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Deficits in facial emotional valence processing in older people with subjective memory complaints: Behavioral and electrophysiological evidence

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Abstract

Subjective memory complaints (SMCs), which occur in the absence of clinical memory deficits, may precede mild cognitive impairment (MCI) or Alzheimer's disease (AD). Some studies have reported a deficit in facial emotion processing in people with MCI or AD. However, it is unclear whether this deficit is also present in older people with SMCs. The present study used behavioral measurements and event-related potentials (ERPs) to investigate the facial emotion processing of 41 older people with SMCs and 38 without SMCs. The task contained 204 images displaying facial emotions (positive, negative, and neutral). In terms of behavior, our results showed that participants with SMCs were slower and less accurate than controls. In terms of ERPs, the N170 latency was longer in men with SMCs than in controls, whereas no differences were observed between groups in the P300 and late positive potential (LPP) latencies or amplitudes. Moreover, in participants with SMCs, higher P300 and LPP amplitudes were related to better performance on working memory, psychomotor speed, and attention. Additionally, women were faster and more accurate than men on the facial emotion-processing task. In sum, these results suggest that older people with SMCs may have deficits in the processing of facial expressions of emotion. However, this deficit seems to affect the structural encoding of faces, rather than the late stages of processing.

KEYWORDS

ERPs, facial emotion processing, LPP, N170, old people, P300, subjective memory complaints

1 | INTRODUCTION

In recent years, subjective memory complaints (SMCs) have received attention because they are considered a prodromic phase of mild cognitive impairment (MCI; Jessen et al., 2010) or Alzheimer's disease (AD; Rönnlund et al., 2015). SMCs occur in the absence of any organic or identifiable condition in a medical or neuropsychological

[Correction added on December 26, 2021 after first online publication: the corresponding author name was inadvertently updated as Vanesa Perez instead of Vanesa Hidalgo. Now it has been corrected.]

examination (Schmand et al., 1996). SMCs are frequently reported by older people (Burmester et al., 2015), with some studies showing a higher prevalence in women (Genziani et al., 2013) and others showing more SMCs in men (Holmen et al., 2013). Likewise, the relationship between SMCs and objective neuropsychological performance varies. Whereas some studies have reported no differences in neuropsychological performance (Peter et al., 2014; Van de Flier et al., 2004), others have related SMCs to worse neuropsychological functioning (Benito-León et al., 2010; Cespón et al., 2018; Stenfors et al., 2013; Vaskivuo et al., 2018). These latter studies have found that older people with SMCs have deficits in cognitive processes related to executive functioning (EF), such as working memory and attentional shifting (Stenfors et al., 2013), inhibitory control (Cespón et al., 2018), and phonologic fluency (Benito-León et al., 2010). Importantly, EF seems to be relevant in facial emotion processing (Ibáñez et al., 2011; Mathersul et al., 2009; Pessoa, 2009).

Facial expressions report how people feel and their tendency toward action (Yang et al., 2015). In this regard, the capacity to extract emotional states from facial expressions is a key component of social functioning (Hinojosa et al., 2015). Consequently, deficits in facial emotion processing affect everyday life and may underlie impaired social skills (Elferink et al., 2015). Despite this, few studies have been carried out on this issue in people with SMCs (Lazarou et al., 2018; Pietschnig et al., 2016), although several studies have examined pathologies characterized by cognitive decline, such as MCI (for review, see: McCade et al., 2011; Schefter et al., 2013; Spoletini et al., 2008; Varjassyová et al., 2013; Yang et al., 2015) and AD (for review, see: Elferink et al., 2015; Fide et al., 2019).

Facial emotion processing is a complex process that involves different cerebral structures, such as the frontal and temporal areas (Ruffman et al., 2008), inferior occipital temporal cortex, fusiform gyrus (Eimer & Holmes, 2007), amygdala, orbitofrontal cortex, basal ganglia, and right parietal cortices (Adolphs, 2002). Facial emotion processing can be analyzed by using event-related potentials (ERPs). Due to their excellent temporal resolution, ERPs provide insight into different stages of emotional processing, including early perceptual processes as well as later processes (Schefter et al., 2013). Regarding early perceptual processing, the N170 is a negative ERP component that peaks at approximately 150–170 ms and reflects the conscious interpretation of a stimulus such as a face (Hinojosa et al., 2015; Rossion, 2014). This component is distributed in the occipitotemporal cortex, with neural generators in the fusiform gyrus (Hinojosa et al., 2015; Sadeh et al., 2008), and it can be modulated by the emotional valence (Qiu et al., 2017). Processing of the emotional valence is also reflected in late components known as P300 (Luo et al., 2010) and late positive potential (LPP; Moran et al., 2013). The activity of the P300 component reflects cognitive processes such as memory encoding and attention, and it is one of the most widely studied (for a review, see Pavarini et al., 2018). Specifically, the amplitude of P300 is sensitive to the amount of attentional resource allocation, and its latency represents the speed with which attention resources are allocated (Polich, 2007). Previous studies reported that P300 latency was longer in older people with SMCs who performed different tasks, such as the Go/No-Go task (Smart et al., 2014), Simon task (Cespón et al., 2018), and auditory oddball task (Gironell et al., 2005). With broader latency than P300, LPP is a slow positive potential that becomes most apparent around 400 to 600 ms after the stimulus at centro-parietal midline sites (Schupp et al., 2006). Furthermore, LPP reflects sustained and motivated attention and an elaborate and controlled processing of the stimulus (Schupp et al., 2006). Specifically, increases in LPP amplitude would reflect the representation of stimuli in working memory (Schupp et al., 2006) and improved recognition memory performance (Olofsson et al., 2008). A prior study reported reduced LPP amplitude in older adults with memory impairments during word encoding and recognition (Kenney et al., 2019). However, to the best of our knowledge, no previous studies have investigated the P300 and LPP activity in facial emotion processing in older people with SMCs.

Given that deficits in facial emotion processing have been widely studied in MCI, and that SMCs are considered a risk factor in developing MCI, we wonder if these deficits also occur in SMCs. Taking this into account, our main aim was to determine whether there are differences in the neuronal correlates and behavioral measures of facial emotion processing between older people with and without SMCs (SMCs and control groups, respectively). Based on previous studies in MCI patients, we expected a slower response time (RT) and worse accuracy in the SMCs compared to the control group (Sarabia-Cobo et al., 2015; Schefter et al., 2013; Yang et al., 2015) on a facial emotion-processing task. We also expected longer latencies and smaller amplitudes in N170, P300, and LPP in SMC participants compared to controls (Asaumi et al., 2014; Schefter et al., 2013; Yang et al., 2015). In addition, considering that difficulties in the processing of facial emotions have been related to EF deficits (Pietschnig et al., 2016; Teng et al., 2007), a second aim was to investigate the possible association between ERP measures and EF performance, assessed with several neuropsychological tests, in older people with and without SMCs. Finally, given that many psychological (Montagne et al., 2005) and physiological (Choi et al., 2015; Li et al., 2008) studies have shown sex differences in facial emotion processing, we included an equal distribution of women and men to explore possible sex-related differences in the SMC and control groups.

2 | METHOD

2.1 | Participants

Eighty-two healthy older people participated in the study (40 men, 42 women). Participants were recruited in classes of La Nau Gran, a study program for people over 55 years old, and through advertisements on the campus of the University of Valencia (Spain).

The exclusion criteria were: history of alcohol or drug abuse; having had surgery under general anesthesia in the past year; uncorrected vision or hearing problems or any illness that involves an alteration of the nervous system and a neurologic or psychiatric disorder; and smoking more than 10 cigarettes a day. In addition, participants were excluded if they took drugs related to cognitive or emotional function, psychotropic substances, or beta-blockers, or if they had experienced a stressful event in the past six months. The participants who met the criteria were contacted by telephone and asked to attend two sessions that took place in the Laboratory of Social Cognitive Neuroscience of the University of Valencia.

All the participants completed the Beck Depression Inventory-II (BDI-II; Beck et al., 1996), and three female participants who scored above 20 were excluded from the analysis. Therefore, the final sample was composed of 79 participants (all right-handed) who were distributed in two groups: SMCs ($n = 41$; 19 men and 22 women) and Control ($n = 38$; 21 men and 17 women). No significant differences in participants' age ($t\,(77) = -1.010$, $p = .316$), sex ($\chi^2 = 0.628$, $p = .428$), or educational level ($\chi^2 = 7.063$, $p = .216$) were observed between the SMC and Control groups (see Table 1).

Participants were distributed in these two groups according to their scores on the Spanish adaptation (Lozoya-Delgado et al., 2012) of the modified version of the Memory Failures of Everyday (MFE-30) questionnaire (Sunderland et al., 1984). This questionnaire contains 30 items about situations and activities of daily life, rated on a 5-point Likert scale ranging from 0 (never or almost never) to 4 (always or almost always). We used these scores to distribute participants in the two conditions: participants who scored above 21 were allocated to the SMCs group, whereas participants who scored equal to or below 21 were included in the Control group. Twenty-one was the mean score obtained by the whole sample on the MFE-30 scale. Lozoya-Delgado et al. (2012) also observed that 21 was the mean score on this questionnaire in a sample of 900 Spanish participants. Notably, cut points and categorical distinctions are used in clinical practice and may be helpful to neuropsychologists using this questionnaire.

The study was performed according to the Declaration of Helsinki, and the Ethics Committee of the University of Valencia approved the protocol (Code: 1034878). All participants received verbal and written information about the study and signed an informed consent.

2.2 | Procedure

Each participant attended two individual sessions on two consecutive days. Sessions lasted approximately two hours, either in the morning (between 10 and 12 am) or in the afternoon (between 15–17 and 17–19 p.m.). Half the participants attended in the morning and the other half in the afternoon. Each participant started both sessions at the same time of the day. The first session consisted of a neuropsychological assessment, and the second session consisted of ERP recording.

In each session, the experimenter checked whether participants had followed the instructions offered previously, which were: abstain from heavy physical activity the day before the session; do not consume alcohol or any stimulant since the night before the session; and sleep as long as usual. Moreover, participants were instructed to drink only water, and not eat, smoke, or take any stimulants such as coffee, cola, tea, or chocolate one hour before the experimental session.

TABLE 1 Means (and standard deviations) for demographic data

Demographic measures	SMCs ($n = 41$)	Control ($n = 38$)	Men ($n = 40$)	Women ($n = 39$)
Sex	19m/22w	21m/17w		
Age	63.9 (5.3)	65.24 (5.7)	65.43 (6.61)	63.72 (5.4)
Educational level				
Primary	5 (6.33%)	3 (3.8%)	3 (7.5%)	5 (12.8%)
Secondary	16 (20.25%)	8 (10.12%)	10 (25%)	14 (35.9%)
University	20 (25.31%)	27 (34.1%)	27 (67.5%)	20 (51.2%)

Abbreviations: Control, no subjective memory complaints; m, men; SMCs, subjective memory complaints; w, women.

2.2.1 | Session one: Neuropsychological assessment

In the first session, the weight and height of the participants were measured. In addition, they completed the MFE-30, the BDI-II, and a General Questionnaire with demographic data. Then, a neuropsychological evaluation was carried out. Participants performed four tests to measure EF domains, namely verbal working memory, visuo-spatial working memory, attention-switching, and verbal fluency.

Verbal working memory

It was evaluated with the Digit Span Test of the Wechsler Memory Scale (Wechsler, 1997). This test consists of two subtests that are administered independently: (a) the Digit Span Forward (DS-Forward), a measure of attention; and (b) the Digit Span Backward (DS-Backward), a measure of the executive component of working memory (Conklin et al., 2000). On the DS-Forward, the subject listens to numbers and has to repeat them in the same order. For the DS-Backward, the subject listens to numbers and has to repeat them in the reverse order. On this task, the sequences start at level 2 and can increase up to level 8. Subjects get two chances for each sequence length; if one of the sequences is performed correctly, the next sequence starts. Two measures were obtained: (a) DS-Forward: total number of correctly recalled trials in the same order; and (b) DS-Backward: total number of correctly recalled trials in the reverse order.

Visuo-spatial working memory

The Automated Working Memory Assessment (AWMA) was used to assess visuo-spatial working memory (Alloway et al., 2008). On the Dot Matrix Forward subtest, the subjects point out the red dots in the same order they appeared. On the Dot Matrix Backward subtest, the subjects point out the boxes in the reverse order to the way they appeared. Two measures were obtained: (a) Dot Matrix-Forward: total number of correct trials in the same order; and (b) Dot Matrix-Backward: total number of correct trials in the reverse order. On this task, the sequences start at level 2 and can increase up to level 8. Subjects get two chances for each sequence length; if one of the sequences is performed correctly, the next sequence starts.

Attention-switching

The Trail-Making Test (TMT) was employed. It consists of two forms: the TMT-A and the TMT-B. The TMT-A was used to assess general psychomotor speed and attention, and the TMT-B was administered to measure the efficiency of attention-switching performance (Reitan, 1992), a component of EF. This test requires participants to connect a series of circles with a pen. On the TMT-A, the circles are numbered from 1 to 25, and participants must connect them in increasing order. The TMT-B contains circles numbered from 1 to 13 and circles lettered from A to L, and participants must connect the circles in order, alternating from a number to a letter. Two measures were obtained: (a) TMT-A: total time required to finish part A; and (b) TMT-B: total time required to finish part B (less time means better performance).

Verbal fluency

To measure phonological fluency, that is, cognitive organization and ability to carry out an unusual word search, focal attention, sustained attention, and inhibition process, participants were asked to generate as many words as possible beginning with the letters F, A, and S in 60 s. In addition, to assess semantic fluency, participants were asked to generate as many words as possible in the semantic category "Animals" in 60 s. Only correct answers were scored; intrusions, repeated attempts, and variations within the same species were not considered. Instructions for the two fluency tasks were given following the administration procedures provided in the Barcelona test (Peña-Casanova, 1991). The measure obtained was the number of correct words listed in each category.

2.2.2 | Session two: Face stimulus task with EEG recording

Twenty-four hours later, participants returned for the second session. The participants were prepared for the EEG recording after a 15-min habituation to the laboratory. Next, the Face Stimulus task was presented and lasted approximately 12 min, with simultaneous EEG recording.

Face stimulus task

Stimuli were 204 facial expressions of emotions with positive, negative, and neutral valences. There were 68 photos for each valence, with male and female models in equal proportion. Photos were presented randomly to the participants. All photos were presented in a uniform size, grayscale, black background, and they were displayed at the center of a 24-inch size screen. All photos were extracted from the Karolinska Emotional Directed Faces (KDEF) database to generate emotional stimuli (Lundqvist et al., 1998).

The stimuli were presented in the following sequence: (1) a fixation mark (+) appeared for 1000 to 1300 ms; (2) the face was presented for 200 ms; and (3) a blank screen was displayed for 800 ms. The images were presented using the E-prime software (v2.0). Participants were instructed to press the 1 key if the facial expression was positive, 2 if it was negative, and 3 if it was neutral. The participants were seated 70 cm away from the screen in a dimly lit, sound attenuated room. The task started with a trial run with 12 stimuli. Participants received feedback after each of these 12 photos, showing whether it was right or wrong.

EEG recording and data analyses

The EEG signal was collected using an EEG cap (Easycap, Falk Minow, Munich, Germany) from a 29-channel system, in accordance with the international 10–20 system (Fp1, Fpz, Fp2, F7, F3, Fz, F4, F8, FCz, M1, T3, C3, Cz, C4, M2, P3, P4, Pz, P4, T5, T6, O1, Oz and O2), using a BrainAmp Standard amplifier system (Brain Products, Germany). The electrode AFz was used as the system ground, and electrodes were referenced to FCz. Vertical and horizontal electro-oculograms were captured by additional electrodes (VEOG−, VEOG+, HEOG−, HEOG+) placed around the eyes. The electrode-to-skin impedances were lowered using electrolyte gel (SUPER-VISC High Viscosity Electrolyte-Gel, EasyCap, Brain Products GmbH), and they were maintained below 5 kΩ before starting the recording. Data were re-referenced to a common average signal of 23 electrodes (Joyce & Rossion, 2005). The EEG and EOG were amplified and then passed through (0.1Hz–30 Hz) a band-pass filter using an IIR filter (24 db/octave roll-off). Stimulus-locked epochs were extracted in a range from −200 to 1000 ms. Trials were then corrected to the mean voltage of the baseline (−200 to 0 ms). Epochs with EOG artifacts, including blinking or eye movement, as well as skin potentials, were corrected off-line using the algorithm by Gratton and Coles (Gratton et al., 1983). Epochs with incorrect responses were removed from averaging. The N170 component was measured at T6 and T5 within the time window of 130–200 ms. The P300 and LPP components were measured at Pz because it is the region where P300 and LPP achieve their maximum amplitude within the time window of 200–500 ms and the mean value of their amplitude within 400–700, respectively. Off-line EEG processing and analyses were performed with Brain Vision Analyzer System (Brain Products, Germany) software. In order to investigate behavioral performance on the face stimulus task, we also calculated average reaction times (RT) and accuracy.

2.3 | Statistical analyses

To investigate differences between groups (SMCs vs. Controls) and sex on demographic and neuropsychological data, Student's *t*-tests and chi-squared, respectively, were performed.

Independent repeated-measures ANOVAs were performed on behavioral performance (RT and accuracy), as well as the latencies and amplitudes of the N170, P300, and LPP components. In these analyses, both *Group* (SMCs, Control) and *Sex* (men, women) were between-subject factors, and *Emotional Valence* (positive, negative, neutral) was the within-subject factor. For the N170 component, *Hemisphere* (left, right) was also included as an additional within-subject factor. The ANOVAs including the Sex of face of stimulus were described in supplementary material. In the case of violation of sphericity, Greenhouse-Geisser corrected values were reported. *Post hoc* comparisons were performed using Bonferroni correction.

In order to examine possible relations between EF performance and amplitudes of the N170 (average of left and right hemisphere), P300, and LPP components, we calculated the valence difference score by subtracting positive and negative faces from neutral faces. To test whether N170, P300, and LPP amplitudes of face valence were correlated with DS-Backward, Dot Matrix-Backward, and TMT-B, we calculated partial Pearson's correlations with DS-Forward, Dot Matrix-Forward, and TMT-A, respectively, as covariates. In addition, to test whether N170, P300, and LPP amplitudes were associated with verbal fluency, we performed bivariate Pearson's correlations.

To investigate the main research question (interaction between Group and Emotional valence), we estimated a sample size of 72 participants for a small to medium effect size ($f = 0.175$, alpha = 0.05 and power = 0.90) for this interaction. We recruited 82 participants to anticipate possible missing data. The level of significance was set at $\alpha = 0.05$, and SPSS 26.0 was used to perform the statistical analysis.

3 | RESULTS

3.1 | Neuropsychological measures

Results indicated that scores on DS-Backward, $t(76) = -2.688$, $p = .009$, and Dot Matrix-Forward, $t(76) = -2.841$, $p = .006$, were lower in the SMCs group than in the Control group. No statistically significant differences were found on any other neuropsychological measures (all $p > .097$).

Descriptive data for the neuropsychological variables are summarized in Table 2.

3.2 | Behavioral performance

Results for RT and accuracy data are presented in Table 3. For RT, a main effect of *Group* was observed, $F(1,77) = 6.268$, $p = .014$, $\eta_p^2 = 0.075$, indicating a longer RT in the SMCs group than in the Control group. A significant main effect was also observed for *Sex*, $F(1,74) = 5.201$, $p = .025$, $\eta_p^2 = 0.066$, with men showing longer RTs than women.

TABLE 2 Means (and standard deviations) for neuropsychological data

Neurophysiological measures	SMCs	Control	Men	Women
DS-Forward	5.88 (0.135)	6.05 (0.160)	5.87 (0.732)	6.05 (1.075)
DS-Backward	5.73 (0.119)	6.26 (0.163)	6.13 (0.951)	5.85 (0.875)
Dot Matrix	4.28 (0.130)	4.84 (0.144)	4.62 (0.935)	4.49 (0.914)
Backward dot matrix	4.23 (0.170)	4.45 (0.149)	4.21 (1.174)	4.46 (0.790)
TMT-A	47.59 (2.584)	46.63 (2.855)	43.83 (16.116)	50.51 (17.335)
TMT-B	96.46 (6.747)	82.74 (4.678)	82.45 (30.414)	97.46 (42.496)
Semantic fluency	20.41 (1.026)	23.05 (1.187)	40.55 (9.837)	40.51 (12.783)
Phonetic fluency	39.78 (1.845)	41.20 (1.759)	22.60 (6.376)	20.74 (7.594)

Abbreviations: Control, no subjective memory complaints; SMCs, subjective memory complaints; TMT, trail making test.

TABLE 3 Means (and standard deviations) for behavioral performance by group and sex

	SMCs	Controls	Men	Women
RT (ms)				
Positive	864.01 (106.50)	811.83 (89.02)	815.70 (109.11)	861.88 (103.62)
Negative	970.53 (106.06)	887.25 (174.48)	893.84 (179.19)	966.75 (99.79)
Neutral	948.80 (117.09)	891.82 (125.23)	893.72 (130.76)	948.36 (111.43)
Accuracy (%)				
Positive	89.7 (5.90)	94.02 (2.30)	92.3 (4.80)	92.22 (4.64)
Negative	72.0 (9.8)	76.4 (7.34)	73.19 (8.22)	74.82 (9.66)
Neutral	85.5 (7.44)	88.06 (7.10)	88.08 (6.28)	86.20 (8.18)

Abbreviations: Controls, no subjective memory complaints; RT, response time; SMCs, subjective memory complaints.

Moreover, a significant effect of *Emotional Valence*, $F(1.799, 131.640) = 28.070$, $p = .001$, $\eta_p^2 = 0.275$, was found. *Post hoc* comparisons showed that RTs were longer for negative and neutral faces than for positive faces (both $p < .001$). No differences were found between negative and neutral ($p = .099$) faces. Interactions were not significant (all $p > .669$).

For accuracy, a significant effect of the *Group* factor, $F(1,74) = 4.680$, $p = .034$ $\eta_p^2 = 0.059$, was found with the SMCs group showing less accuracy than the Control group. We also found a significant effect of *Emotional Valence* $F(1.706, 126.261) = 81.677$, $p = .001$, $\eta_p^2 = 0.525$. Accuracy was better for positive faces than for negative and neutral faces (both $p = .001$), and better for neutral faces than for negative faces ($p = .001$). Neither the main effect of Sex ($p = .866$) nor any interaction reached statistical significance (all $ps > 944$).

3.3 | ERP data analyses

3.3.1 | N170

For N170 latencies, the effect of *Emotional Valence* was significant, $F(2,138) = 8.462$, $p < .001$, $\eta_p^2 = 0.109$, with longer N170 latencies for negative faces than for positive ($p = .001$) and neutral ($p = .005$) faces. Moreover, we observed a significant effect of Sex, $F(1,69) = 6.396$, $p = .014$, $\eta_p^2 = 0.085$, with men showing longer latencies than women. In addition, a significant interaction between Group*Sex, $F(1,69) = 4.389$, $p = .040$, $\eta_p^2 = 0.060$, was found. *Post hoc* analyses revealed that men with SMCs showed longer latencies than women with SMCs ($p < .001$) (see Figure 1). We also found a significant Emotional Valence*Group*Sex interaction, $F(2,138) = 3.379$, $p = .037$, $\eta_p^2 = 0.047$. *Post hoc* analyses revealed that men in the SMCs group showed longer latencies than women in the SMCs group for negative ($p = .007$), positive ($p = .002$), and neutral ($p < .001$) faces. Furthermore, men with SMCs showed longer latencies than men in the control group for positive ($p = .016$) and neutral ($p = .005$) faces, but not for negative faces ($p = .114$). In addition, women with SMCs revealed longer latencies for positive ($p = .027$) and negative faces ($p = .002$) than for neutral faces (see Figures 1a and 2). The remaining interactions were not significant (all $p > .806$; see Figure 1).

For the N170 amplitudes, results showed a main effect of *Hemisphere*, $F(1,69) = 7.262$, $p = .009$, $\eta_p^2 = 0.095$, with higher amplitudes registered in the right hemisphere than in the left hemisphere. The Hemisphere*Sex interaction

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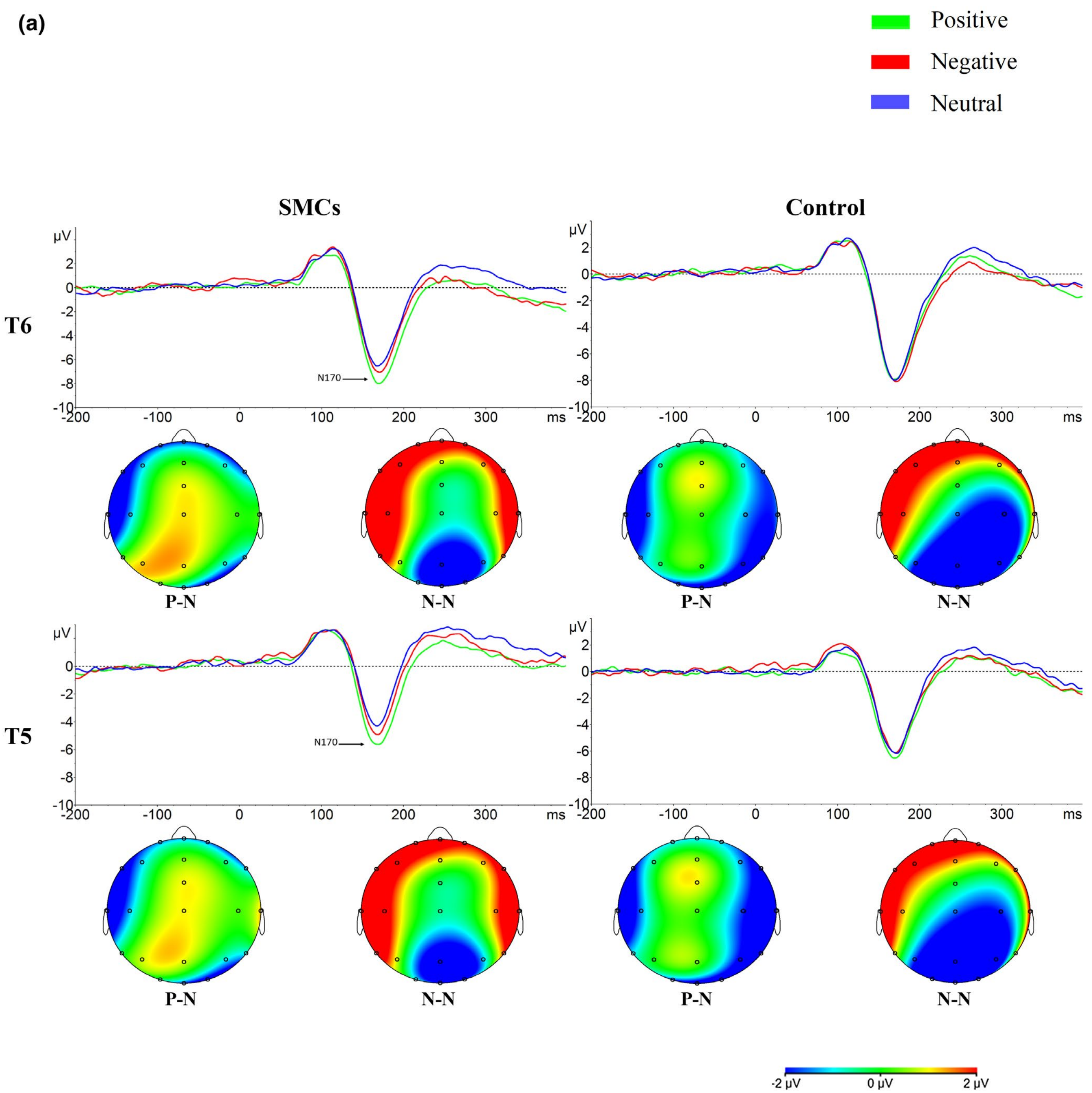

FIGURE 1 Legend on next page

was also significant $F(1,69) = 4.671$, $p = .034$, $\eta_p^2 = 0.063$, with women eliciting higher amplitudes over the left hemisphere than men ($p = .043$). Other factor and interaction effects were not significant (all $p > .940$; see Figure 1).

3.3.2 | P300

For P300 latencies, the analyses indicated that the effects of *Emotional Valence*, *Group*, *Sex*, and their interactions were not significant (all $p > .876$) (see Figures 3 and 4).

For P300 amplitudes, results showed a main effect of *Emotional Valence*, $F(2,152) = 7.902$, $p = .001$, $\eta_p^2 = 0.094$. *Post hoc* comparisons revealed that the amplitudes were significantly higher for negative faces than for positive faces ($p = .015$), and for neutral faces than for positive faces ($p = .002$), but not for negative and neutral ($p > .99$) faces. In addition, the *Sex* factor was significant, $F(1,76) = 7.626$, $p = .007$, $\eta_p^2 = 0.091$,

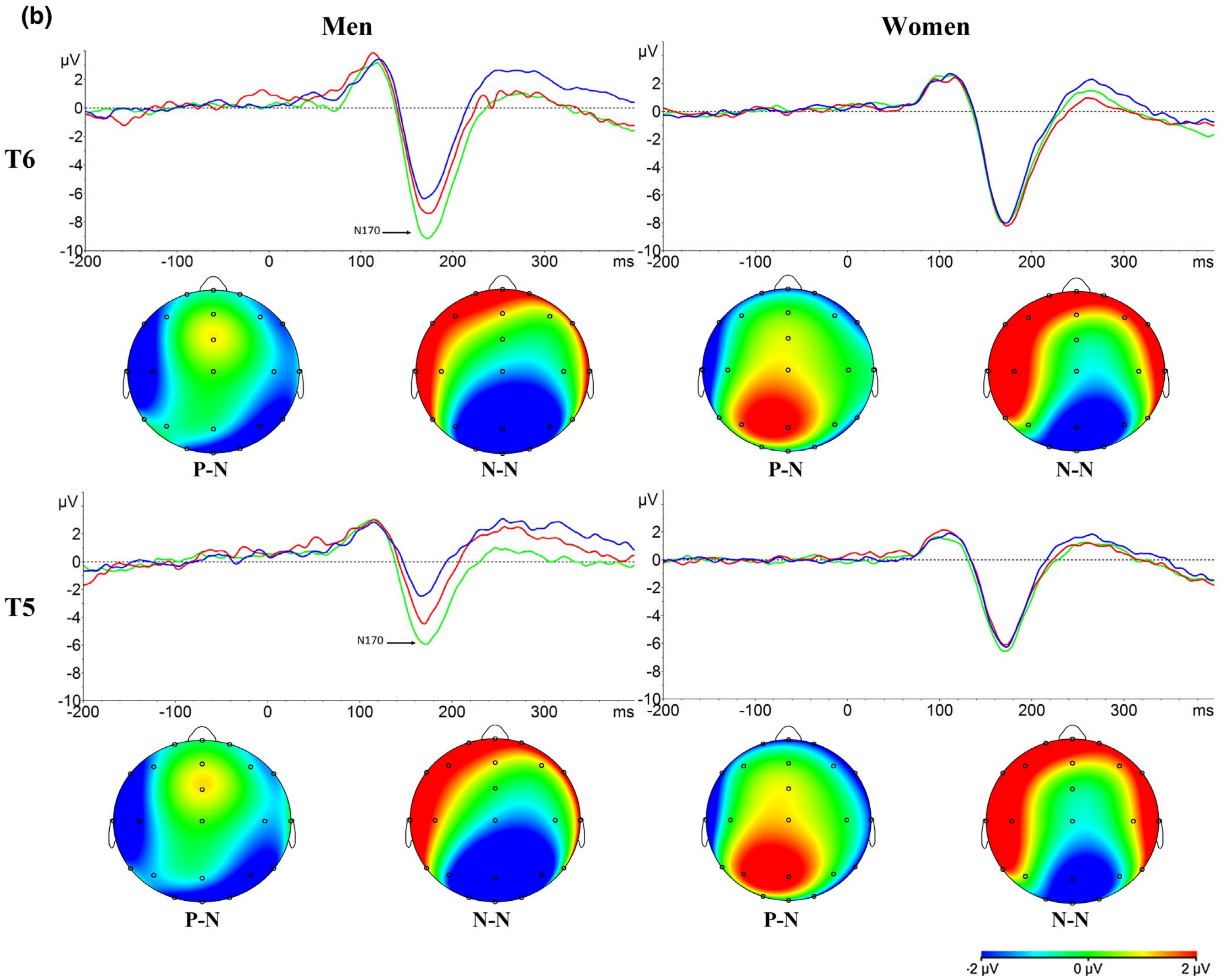

FIGURE 1 N170 latencies and amplitudes by groups and sex. (a) Grand average N170 for positive, negative, and neutral faces recorded in the right and left hemispheres in older people with and without subjective memory complaints. (b). Grand average N170 for positive, negative, and neutral faces recorded in the right and left hemispheres in men and women. Topographical distribution maps of the difference waves (P-N: positive vs. neutral and N-N: negative vs. neutral) are also shown in the time interval of 160–180 ms

with men showing smaller P300 amplitudes than women (see Figure 3b). No other factor or interaction effect reached statistical significance (all p >.591) (see Figure 3).

3.3.3 | LPP

For LPP latencies, the analyses revealed that *Emotional Valence* was significant, $F(2,198) = 6.528$, $p = .002$, $\eta_p^2 = 0.118$. *Post hoc* comparisons showed longer latencies for positive faces than for neutral faces ($p = .008$), but no other significant differences were found (all $p > .746$). The main effects of *Group*, *Sex*, and other interactions were not significant (all $p > .933$; see Figures 3 and 4).

For LPP amplitudes, the analyses indicated that *Emotional Valence*, *Group*, *Sex*, and their interactions were not significant (all $p > .941$; see Figure 3).

3.4 | Relationships between ERPs and EF performance

Table 4 shows the relationships between the P300, N170, and LPP amplitudes and EF performance. Because we are interested in emotion-related modulation, in the correlation analyses we used the difference score (negative vs. neutral and positive vs. neutral) for the amplitudes of the ERP components. In the SMC group, higher P300 amplitude for negative versus neutral faces was correlated with

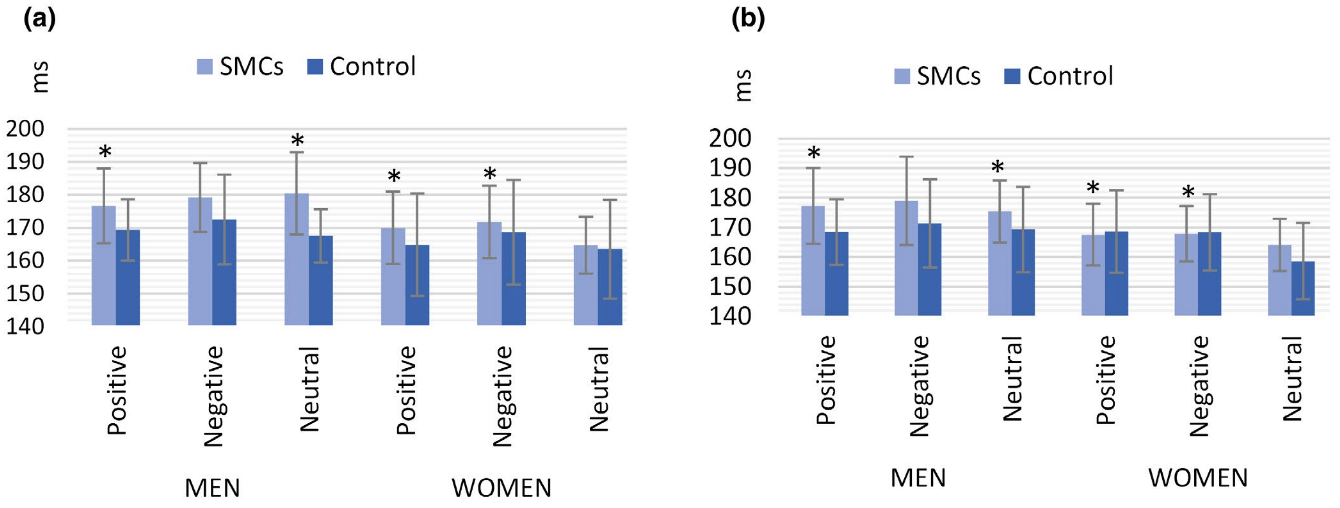

FIGURE 2 Mean latencies (ms) for the N170 component at the T6 electrode (a) and at the T5 electrode (b). Error bars indicate the standard error of the mean

better performance on DS-Backward ($r = 0.367$, $p = .026$) and Dot Matrix-Backward ($r = 0.343$, $p = .035$), and worse performance on TMT-B ($r = -0.375$, $p = .019$). Moreover, a higher LPP amplitude for negative versus neutral faces was associated with better performance on DS-Backward ($r = 0.353$, $p = .035$) and TMT-B ($r = -0.466$, $p = .003$).

In the Control group, a higher P300 amplitude for negative versus neutral faces was correlated with worse performance on Dot Matrix-Backward ($r = -0.349$, $p = .043$). Moreover, a higher N170 amplitude for positive versus neutral faces was correlated with worse performance on Dot Matrix-Backward ($r = -0.388$, $p = .023$). In contrast, a higher N170 amplitude for negative versus neutral faces was correlated with better performance on the same task ($r = 0.396$, $p = .020$).

4 | DISCUSSION

The main aim of the current study was to determine whether facial emotion processing was different in older people with and without SMCs by comparing behavioral and ERP data. Summarizing the main findings, in agreement with the behavioral hypothesis, participants with SMCs had longer RTs and less accuracy on facial emotional processing than participants without SMCs. In addition, we investigated whether SMCs participants showed longer latencies and smaller amplitudes in N170, P300, and LPP than participants without SMCs. In this regard, ERP analyses revealed group differences only in the N170 component. More specifically, men with SMCs showed longer latencies than men in the control group, and men with SMCs revealed longer latencies than women with SMCs. Moreover, women with SMCs showed longer latencies for positive and negative faces than for neutral faces. In contrast, we failed to find differences in P300 and LPP latencies and amplitudes between participants with and without SMCs. Furthermore, regarding the possible association between ERP measures and EF performance, we found that higher amplitudes of P300 and LPP for negative versus neutral faces were associated with higher levels of verbal and visuo-spatial working memory and general psychomotor speed and attention.

At the behavioral level, supporting our hypothesis, results showed that participants with SMCs performed worse than controls on the facial emotion processing task, reflected in longer RTs and less accuracy. Our findings are similar to previous studies on facial emotion processing in people with MCI and AD (Pietschnig et al., 2016; Teng et al., 2007; Varjassyová et al., 2013; Yang et al., 2015). Thus, this deficit in these patients may be an effect of progressive global cognitive degeneration (Pietschnig et al., 2016; Spoletini et al., 2008) detected earlier.

Regarding the ERP hypothesis, in the current study, on the one hand, we found that men with SMCs showed longer latencies than men in the control group for positive and neutral faces but not for negative faces. On the other hand, women with SMCs revealed longer latencies for positive and negative faces than for neutral faces. Additionally, men with SMCs also exhibited longer latencies for the three valences than women with SMCs. Although sex-specific differences in facial emotion processing have been previously reported in the general population (Herlitz & Lovén, 2013), only one study has explored the role of sex in people with SMCs (Pietschnig et al., 2016). This study demonstrated a strong disadvantage for men with SMCs, compared to women, on a facial

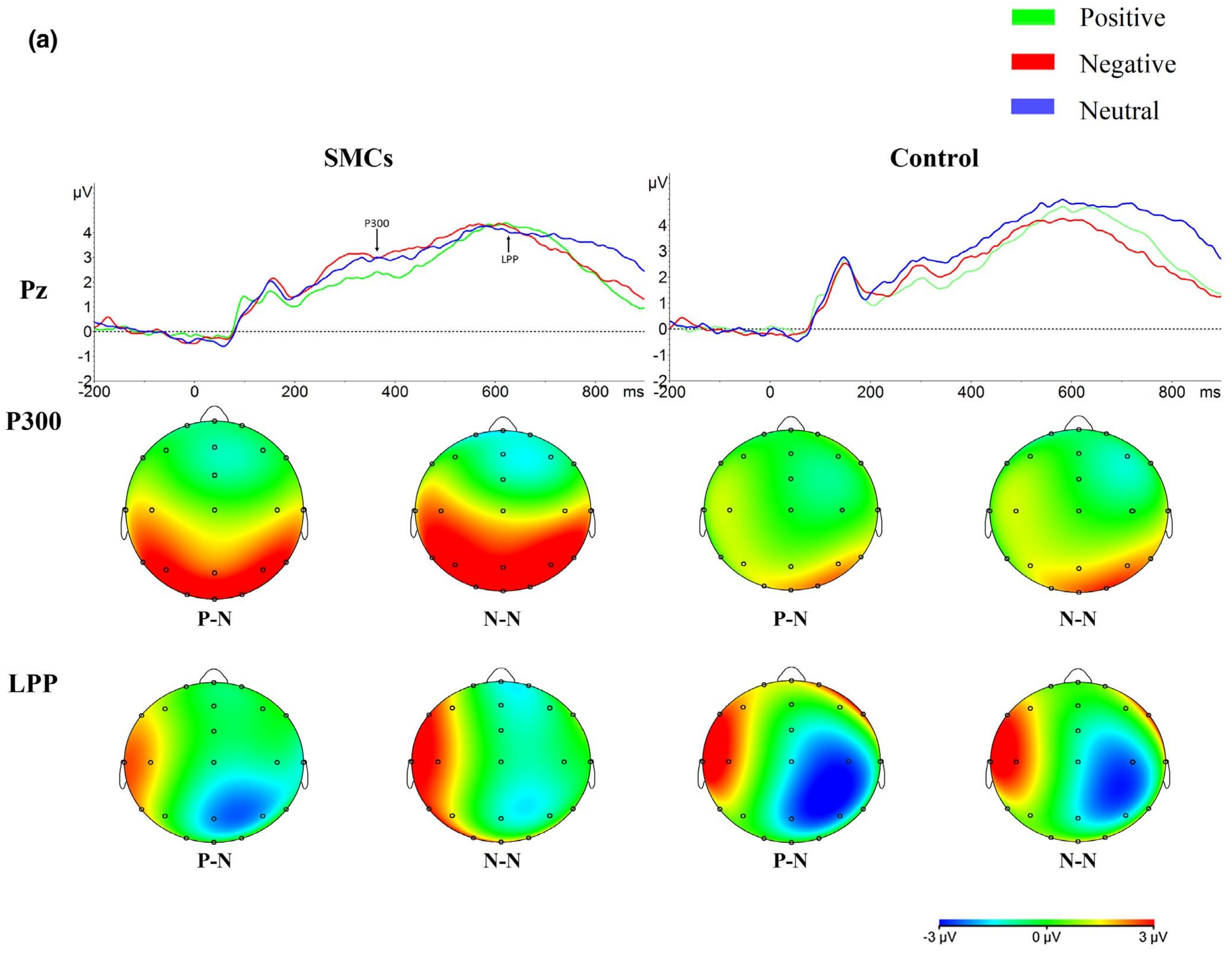

FIGURE 3 Legend on next page

emotion recognition task, which could be consistent with our neural findings. Our results suggest that the difficulties in facial emotional processing are experienced differently depending on the sex of the individual. In this vein, potential deficits in facial emotion processing in men with SMCs deserve attention. However, it is important to note that our study may be underpowered to detect more subtle sex-related differences. Therefore, more research is needed to investigate this idea.

The N170 component is considered an indicator of face structure encoding (Eimer, 2000), where the structural representation of the face is associated with semantic learning to form an internal representation of a human face (Sagiv & Bentin, 2001). Although the findings regarding the sensitivity of the N170 to facial expression are inconsistent (see review: Hinojosa et al., 2015), one study reported that the N170 component participates in the processing of facial expressions, especially the early processing of emotional valences (Qiu et al., 2017). Hence, prolonged N170 latencies indicate that face structure encoding and emotional processing may be slower in older people with SMCs. Similar results have been reported in people with MCI (Schefter et al., 2013; Yang et al., 2015). Interestingly, previous studies revealed that prolonged face structure encoding is associated with longer RTs and has a negative correlation with accurately recognizing emotional faces (Schefter et al., 2013). Our behavioral data are consistent with this interpretation.

We did not find differences in P300 or LPP latencies or amplitudes in older people with and without SMCs. However, previous studies of P300 reported impairments in facial emotion processing in people with MCI and AD (Asaumi et al., 2014; Morgan et al., 2008). These mixed findings could be explained by methodological differences, such as the type of stimuli used, the difficulty of the task, or the severity of the participants' deficits. Additionally, these latter components (P300 and LPP) indicate an elaborate evaluation of emotional stimuli, and these components are susceptible to top-down processing, which involves sustained attention to visual emotional stimuli (Schupp et al., 2006). Our results indicate that later processing phases of emotional faces may be preserved in older people with SMCs.

PSYCHOPHYSIOLOGY

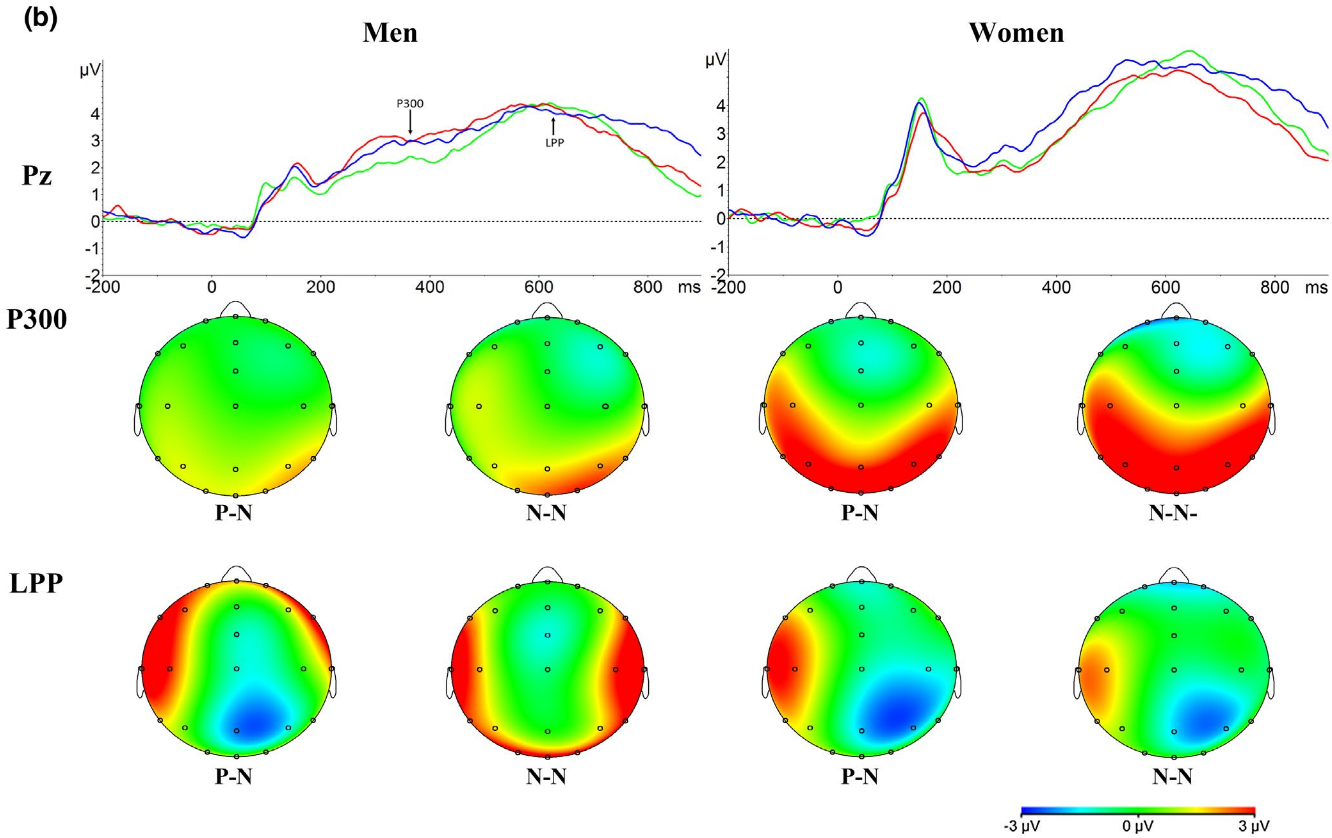

FIGURE 3 P300 and late positive potential (LPP) latencies and amplitudes by group and sex. (a) Grand average P300 for positive, negative, and neutral faces in older people with and without subjective memory complaints. (b) Grand average P300 for positive, negative, and neutral faces recorded in men and women. *$p < .05$. Topographical distribution maps of the difference waves (P-N: positive neutral and N-N: negative vs. neutral) are also shown in the time interval of 200–500 ms for P300 and time interval of 450–700 for LPP

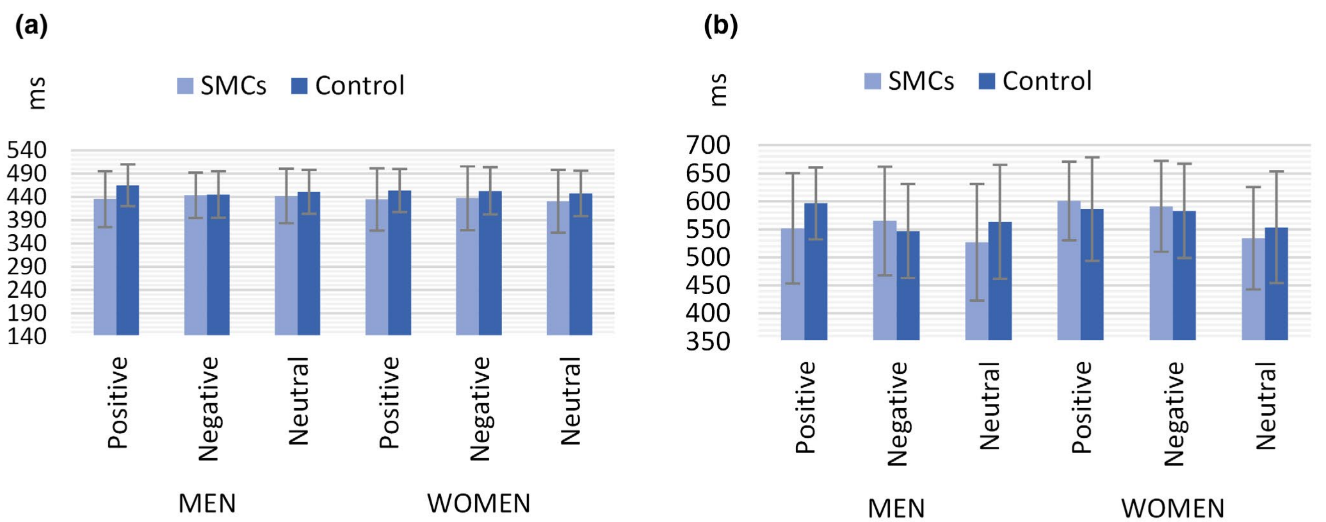

FIGURE 4 Mean latencies (ms) for the P300 component at the Pz electrodes (a) and for the late positive potential (LPP) component at the Pz electrode (b). Error bars indicate the standard error of the mean

Alternatively, the deficit in facial emotion processing might be associated with a decline in several executive functions. It has previously been proposed that facial emotion processing is interlinked with executive functioning (Ibáñez et al., 2011; Mathersul et al., 2009; Pessoa, 2009; Teng et al., 2007). In this regard, correlation analyses

TABLE 4 Correlations between N170, P300, and LPP amplitudes and executive function performance for Subjective memory complaint and Control groups

Groups		Valences	DS-backward	Dot matrix-backward	TMT B	Semantic fluency	Phonological fluency
SMCs	P300	P-N	$r = -0.028$	$r = 0.307$	$r = -0.249$	$r = -0.167$	$r = -0.142$
			$p = .868$	$p = .061$	$p = .127$	$p = .304$	$p = .382$
		N-N	**$r = 0.367$**	**$r = 0.343$**	**$r = -0.375$**	$r = -0.017$	$r = 0.043$
			$p = .026$	**$p = .035$**	**$p = .019$**	$p = .919$	$p = .794$
	N170	P-N	$r = 0.035$	$r = 0.196$	$r = -0.080$	$r = -0.058$	$r = -0.009$
			$p = .839$	$p = .238$	$p = .630$	$p = .720$	$p = .957$
		N-N	$r = 0.007$	$r = 0.232$	$r = -0.275$	$r = 0.238$	$r = 0.096$
			$p = .967$	$p = .161$	$p = .091$	$p = 139$	$p = .556$
	LPP	P-N	$r = 0.124$	$r = 0.234$	$r = -0.248$	$r = -0.160$	$r = -0.237$
			$p = .473$	$p = .164$	$p = .134$	$p = .330$	$p = .146$
		N-N	**$r = 0.353$**	$r = -0.055$	**$r = -0.466$**	$r = 0.124$	$r = -0.089$
			$p = .035$	$p = .745$	**$p = .003$**	$p = .451$	$p = .590$
Control	P300	P-N	$r = 0.164$	$r = 0.188$	$r = -0.100$	$r = 0.008$	$r = 0.283$
			$p = .354$	$p = 0.287$	$p = .575$	$p = 964$	$p = .100$
		N-N	$r = 0.321$	**$r = -0.349$**	$r = -0.051$	$r = -0.222$	$r = -0.045$
			$p = .064$	**$p = .043$**	$p = .775$	$p = .200$	$p = .799$
	N170	P-N	$r = -0.132$	**$r = -0.388$**	$r = -0.034$	$r = -0.075$	$r = 0.181$
			$p = .458$	**$p = .023$**	$p = .847$	$p = .670$	$p = .298$
		N-N	$r = -0.235$	**$r = 0.396$**	$r = -0.120$	$r = 0.225$	$r = 0.133$
			$p = .181$	**$p = .020$**	$p = .500$	$p = .194$	$p = .446$
	LPP	P-N	$r = 0.253$	$r = -0.163$	$r = 0.148$	$r = -0.076$	$r = 0.095$
			$p = .156$	$p = .365$	$p = .412$	$p = .667$	$p = .593$
		N-N	$r = 0.269$	$r = -0.182$	$r = 0.101$	$r = -0.125$	$r = 0.026$
			$p = .130$	$p = .310$	$p = .577$	$p = .483$	$p = .884$

Notes: Significant partial correlations are displayed in bold. In correlation analyses we represent all correlations in italic and significant correlations in bold with italic.

Abbreviations: Control, no subjective memory complaints; N-N, negative vs. neutral; P-N, positive vs. neutral; SMCs, subjective memory complaints; TMT, trail making test.

indicated that higher P300 and LPP amplitudes for negative vs. neutral faces were associated with working memory. P300 and LPP components increase their amplitudes for emotionally intense images (Schupp et al., 2006). From a biological perspective, negative faces have adaptive significance; however, in cognitive research, these increased amplitudes are associated with the meaning of task-relevant stimuli rather than their emotional significance (Olofsson et al., 2008; Schupp et al., 2006). Hence, the increased amplitudes found in the components would reflect a greater cognitive effort. Specifically, the LPP amplitude reflects the representation of stimuli in working memory. Thus, the working memory can also influence emotional processing because it maintains, stores, and updates facial features (Phillips et al., 2008). Therefore, top-down processes such as emotional evaluation appear to interact with working memory in the long-wave ERP range.

Using other experimental paradigms, researchers reported a relationship between facial emotion processing and EF in older people with SMCs (Pietschnig et al., 2016) and MCI (Teng et al., 2007). These authors suggest that poorer performance on EF tests may also serve as an index of generally increased degeneration in the frontal lobes, including the orbitofrontal regions, which may contribute to impairments in facial emotion processing (Teng et al., 2007). Likewise, the TMT-B (test sensitive to frontal lobe damage; Gouveia et al., 2007) correlated with the valence of the faces (negative vs neutral) in both components, P300 and LPP, suggesting that the processing of negative valences depends on executive functioning.

Regarding sex differences, our data indicate better performance by women than by men, regardless of the group, based on both the behavioral and ERP (N170, P300, and LPP) data. Our research supports and extends the evidence showing that women process affective information significantly better than men (Campanella et al., 2004; Choi et al., 2015; Li et al., 2008). This is consistent with the assumption that women show greater empathy, emotion recognition abilities, and interest in social information than men (Collignon et al., 2010; Lawrence et al., 2015; Proverbio, 2017).

Finally, in the behavioral data, on the one hand, the whole study sample was slower and less accurate on negative faces than on neutral and positive faces. This result is congruent with previous research (Carstensen et al., 2006; Mather & Carstensen, 2005; Ruffman et al., 2008), and it has been attributed to the positivity bias effect associated with aging, defined as a tendency for older people to attend better to positive emotional information than to negative and neutral emotional information (Mather & Carstensen, 2005; Ruffman et al., 2008). This age-related positivity effect could be attributed to an adaptive strategy to preserve emotion regulation and avoid social conflict (Carstensen et al., 2006; Ruffman et al., 2008). Another possible explanation may come from the theory of dynamic integration. This theory suggests that processing negative information is more cognitively demanding than processing positive information. Consequently, older people would process the latter better (Labouvie-Vief, 2003). On the other hand, in the whole sample, N170 amplitude elicited in the right hemisphere was higher than in the left hemisphere. This result emphasizes the role of the right hemisphere in face recognition tasks (Leleu et al., 2010), and it adds to a large body of evidence indicating increased N170 amplitude over the right hemisphere in response to emotional faces (Bentin et al., 1996; Luo et al., 2010).

A crucial strength of this study is the use of a reasonable sample of carefully selected participants. However, some limitations must be considered. Our participants had above-average education levels, which may not be representative of the population. Our stimuli only include stationary faces, which may not reflect the difficulties that older people with SMCs might have in real life. Further studies using dynamic stimuli may offer a deeper understanding of emotional processing.

In conclusion, our results suggest that older people with SMCs show deficits in facial emotion processing that particularly affect early phases of face structure encoding and emotional valence processing. However, we failed to confirm deficits in the later and more complex stages of emotional processing in this population. Moreover, positive associations were observed between the P300 and LPP components and performance on tests of EF, suggesting that deficits in EF are likely to cause problems in facial emotion processing. These deficits could be due to the progressive degeneration of the brain structures modulating this process. These findings in this population can provide an opportunity to study deficits in emotional processing earlier in the degenerative process associated with MCI and AD.

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AUTHOR CONTRIBUTIONS

Vanesa Perez: Data curation; Formal analysis; Investigation; Methodology; Writing—original draft. **Ruth Garrido-Chaves:** Investigation; Methodology; Writing—review & editing. **Mariola Zapater-Fajari:** Data curation; Methodology; Writing—review & editing. **Matias M. Pulopulos:** Conceptualization; Supervision; Writing—review & editing. **Fernando Barbosa:** Conceptualization; Supervision; Writing—review & editing. **Vanesa Hidalgo:** Conceptualization; Methodology; Supervision; Writing—original draft; Writing—review & editing. **Alicia Salvador:** Conceptualization; Funding acquisition; Methodology; Project administration; Resources; Writing—review & editing.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website. Supplementary Material

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