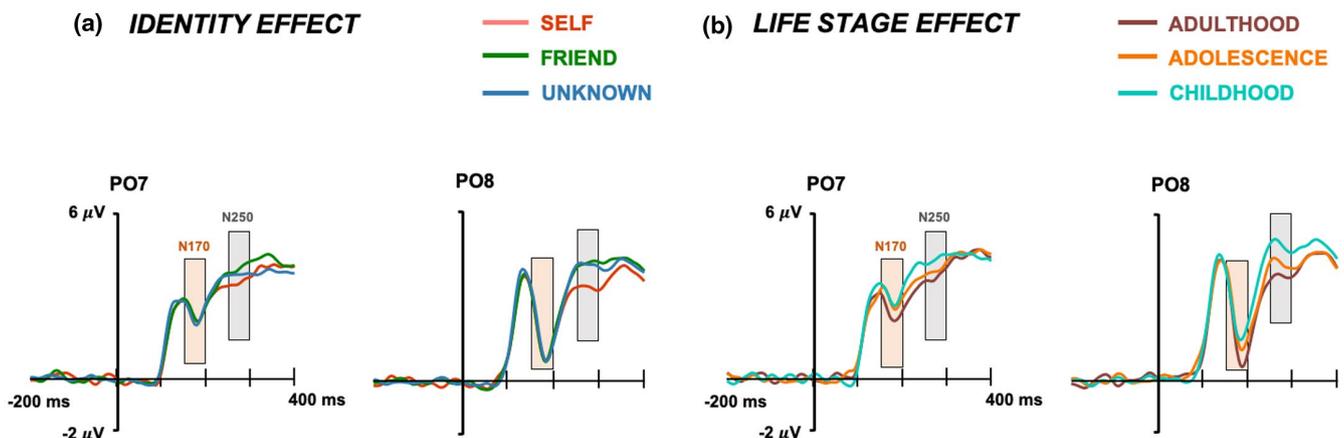


FIGURE 2 Grand averages of N170 and N250 waveforms corresponding to the main effects of identity (a) and life stage (b)

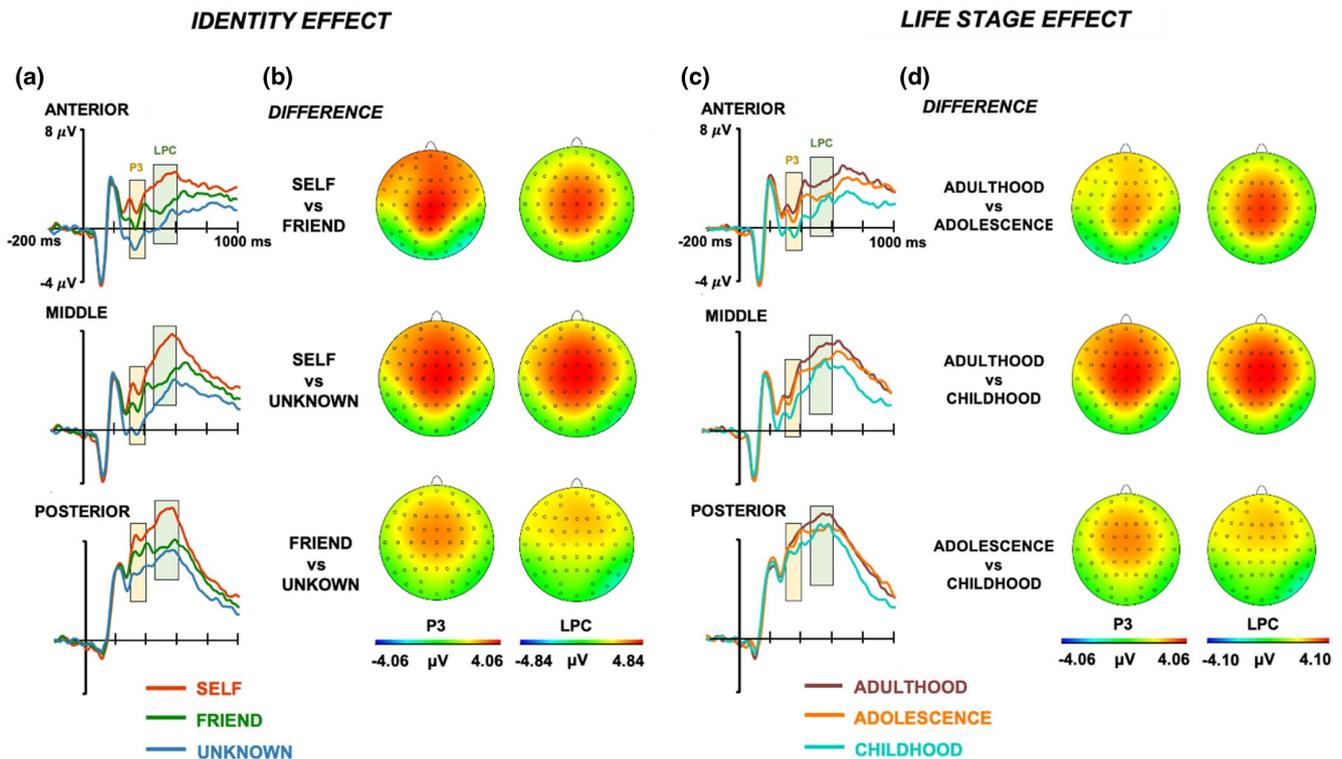


FIGURE 3 Grand average of P3 and LPC waveforms of the three ROIs for the identity (a) and life stage (c) effects. Topographic maps for the difference waves for the identity (b) and life stage (d) effects at selected time-windows

amplitudes for adulthood and adolescence significantly larger compared to childhood ($p < .001$; $p = .002$, respectively), but the comparison between adulthood and adolescence was not significant ($p = .186$).

With regard to the topographical effects underlying the data, the interaction between Identity \times ROI revealed a significant effect ($F_{(2, 38)} = 3.502$, $p = .036$, $\eta_p^2 = .146$), indicating that the largest mean differences between all identity conditions were more noticeable at the central region (all $ps \leq .012$), followed by anterior and posterior regions, respectively (all $ps \leq .042$; all $ps \leq .043$). Furthermore, there was found a significant interaction between Life stage \times ROI ($F_{(2, 38)} = 16.927$, $p \leq .001$, $\eta_p^2 = .47$). Pairwise comparison showed that the mean difference between adulthood and childhood as well as the comparison between adolescence and childhood was more remarkable at the anterior region (all $ps \leq .001$), followed by the central region (all $ps \leq .002$), and was nonsignificant at the posterior region (all $ps > .1$). Also, the P3 amplitude for adolescence was significantly larger than childhood only in the anterior region ($p = .048$). No further significant interaction effects associated with the ROI factor were found.

3.2.4 | Late positive complex

The repeated-measures analysis on the LPC amplitude revealed the only significant effect involving the block factor

(see Table 1). This main effect was associated with a significantly larger amplitude for the life stages block than the identity block ($\Delta = .79 \mu\text{V}$, 95% CI [0.05, 1.52], $p = .038$). No further significant interaction effects related to the block factor were found. The ANOVA yielded a significant identity main effect, indicating that the self was larger compared to close-friend ($p < .001$) and to unknown ($p < .001$), while the difference between close-friend and unknown did not reach the level of statistical significance ($p = .066$). The LPC showed a significant main effect for the life stage, being significantly larger the amplitude for adulthood compared to adolescence ($p = .008$) and to childhood ($p = .007$), while the difference between adolescence and childhood was nonsignificant ($p = .171$).

There was a significant interaction between Identity \times ROI ($F_{(2, 38)} = 6.393$; $p = .004$, $\eta_p^2 = .25$). Particularly, the mean amplitude for the self was significantly larger than the close-friend along anterior, central, and posterior regions (all $ps < .001$), as well as compared to the unknown (all $ps < .001$). Nevertheless, the only ROI that significantly discriminate the difference between close-friend and unknown was the anterior region ($p = .036$), but not the central and posterior regions ($p = .068$; $p = .273$, respectively). Moreover, the interaction between Life stage \times ROI was significant ($F_{(2, 38)} = 3.649$, $p = .033$, $\eta_p^2 = .16$). Whereas the mean amplitude for adulthood was larger than adolescence at the anterior region ($p = .029$) and most notably at the central region

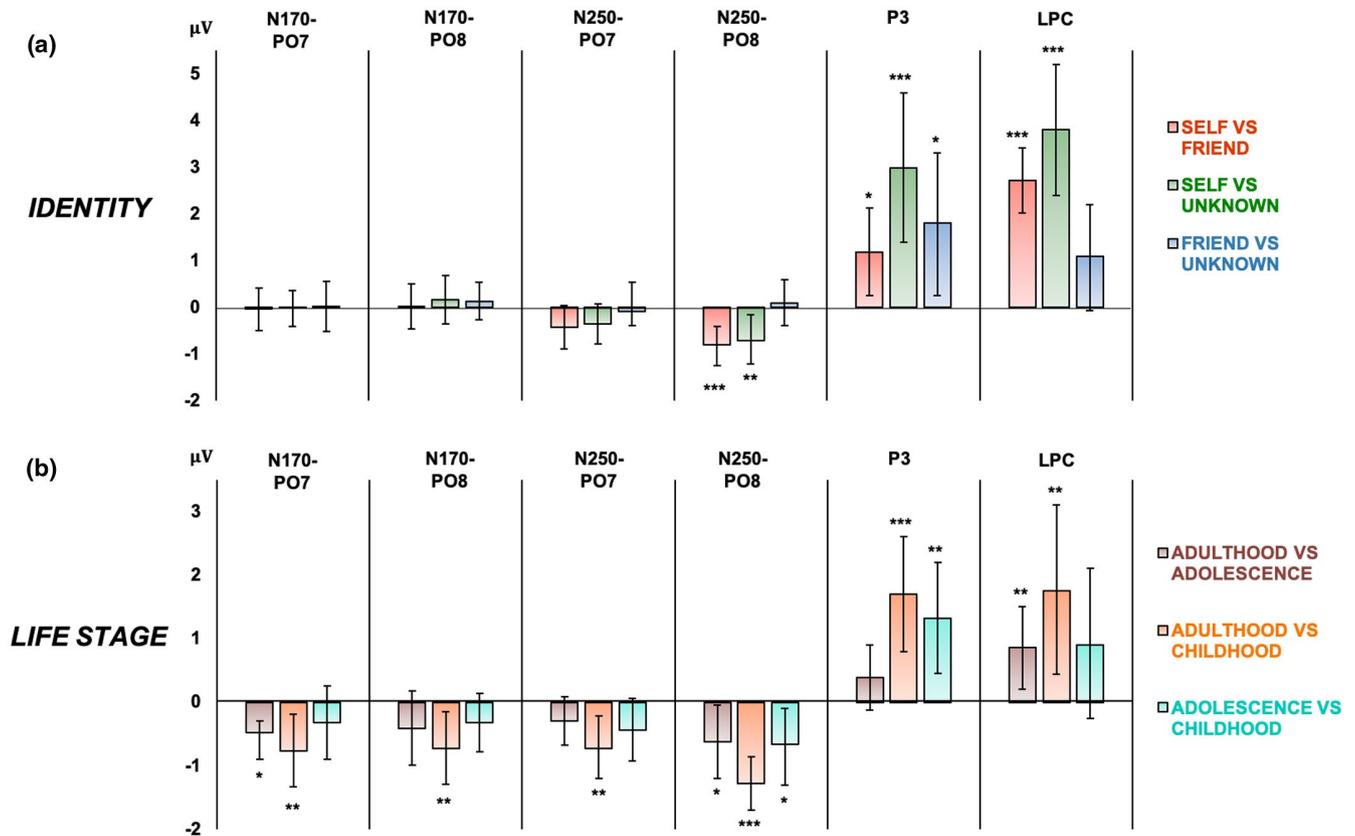
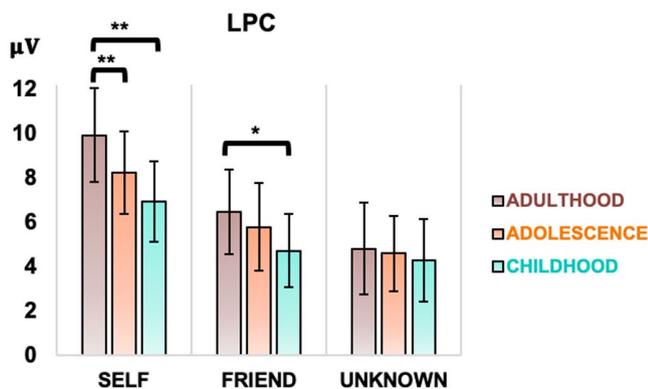


FIGURE 4 ERP bar graphs (mean differences and error bars denote 95% confidence intervals of the effect sizes) for the main effects of identity (a) and life stage (b)

(a) **IDENTITY × LIFE STAGE**
Self-continuity across time



(b) **LIFE STAGE × IDENTITY**
Self vs others at each life stage

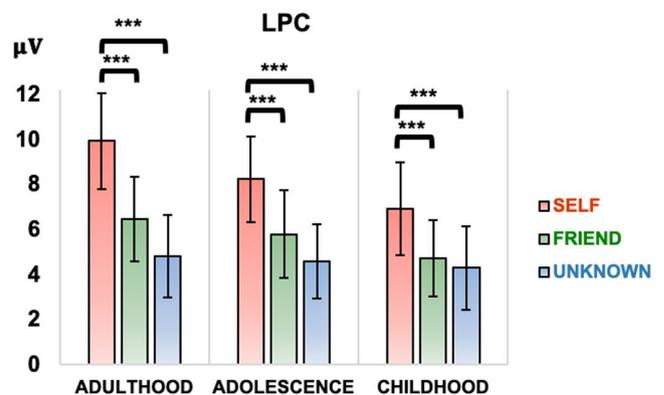


FIGURE 5 ERP bar graphs (mean and error bars denote 95% confidence intervals) for the interaction between identity and life stage. The ERP graph on the left (a) illustrates the continuity of each identity across time; likewise, the ERP graph on the right (b) shows at each life stage the comparison between identities. Note that the data do not interact with ROI, corresponding to the three ROIs collapsed. Only significant results are depicted

($p = .003$), it did not reach the level of statistical significance at the posterior region ($p = .053$). Similarly, the comparison between adulthood and childhood was more remarkable at

anterior and central regions ($p = .003$; $p = .006$, respectively), again, it did not reach the level of statistical significance at the posterior region ($p = .051$). Last, the LPC amplitude for

TABLE 1 Statistical analysis of Identity and Life stage effects corresponding to each ERP component

Factors (<i>df</i>)	N170-F (η_p^2)		N250-F (η_p^2)		P3-F (η_p^2)	LPC-F (η_p^2)
	PO7	PO8	PO7	PO8		
Block (1,19)	1.193 .059	1.138 .57	.379 .02	.067 .01	3.086 .14	5.001* .21
Identity (2,38)	.020 .001	.475 .625	3.535* .16	10.83*** .36	15.78*** .45	43.440*** .70
Life Stage (2,38)	7.469** .282	6.260** .248	8.595** .31	18.13*** .49	17.86*** .48	9.112** .324
Block × Identity (2,38)	.121 .006	1.306 .064	.535 .03	1.801 .09	1.589 .08	.262 (.01)
Block × Life Stage (2,38)	2.863 .131	.367 .019	.097 .01	.173 .01	.18 .01	1.234 .06
Identity × Life Stage (4,76)	1.304 .064	.109 .006	.476 .02	1.877 .09	2.367 .11	4.026** .18
Block × Identity × Life Stage (4,76)	.866 .044	.047 .002	1.348 .07	.221 .01	.681 .03	2.006 .010

Note: *df*, degrees of freedom; n.s., not significant.

* $p < .05$;

** $p < .01$;

*** $p < .001$.

adolescence was significantly larger than childhood exclusively at the anterior region ($p = .029$), while it was nonsignificant at central and posterior regions ($p = .205$; $p = .792$, respectively). No further significant interaction effects involving the ROI factor were found.

For the purpose of this study, it was relevant to examine the two-way interaction between Identity × Life stage. In this regard, the ANOVA for the LPC amplitude revealed a significant effect as shown in Table 1. On one side, comparing self across time (see ERP bar graph, Figure 5a), the mean amplitude for adulthood was larger compared to adolescence ($p = .004$) and childhood ($p = .003$), but no difference was found between adolescence and childhood ($p = .089$). Likewise, comparing close-friend across time, the mean amplitude for adulthood was significantly larger compared to childhood ($p = .019$). On the other side, comparing all identities at each life stage (see ERP bar graph, Figure 5b), self was significantly larger than close-friend at each life stage (all $ps < .001$), as well as compared to unknown (all $ps < .001$). No differences were found between close-friend and unknown at any life stage (all $ps \geq .082$).

4 | DISCUSSION

The present study aimed to analyze the neural correlates of self-identity representation and its continuity across time. In particular, this study addresses two questions, namely, how and when the brain discriminates self-identity from others,

and how the own identity is processed in spite of changes across time. Overall, this study provides new evidence about specific neural correlates to self-identity, indicating self-preferential processing compared to other identities (close-friend and unknown people), beginning as early as 250 ms. Importantly, such preferential processing is modulated across life stages (childhood, adolescence, adulthood).

Regarding the first question, the ERP modulations reported in this work provide support for a specific self-representation pattern that is sensitive to the temporal dimension throughout life stages, particularly reflected by the LPC amplitudes. These findings might be due to particular access to personal knowledge and personal relevance associated with self-face processing. This representation seems to be stable and is also updated across time as a result of plasticity mechanisms and development. Concerning the relationship between the past self and the past close-friend, the results of this study revealed similarities at certain stages of information processing (i.e., N250 and P3 components), while differences were found at other processing stages (i.e., LPC) not described so far. Furthermore, the results of this study suggest the P3 as the most robust neural marker for distinguishing the self from other identities, regardless of temporal perspective.

4.1 | Behavioral findings

The behavioral results indicate that the participants had a substantially better performance for identity recognition than

for life stage recognition. In addition, more misclassification rates occurred during the judgments of the life stages of the unknown person. These results may suggest a potential difference between blocks in cognitive demands, yielding larger difficulty in the life stage block. Increasing the interval between ages would probably facilitate its discrimination, decreasing misclassification, but intermediate ages would increase difficulty. Another factor that might explain the better performance in recognizing identity is familiarity with the presented stimuli. Familiarity with close-friend's face and, particularly with proper face, would make them more easily recognizable in an identity task. Furthermore, in agreement with previous studies (Apps et al., 2012; Kotlewska & Nowicka, 2015) we observed a better performance with stimuli referred to the present than to the past.

4.2 | Self-identity is better reflected by later components

Our results support that the N170 is insensitive to an effect of face familiarity. This is in accordance with previous works (Alzueta et al., 2019; Butler et al., 2013; Kotlewska & Nowicka, 2015; Miyakoshi et al., 2008, 2010; Sui et al., 2006; Tanaka et al., 2006; Xu et al., 2017). In turn, this pattern is consistent with the proposal that the N170 reflects an automatic mechanism detecting the global configuration of a face in a recognition task, rather than identifying the identity of a face (Olivares et al., 2015; Schweinberger & Neumann, 2016). Previous studies have described an own-age bias, that is, the adults recognize adult faces more accurately than children's faces, whereas children recognize children's faces more accurately than adult faces (Harrison & Hole, 2009; Hills & Lewis, 2011). This might be consistent with our findings on the N170 related to the discrimination of global perception properties between current "adulthood" faces and younger faces (i.e., "adolescence" and "childhood" faces).

At later latencies, the N250 was the earliest neural response discriminating self-faces from other faces. This finding is in consonance with previous works (Miyakoshi et al., 2008; Scott et al., 2005; Tanaka et al., 2006; Woźniak et al., 2018), and supports the idea that the N250 is involved in the access of self-face recognition units from long term memory. This access to personal knowledge enables the basic function of self-awareness and categorization (recognition of oneself). Likewise, the lower amplitude found for self-faces at this stage of the processing could indicate the facilitation of attentional resources for self-recognition (Olivares et al., 2015; Schweinberger & Neumann, 2016). However, the N250 was unable to distinguish the self as a function of time, as life stage and identity did not interact during this window.

After 250 ms of stimulus onset, self-related processing elicited a long-lasting positivity, that is, both P3 and LPC. These

components were able to discriminate between the self and other identities, and this was so regardless of task demands. The P3 has been proposed as a robust and specific index for self-referential processing, reflecting the mobilization of attentional resources to a task-relevant target event. These results are in line with previous research (Keyes et al., 2010; Knyazev, 2013; Miyakoshi et al., 2010; Sui et al., 2006; Xu et al., 2017). Studies on the neural underpinnings of self-relevant processing have suggested that the larger the long-lasting positivity, the more important is the self-related content (Anaki & Bentin, 2009; Chen et al., 2011; Muñoz et al., 2020; Tacikowski & Nowicka, 2010; Xu et al., 2017). In other words, larger amplitudes in later components might reflect the increased allocation of attention, and more elaborate processing, presumably due to the meaningfulness of self-relevant information.

The P3 may reflect the categorization of the stimulus, involving larger facilitation due to self-preferential access in face recognition units from long term memory, as well as emotional saliency characteristics. The larger LPC amplitude could reflect a step further in the cognitive re-evaluation process, engaging more allocation of attentional resources as a result of deeper attribution of personal meaning and relevance associated with self-related information. Therefore, self-referential processing includes a certain degree of personal knowledge involving episodic memory (e.g., specific autobiographical events), semantic memory knowledge (e.g., facts about oneself), the first-person perspective of the self (Gillihan & Farah, 2005), as well as top-down attentional control (Humphreys & Sui, 2016).

It should be noted that our results provide evidence of a high degree of consistency involving self-related effects in both explicit and implicit attentional contexts. Given that no statistical differences were found as a function of each block, it seems that the preferential processing of self-related information could emerge regardless of whether the task demands are implicit or explicit. This is in consonance with previous studies that have examined the relationship between targeted or explicit processing versus automatic or implicit processing related to self-face recognition (Geng et al., 2012; Sui et al., 2006). Accordingly, these findings on self-face recognition could reflect the activation of a core self-representation, which is probably operating as an integrative hub that increases coupling across different stages of self-related processing (i.e., perception, memory, attention and decision making), along with emotion and reward (Berkman et al., 2017; Sui & Humphreys, 2015).

4.3 | The temporal perspective on the self-identity

The LPC was the most sensitive component of the temporal factor of the self. Concerning the self-continuity across time

(see Figure 5a), there is a larger self-specificity response for the current compared to more-distant past “childhood,” as reported by previous research (Apps et al., 2012; Butler et al., 2013; D’Argembeau et al., 2008). A very similar response was also found for the close-friend condition (Butler et al., 2013). The absence of difference between past selves (both adolescence and childhood) might be related to similar levels of attentional resources engaged during categorization and recognition, according to previous studies (Kotlowska & Nowicka, 2015; Polich, 2007). This may be consistent with certain stability of identity arranged during adolescence (McAdams, 2013). Interestingly, however, a novel finding of this study is that the LPC could distinguish self-identity from other identities across all life stages in both blocks (see Figure 5b). In addition, this distinctive pattern of the LPC might confirm the allocation of exclusive personal relevance for the self throughout the different life stages, specially, differentiating the current self and past selves (both adolescence and childhood).

The personal relevance attributed to the processes reflected in the LPC might be associated with a wider enrichment of information for oneself compared to others in the memory system and its interaction with the emotional characteristics of the stimuli. Self-relevant and emotional information have been explored in previous research regarding language comprehension, suggesting that a self-relevant context could lead to top-down attentional effects (Fields & Kuperberg, 2012, 2016). Recent studies have proposed that the LPC, in a distant temporal perspective of self-perception, is more sensitive to semantic memory rather than episodic memory (Renoult et al., 2016; Tanguay et al., 2018). It seems, therefore, that personal knowledge is related to either semantic or episodic memory, depending to some extent on time perspective, though further studies should test this idea. Interestingly, we have found a certain degree of self-continuity across time. Despite physical changes, self-awareness allows one to keep a unique sense of the self regardless of the life stages, that is, preserving the identity of the person across time. This is what Northoff (2016a) refers to the sense of continuity of a person across time as the diachronic identity (similar to the minimal self, Gallagher, 2000). Hence to our knowledge, the current findings on LPC expand prior work that accounts the self-continuity as the temporal core of personal identity (Northoff, 2017).

4.4 | Limitations

We first acknowledge a likely limitation in the sample size, which could affect the statistical power. Collecting participants that should provide us with several photos (their own faces and a close-friend’s faces) of a certain kind (three different ages, direct gaze, neutral expression, high quality) was problematic. Nonetheless, current statistical results are

accompanied by the power score (partial eta squared) and 95% confidence intervals. A second limitation comes from the fact that the participants perform a recognition task with the same facial stimuli in two different blocks (identity and life stage recognition). Thus, it might be the case that identity processes (e.g., self-relevance) were taking place implicitly during the life stages block, while life stage processes (e.g., recognition of children’s faces) were taking place implicitly during the identity block. However, in the present work, we have examined both blocks together, and we have not found any particular interaction of the demands of each block with the processes of identity and life stage. It should be noted that explicit and implicit processes associated with identity and life stages, respectively, have not been dissociated in the presented results. Besides, since the order of presentation of the blocks was randomized, we assume that these effects are dissipated throughout the sample.

4.5 | Concluding remarks

Our results provide new evidence about specific ERP modulations related to self-processing in a temporal perspective. The N170 was elicited by changes in the global face configuration across time, regardless of the face identity. The N250 reflects the earliest neural marker for the self-preferential access over other identities, most likely due to the facilitation of attentional resources for the access of one’s face from long-term memory. The P3 was a more robust index of self-representation, and it may reflect the categorization of the stimulus (self-awareness) and emotional saliency processing. The LPC extends a step further in the self-referential stimulus processing, and it seems to expand the personal significance associated with self-related information. Furthermore, the LPC was the most sensitive component to the temporal perspective of the self, discriminating the self and its continuity across time, as well as discriminating the self-identity from other identities across all life stages. This finding would suggest a key role of the processes reflected by the LPC, presumably engaging larger self-relevant and self-related information. Overall, this particular cognitive representation seems stable, and it may also be updated across time.

ACKNOWLEDGMENTS

This study was supported by Grant No. PSI2017-82357-P from the Spanish Ministry of Economy and Competitiveness (MINECO), and by Grant No. FPU18/02223 from the Spanish Ministry of Sciences, Innovation, and Universities.

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Miguel Rubianes Méndez: Conceptualization; Data curation; Formal analysis; Investigation; Methodology;

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

The data used for statistical analysis can be found on the Open Science Framework platform (<https://osf.io/9hfd5/>).

How to cite this article: Rubianes M, Muñoz F, Casado P, et al. Am I the same person across my life span? An event-related brain potentials study of the temporal perspective in self-identity. *Psychophysiology*. 2020;00:e13692. <https://doi.org/10.1111/psyp.13692>