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Research Report

Effects of aging on face processing: An ERP study of the own-age bias with neutral and emotional faces

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ABSTRACT

Older adults systematically show an enhanced N170 amplitude during the visualization of facial expressions of emotion. The present study aimed to replicate this finding, further investigating if this effect is specific to facial stimuli, present in other neural correlates of face processing, and modulated by own-age faces. To this purpose, younger ($n = 25$; $M_{age} = 28.36$), middle-aged ($n = 23$; $M_{age} = 48.74$), and older adults ($n = 25$; $M_{age} = 67.36$) performed two face/emotion identification tasks during an EEG recording. The results showed that groups did not differ regarding P100 amplitude, but older adults had increased N170 amplitude for both facial and non-facial stimuli. The event-related potentials analysed were not modulated by an own-age bias, but older faces elicited larger N170 in the Emotion Identification Task for all groups. This increased amplitude may reflect a higher ambiguity of older faces due to age-related changes in their physical features, which may elicit higher neural resources to decode. Regarding P250, older faces elicited decreased amplitudes than younger faces, which may reflect a reduced processing of the emotional content of older faces. This interpretation is consistent with the lower accuracy obtained for this category of stimuli across groups. These results have important social implications and suggest that aging may hamper the neural processing of facial expressions of emotion, especially for own-age peers.

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1. Introduction

Faces are ubiquitous stimuli in our daily lives, providing a salient source of social information. To accurately infer others' emotions from their faces is the first step for successful social interactions (Barrett et al., 2019), and deficits in this ability are a critical factor of interpersonal conflicts (e.g., Kornreich et al., 2002), reduced social competence (Nienow et al., 2006), and development or maintenance of psychopathology (for a review, see Cotter et al., 2018). Social isolation has negative implications for well-being at any age, but these effects are more damaging in aging as older adults with stronger social relations are less likely to decline in cognitive functions than their socially disengaged peers (Charles & Carstensen, 2010).

Despite the role that face processing may have on older adults' health and well-being, the effects of aging on this ability are not fully understood. Two meta-analyses (Gonçalves et al., 2018a; Ruffman et al., 2008) showed that older adults are less accurate than younger adults at identifying facial expressions of anger, fear, sadness, and surprise. However, less robust results were found for disgust and happiness. Regarding disgust, Ruffman et al. (2008) found a trend for older adults to be better than younger adults at identifying disgusted facial expressions, while Gonçalves and colleagues (2018) found no differences between groups in the identification of this emotion. Regarding happiness, both meta-analyses found an impaired performance for older adults, but the contrast between younger and older adults for this emotion had lower effect sizes (Gonçalves et al., 2018a; Ruffman et al., 2008).

The general decline in emotion identification during aging has been associated with an age-related reduction in the functional and structural integrity of neural regions related to face processing (Mather, 2016). For instance, neuroimaging results showed that aging reduces the neural specialization for faces in the ventral visual cortex (Goh et al., 2010), as well as the recruitment of fusiform face area to identify faces (Grady et al., 2000). In addition, the white matter tracts passing through the right fusiform gyrus have a more pronounced reduction in their structural integrity among older adults, considering the general white matter integrity of this group (Thomas et al., 2008).

Despite this functional and anatomical evidence, electrophysiological results showed that, compared to younger adults, older adults may engage additional neural activity during the visualization of faces, as shown by their enhanced N170 amplitude (Boutet et al., 2021; Daniel & Bentin, 2012; Gao et al., 2009; Gonçalves et al., 2018b; Fernandes et al., 2019; de Fockert et al., 2009; Liao et al., 2017, but see Dieber et al., 2010).

The N170 is an Event-related Potential (ERP) characterized by a negative deflection peaking around 170 ms at occipito-temporal electrodes. As its amplitude is significantly larger for faces than other objects, the N170 is considered a neural correlate of face structural encoding, generated in the fusiform gyrus (Gao et al., 2019; Hinojosa et al., 2015; Rossion & Gauthier, 2002). Nevertheless, the N170 is also elicited when the face-specific structural encoding is interrupted, such as scrambled faces (e.g., Zion-Golumbic & Bentin, 2007), being larger and slightly delayed in inverted faces (e.g., Rossion & Gauthier, 2002).

Considering that scrambling and inversion hinders the structural processing of the face, the N170 was proposed as a neural index of the detection of faces or face-related information in the visual field. This detection initiates perceptual processes that facilitate the individualization and identification of faces within-category (Bentin et al., 2006; Zion-Golumbic & Bentin, 2007). Accordingly, the increased amplitude and latency of the N170 for stimuli with relevant information spatially distorted or missing may reflect an increased difficulty to associate faces to their category (Gao et al., 2009).

As the N170 is the most important electrophysiological correlate of face processing (Bentin et al., 2006), the increased amplitude found for middle-aged (Chaby et al., 2001, 2003) and older adults (e.g., Boutet et al., 2021) is endowed with high relevance, particularly when it co-occurs with a preserved emotion identification (Gonçalves et al., 2018b). Furthermore, middle-aged and older adults do not show the typical right hemisphere lateralization of the N170 (Chaby et al., 2001, 2003; Daniel and Bentin, 2012; Gao et al., 2009; Liao et al., 2017; Komes et al., 2014, but see de Fockert et al., 2009), which is in line with the aging compensation hypothesis (Reuter-Lorenz & Cappell, 2008). According to this hypothesis, the aging brain compensates structural losses by recruiting previously unrelated neural regions, particularly in the contralateral areas (Sullivan & Pfefferbaum, 2006), resulting in a reduction of the hemispheric asymmetry in older adults (Cabeza, 2002).

Through an ERP methodology, this study aimed to disentangle the effects of aging on face/emotion processing, while overcoming a limitation typically found in this field, related to the use of younger adults' faces on tasks targeting older adults (Fernandes et al., 2021). This methodological limitation has hampered the investigation about the effects of aging on the neural processing of facial expressions of emotion, considering the possible own-age bias effect.

According to the own-age bias effect, participants are typically more accurate with faces of their own-age (Rhodes & Anastasi, 2012), which may be associated to greater activity in the amygdala (Wright et al., 2008), insula, and medial prefrontal cortex elicited by own-versus other-age faces (Ebner et al., 2013). This greater activity may be associated with greater exposure to own-age persons in daily routines and/or greater social relevance attributed to own-age faces as they represent potential partners for interaction. Nevertheless, the own-age bias has been found for memory and attention, and the results from emotion identification tasks have consistently shown that both younger and older adults are more accurate at identifying emotions in younger than older faces (Ebner et al., 2011, 2012, 2013; Ebner & Johnson, 2009; Riediger et al., 2011; Ziaei et al., 2019).

It is hypothesized that these results may reflect a higher ambiguity of older faces due to age-related changes in physical features of the face, such as muscle tissue or wrinkles (Wiese et al., 2013), but this hypothesis has been sparsely tested through neuroimaging methodologies, which would allow scanning the neuronal processing underlying these behavioural findings. Among neuroimaging methodologies, an ERP approach would be privileged considering that a higher ambiguity of older faces would elicit larger amplitudes in the ERPs related to face processing, reflecting more neuronal resources to decode.

To the best of our knowledge, only two studies explored own-age bias in face/emotion processing tasks with an ERP methodology (Ebner et al., 2011; Fölster & Werheid, 2016), but only Fölster and Werheid (2016) included a sample of older participants. Using facial expressions of happiness and sadness, their results showed larger N170 amplitudes elicited by older compared to younger faces, consistently with the hypothesis raised above regarding the higher ambiguity of older faces. Furthermore, the authors did not find an own-age bias on the N170, as shown by non-significant group by age of actor interaction (Fölster & Werheid, 2016).

The present study aims to expand this knowledge by amplifying this research to a lifespan analysis (by including a sample of younger, middle-aged, and older adults), and to the categorical emotion of disgust (whose identification is unimpaired in older adults; Gonçalves et al., 2018a; Ruffman et al., 2008). Moreover, we aim to explore if the enhanced N170 systematically found for older participants is specific to faces or general to other visual stimuli, by including a task composed of faces and other frequent and face-like stimuli. Finally, we aim to extend this research to other ERPs associated with face/emotional processing–the P100 and P250.

The P100 is a positive peak around 100 ms post stimulus at occipital sites, which is the earliest component elicited by faces and generated in extrastriate visual areas (Brodmann's area 18/19; Di Russo et al., 2002). The results regarding the effects of aging in P100 are inconsistent, with some showing significant age-related differences (e.g., Gao et al., 2009; Wiese et al., 2013) but not others (e.g., Gonçalves et al., 2018b; Komes et al., 2014). However, as this ERP component indexes the processing of basic visual information, examining its modulation due to aging may provide a way to test the perceptual degradation hypothesis (Boutet et al., 2021). According to this hypothesis, the age-related deficits in encoding of low-level image properties has a negative cascading effect on subsequent processing stages (Monge & Madden, 2016; Wiese et al., 2013).

Another ERP component associated with face/emotion processing is the P250 (Caharel et al., 2007; Marzi & Viggiano, 2007), also referred in the literature as P200 or P2 (Boutet et al., 2021). This ERP component is a positive wave emerging between 200 and 250 ms post stimuli at occipital electrodes, and may reflect the comparison of sensory inputs with those stored in memory (e.g., Tremblay et al., 2014), the deeper processing of ambiguous stimuli (Latinus & Taylor, 2006), and/or the detection of deviations from prototypicality (e.g., Kloth et al., 2017; Schweinberger & Neumann, 2016). Similarly to the P100, the results regarding the effects of aging on the P250 are inconsistent, with some showing that aging delays and decreases the amplitude of the P250 (Bieniek et al., 2013; Chaby et al., 2003; Wiese et al., 2008) but not others (Komes et al., 2015). However, the literature suggests that the P250 can be used to understand if older adults experience difficulties during comparison of sensory inputs with stored face representations.

The ERP components analysed here can be grouped in a robust positive-negative-positive (P100–N170–P250) complex (Puce et al., 2013), and this study aims to investigate the effects of age (of the participants and of the facial stimuli) in this ERP complex. According to the previous literature conducted with similar tasks (Fölster & Werheid, 2016), we hypothesize enhanced N170 amplitude for older adults in comparison with younger and middle-aged adults (H1) along with higher ERP amplitudes for faces of older adults compared to other stimuli (H2). With an exploratory purpose, to fulfil the remaining goals of the present study, we will analyse the accuracy rates of both tasks, as well as amplitudes and latencies of the P100 and P250.

2. Method

In the following sections we report how we determined our sample size, all inclusion/exclusion criteria (which were established prior to the participants' recruitment), all data exclusions, all experimental manipulations and measures included in the study.

2.1. *Participants*

A total of 80 participants were recruited from the local community and University and divided in three age groups: younger adults (20–39 years); middle-aged adults (40–59 years); and older adults (60–80 years). While no previous power analysis was conducted at the time, we recruited a similar number of participants as previous studies (e.g., Boutet et al., 2021; Fölster & Werheid, 2016). Participants were included in the study if they had more than four years of formal education, normal or corrected-to-normal vision, a score equal or superior to 22 – cut-off for mild cognitive impairment–in the Montreal Cognitive Assessment (MoCA; Freitas et al., 2014; Nasreddine et al., 2005), did not use psychotropic medication, and did not have a history of brain injury, neurological or psychiatric diagnosis. However, seven participants were excluded due to the absence of the ERP components of interest in one of the experimental tasks. This resulted in a final sample of 73 participants: 25 younger adults (15 female; $M_{age} = 28.36$, $SD = 6.38$), 23 middle-aged adults (13 female; $M_{age} = 48.74$, $SD = 6.12$), and 25 older adults (14 female; $M_{age} = 67.36$, $SD = 5.02$) Groups were statistically matched for handedness ($\chi 2$ (2, 73) = 0.946, $p = .623$) and sex ($\chi 2$ (2, 73) = 0.096, $p = .953$).

The study was approved by the local Ethics Committee. Participants provided written informed consent and were compensated with a fixed amount of 15€ (gift card) for their time.

2.2. *Instruments and tasks*

2.2.1. *Face Processing Task*

The task included 180 stimuli: 90 faces (45 female; 30 faces of younger adults, 30 middle-aged adults and 30 older adults), 30 houses (stimuli often found in everyday life, structurally similar to faces; Filliter et al., 2015), 30 mugs (stimuli often found in everyday life, structurally different from faces), and 30 butterflies. The stimuli were organized in one practice block (27 trials), and two experimental blocks (90 trials each), divided by an unlimited pause. The structure of one trial per category is depicted in Fig. 1.

The facial stimuli were selected from the FACES Life-Span Database (Ebner et al., 2010), according to the highest accuracy rates in the emotional identification of the validation study. All the faces were from unrepeated white actors, displaying a

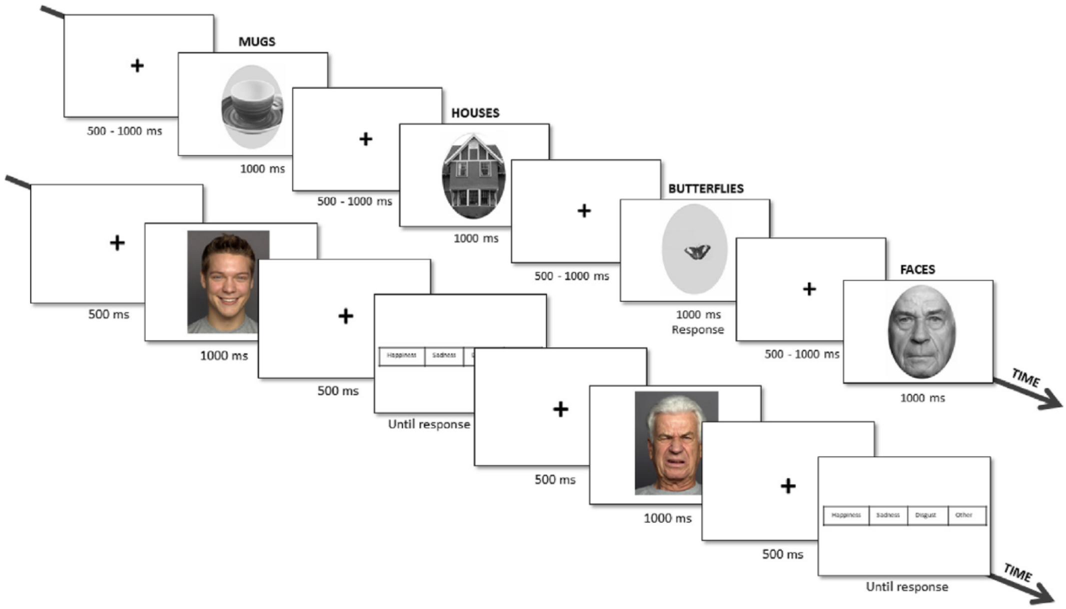

Fig. 1 — Schematic representations of the Face Processing Task (above) and the Emotion Identification Task (below).

neutral expression, closed mouth, and direct eye contact. For the "houses" category, the 30 stimuli with the greatest face-likeness on a 7-point Likert scale were selected from the original study ($M_{\text{face-likeness}} = 4.28$, $SD = 0.95$; Filliter et al., 2015). The remaining stimuli were randomly selected from their original datasets (see Konkle et al., 2010 for mugs, and Vagnoni et al., 2012 for butterflies).

The stimuli were resized in IrfanView Thumbnails (version 4.51; www.irfanview.com), obtaining a final size of 441 × 600 pixels. Pictures were converted to grayscale, as the original houses were at grayscale. Considering that original pictures had different sizes, they were enclosed within an oval frame using GIMP (version 2.8; www.gimp.org) to ensure the same number of pixels per stimulus.

Participants were instructed to attend to all stimuli and to press a button of a response box with their dominant hand when they saw a butterfly. The goal of the task is to assess neural processing of faces of different ages, houses (stimuli often found in everyday life, structurally similar to faces), and mugs (stimuli often found in everyday life, structurally different from faces). Thereby, the "butterflies" category was included to avoid a passive viewing task, since it is not recommended during EEG recordings. In this sense, the neural activity elicited by these stimuli was removed from the EEG analysis, and we only analyse data from five conditions: houses, mugs, younger faces, middle-aged faces, and older faces. The accuracy rates were analysed as a manipulation check, in order to verify if participants were engaged with the task.

2.2.2. *Emotion identification task*

To this task, we selected a set of 20 stimuli (10 female) from younger, middle-aged, and older actors displaying facial expressions of happiness, sadness, and disgust. Each stimulus was repeated twice and organized in two experimental blocks of 180 stimuli, divided by an unlimited pause. The first experimental block was preceded by a training block of 3 trials. In total, participants saw 40 trials per condition. The selected stimuli were the most accurately identified facial expression of emotion in the original validation study (Ebner et al., 2010), and did not significantly differ in terms of arousal according to a previous pilot study ($n = 10$; $M_{younger\ faces} = 5.80$; $SD_{younger\ faces} = 1.28$; $M_{middle\text{-}aged\ faces} = 6.04$; $SD_{middle\text{-}aged\ faces} = 1.15$; $M_{older\ faces} = 6.06$; $SD_{older\ faces} = 1.04$; $F < 1$, $p = .394$). The emotional categories were selected according to the results of previous meta-analyses (Gonçalves et al., 2018a; Ruffman et al., 2008), namely that older adults, when compared to younger adults, show impairment in recognizing happiness, low impairment for sadness, and no impairment for disgust. Participants were instructed to identify the emotion displayed by the facial stimuli, through a response box containing four buttons corresponding to labels displayed in the response slide (1-Happiness, 2-Sadness, 3-Disgust, 4-Others). Participants should respond in the response slide to avoid artifacts of preparatory response potentials during the target stimuli. The structure of two trials of this task is depicted in Fig. 1. In total, this task was composed of nine conditions: younger faces–happiness, younger faces–sadness, younger faces -disgust; middle-aged faces–happiness, middle-aged faces–sadness, middle-aged–disgust; and older faces–happiness, older faces–sadness, older faces–disgust).

2.3. *Procedure*

Participants were tested individually in two experimental sessions. The first session aimed to assess inclusion/exclusion criteria, and to collect demographic and neurocognitive data. Participants who fulfilled the inclusion criteria were recruited for the second session, in which the experimental tasks were performed. Participants sat inside an EEG chamber, with ~115 cm between them and the screen where stimuli were displayed. The order of the two tasks (Face Processing and Emotion Identification Tasks) was counterbalanced, and both were delivered in E-Prime 2.0 (2011, Psychology Software

Tools, Inc., Sharpsburg, PA, USA). The stimuli were presented on a 17″ screen with a refresh rate of 60 Hz (visual angle: 9.46° × 12.84° for the Face Processing Task; 14.55° × 18.13° for Emotion Identification Task). This study was not pre-registered.

2.4. *EEG recording and processing*

The electroencephalographic (EEG) data was recorded with a 128-electrode Hydrocel Geodesic Sensor Net, a Net Amps 300 amplifier (8-bit digital input; Electrical Geodesics Inc., Eugene, EUA), and a digitizing rate of 500 Hz. Impedances were kept below 50 kOhm for all electrodes (as this is a high input impedance system), which were referred to Cz during recording. EEG data processing was conducted using EEGLAB v2021.0 as a toolbox of MATLAB 2017b.

During the offline processing, EEG recordings were down-sampled to 250 Hz and band-pass filtered (0.1–30 Hz). Bad channels were removed (maximum of 10% of the sensors), and data was decomposed via Independent Components Analysis (ICA). Eye blink, saccade and heart rate artifacts were corrected by subtracting the respective component from the data. The channels removed were interpolated, the EEG signal was re-referenced offline to the average of all electrodes and segmented into epochs ranging −200 to 800 ms, time-locked to stimuli onset. All segments were visually inspected by an experienced researcher, and the remaining artefactual epochs were manually rejected before averaging. The artefacts were detected on basis of deflections resulting from eye blinks (large deflections observed across all electrodes), large eye movements as saccades (as observed in the frontal electrodes), muscle/movement artefacts (observed as high–frequency activity) and large amplitude electrode noise. We used visual inspection as the best approach to ensure we maximize the data retention (the percentage of epochs rejected by group and condition is reported on Table S4).

All epochs were baseline corrected (200 ms pre-stimulus) and averaged by condition. The Face Processing Task consists of five conditions (houses, mugs, younger faces, middle-aged faces, and older faces), while the Emotional Identification Task consists of nine conditions (younger faces–happiness, younger faces–sadness, younger faces–disgust; middle-aged faces–happiness, middle-aged faces–sadness, middle-aged–disgust; and older faces–happiness, older faces–sadness, older faces–disgust).

In both tasks, the three ERP components were analysed for each participant. As the peak latency of the components increases during the lifespan (e.g., Bieniek et al., 2013), the time windows of each ERP component were defined based on the grand average of each group, including the waveform of each participant. That is, we obtained the peak latency of each condition from the grand averages of each task (Figs. 3 and 4), and we computed the mean latencies of all conditions by group. The time-window of each ERP of interest was defined as ±50 ms around the peak latency obtained for each group (for similar method, see Cespón et al., 2013; Eppinger et al., 2008; Ferdinand & Kray, 2013; Fernandes et al., 2018; Fernandes et al., 2022; Friedman, 2012).

As result, in the Face Processing Task, the P100 was quantified as the peak amplitude in the time window of 90–190 ms for the three groups. The N170 was quantified as the peak amplitude in the time window of 140–240 ms for the younger group, 150–250 ms for the middle-aged group, and 160–260 ms for the older group. The P250 was quantified as the mean amplitude in the time window of 220–320 ms for the younger group, 230–330 ms for the middle-aged group, and 240–340 ms for the older group. In the Emotional Processing Task, the peak amplitude of the P100 was quantified in the time window of 80–180 ms for the three groups, the N170 was quantified as in the previous task, and the mean amplitude of the P250 was quantified in the time-window of 220–320 for the younger group, 240–340 ms for the middle-aged group, and 270–370 ms for the older group. Within these time-windows, we obtained the local (positive or negative) peaks for the P100 and N170, and the mean amplitude of the time-window for the P250. Based on previous literature (Rossion & Jacques, 2012), as well as the inspection of topographical maps, two regions where peaks were most prominent (maximum positive/negative voltage) were selected for peak scoring. The P100 and P250 were measured at O1/O2 cluster (O1: 65, 66, 70, 71; O2: 76, 84, 83, 90), while the N170 was measured at P7/P8 clusters (P7: 50, 57, 58, 63, 64; P8: 95, 96, 99, 100, 101).

2.5. *Statistical analysis*

To analyse the behavioural results, the accuracy rates (% of correct responses in relation to the number of trials) were computed for each participant and condition. In the Face Processing Task, this variable was computed for the correct identification of the target condition (butterflies), and the results were compared through independent one-way ANOVAs, using *group* as a between-subjects factor. Regarding electrophysiological data, the amplitudes and latencies of each ERP were analysed through repeated-measures ANOVAs, with *group* as between-participants factor, and *condition* (houses, mugs, younger faces, middle-aged faces, and older faces) and *hemisphere* (left, right), as within-participant factors.

In the Emotion Identification Task, accuracy was defined as the correct identification of the emotion portrayed. To investigate the effects of *group* (younger adults, middle-aged adults, and older adults), *age of actor* (younger faces, middle-aged faces, and older faces), and *emotion* (happiness, sadness, and disgust) on the behavioral results, we performed a repeated-measures ANOVA, with *age of actor* and *emotion* as within-participants factors and *group* as between-participants factor. Regarding electrophysiological data, the amplitudes and latencies of each ERP were analysed through repeated-measures ANOVAs, with *group* as between-participants factor, and *hemisphere* (left, right), *age of actor* and *emotion* as within-participant factors.

We hypothesized an enhanced N170 amplitude for older adults in comparison with younger and middle-aged adults (H1) along with higher ERP amplitudes elicited by older faces compared to other stimuli (H2). These hypotheses were addressed by exploring the main effect of *group* (both tasks) and condition (Face Processing Task) or actors' age (Emotion Identification Task) in the statistical models built to the N170 amplitude. The own-age bias effect was investigated by exploring the condition*group (Face Processing Task) or age of actor*group (Emotion Identification Task) interactions. With an exploratory purpose, to fulfil the remaining goals of the present study, this analytical method was also applied to behavioural results, amplitudes, and latencies of the P100 and P250, as well as to latencies of the N170.

Statistical analyses were performed using SPSS 27 (IBM Corp., Armonk, NY, USA). The threshold for statistical significance was set at $\alpha = .05$ for all analyses. In case of a violation of sphericity, Greenhouse-Geisser corrected results were reported. Post-hoc analyses were corrected for multiple comparisons using the Sidak procedure.

The experimental tasks,[1] data collected, the MATLAB scripts, the SPSS syntaxes, and the data processing logs are openly available at https://osf.io/yka8p/

3. Results

3.1. Confirmatory results

3.1.1. Face Processing Task

N170 Peak amplitude. We found a main effect of *group*, F (2, 69) = 4.56, $p = .014$, $\eta^2_p = .117$), revealing that older adults had higher amplitudes than younger adults ($p = .015$). We also found a main effect condition (F (4, 202) = 113.14, $p < .001$, $\eta^2_p = .621$, $\varepsilon = .755$), revealing that N170 amplitudes were larger for faces (independently of the age of actor) than for mugs and houses (all $p < .001$). The condition*group interaction was significant, F (8, 276) = 2.35, $p = .018$, $\eta^2_p = .064$, showing that older adults had higher amplitudes than younger adults for faces of younger ($p = .017$) and middle-aged actors ($p = .019$), for mugs ($p < .001$) and houses (both $p = .003$). Middle-aged adults also had larger N170 amplitudes than younger adults for faces of middle-aged actors ($p = .041$) and mugs ($p = .003$).

3.1.2. Emotion identification task

N170 Peak amplitude. We found a main effect of *group*, F (2, 70) = 5.08, $p = .009$, $\eta^2_p = .127$, revealing that older adults had higher amplitudes than younger adults ($p = .007$). We also found a main effect of the age of actor (F (2, 130) = 19.18, $p < .001$, $\eta^2_p = .215$), revealing that older faces elicited higher amplitudes than middle-aged and younger faces (both $p < .001$). The age of actor*group interaction was non-significant, F (4, 280) = 1.28, $p = .281$, $\eta^2_p = .215$.

3.2. Exploratory results

3.2.1. Behavioural results

Emotion Identification Task. We found a main effect of *group*, F (2, 70) = 7.70, $p < .001$, $\eta^2_p = .182$, revealing higher accuracy rates for younger ($p = .012$) and middle-aged adults ($p = .001$), compared to older adults. We also found a main effect of *age of actor*, F (2, 152) = 21.37, $p < .001$, $\eta^2_p = .383$, revealing that emotions were more accurately identified when expressed by younger actors, compared to middle-aged and older actors (both $p < .001$). The age of actor*group interaction was also significant (F (4, 140) = 57.35, $p = .037$, $\eta^2_p = .070$), revealing that younger adults had higher accuracy rates than older adults for emotions displayed by younger ($p = .002$) and middle-aged faces ($p = .016$), while middle-aged adults had higher accuracy rates than older adults for all conditions (all $p < .003$). The behavioral results are available in the Supplementary Material (Tables S1). Descriptive statistics of the Emotion Identification Task are also displayed in Fig. 2.

3.2.2. Electrophysiological results

3.2.2.1. Face Processing Task. **P100 Peak amplitude**. We did not find significant main effect of group ($F < 1$, $p = .468$), condition (F (4, 240) = 1.66, $p = .158$, $\eta^2_p = .023$, $\varepsilon = .855$), nor a significant group*condition interaction ($F < 1$, $p = .510$) for the P100 peak amplitude.

P100 Peak latency. We did not find a main effect of group ($F < 1$, $p = .628$), but we found a main effect of condition, F (4, 220) = 14.38, $p < .001$, $\eta^2_p = .170$, $\varepsilon = .854$, revealing that houses had lower latencies than the remaining stimuli (all $p < .001$). The group*condition interaction was non-significant ($F < 1$, $p = .450$).

N170 Peak Latency. We found a main effect of *group*, F (2, 69) = 12.28, $p < .001$, $\eta^2_p = .263$, revealing that older adults had higher latencies than younger ($p < .001$) and middle-aged adults ($p = .007$). We also found a main effect of condition, F (4, 181) = 30.88, $p < .001$, $\eta^2_p = .309$, $\varepsilon = .705$, revealing that mugs elicited higher latencies than the remaining conditions (all $p < .001$). Moreover, faces of older actors elicited higher latencies than faces of younger adults ($p = .037$). The interaction condition*group was significant, F (8, 276) = 2.46, $p = .014$, $\eta^2_p = .067$, showing that older adults had higher latencies than younger adults for all conditions (all $p < .008$), as well as higher latencies than middle-aged adults for all conditions (all $p < .009$), except mugs. Middle-aged adults had higher latencies than younger adults for mugs ($p = .009$).

P250 Mean amplitude. We found a main effect of *group*, F (2, 70) = 5.74, $p = .005$, $\eta^2_p = .141$, revealing that younger adults had higher mean P250 amplitudes than middle-aged ($p = .011$) and older adults ($p = .002$). The main effect of *condition* ($F < 1$, $p = .573$), and the interaction condition*group ($F < 1$, $p = .445$) were both non-significant.

3.2.2.2. Emotion identification task. **P100 Peak amplitude**. We did not find a significant main effect of group, F (2, 70) = 0.37, $p = .693$, $\eta^2_p = .010$, age of actor (F (2, 140) = 0.65, $p = .522$, $\eta^2_p = .009$), nor an age of actor*group interaction, F (4, 280) = 0.94, $p = .442$, $\eta^2_p = .026$).

P100 Peak latency. The main effect of group was near significant F (2, 70) = 2.91, $p = .060$, $\eta^2_p = .077$, but the main effect of age of actor was non-significant, F (2, 140) = 1.22, $p = .298$, $\eta^2_p = .017$, $\varepsilon = .598$, along with the age of actor*group interaction, F (4, 280) = 0.77, $p = .548$, $\eta^2_p = .021$.

N170 Peak latency. We found a main effect of group, F (2, 70) = 11.24, $p < .001$, $\eta^2_p = .243$, and age of actor, F (2, 113) = 23.56, $p < .001$, $\eta^2_p = .252$, $\varepsilon = .805$. The N170 latencies were higher for older adults compared to middle-aged ($p = .025$) and younger adults ($p < .001$), as well as for older faces compared to middle-aged and younger faces (both

[1] Only the programming in e-prime and house stimuli used is made available. Legal copyright restrictions do not permit us to publicly archive the full set of stimuli used in this experiment. Readers seeking access to the face stimuli are advised to submit a request at https://faces.mpdl.mpg.de/imeji/.

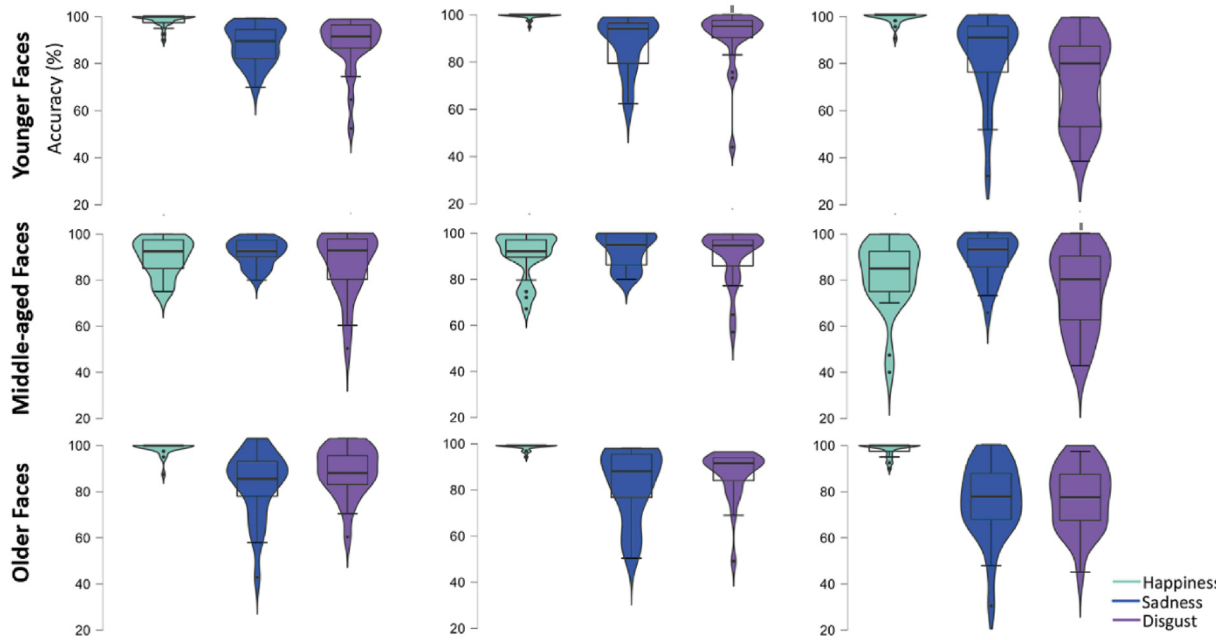

Fig. 2 – Violin plots are presented to depict the distribution of the accuracy rates found in the Emotion Processing Task by group (younger, middle-aged, and older adults) and by age of the actor (younger, middle-aged, and older faces). These plots highlight the spread of the kernel density estimation of the underlying data distribution (via their envelope) and quartiles (via the boxplots). Violin plots were generated using JASP (version 0.15; JASP Team, 2021).

$p < .001$). Middle-aged faces also elicited higher latencies than younger faces ($p = .015$). However, the age of actor*group interaction was non-significant, F (4, 280) = 1.14, $p = .342$, $\eta^2_p = .031$.

P250 Mean amplitude. We found a main effect of age of actor, F (2, 140) = 4.56, $p = .012$, $\eta^2_p = .061$, $\varepsilon = .838$, revealing that younger faces elicited higher P250 than older faces ($p = .035$). However, the main effect of group was near significant, F (2, 70) = 2.81, $p = .067$, $\eta^2_p = .074$, and the age of actor*group interaction did not reach statistical significance ($F < 1$, $p = .816$).

Descriptive statistics of ERP amplitudes and latencies for both tasks are available in the Supplementary Material (Tables S2 and S3). Moreover, the remaining main effects or interactions that were extracted from the statistical models but that did not correspond to goals of the present study are also reported in supplementary material (Table S4 and S5).

4. Discussion

Previous research has systematically showed that older adults, compared to younger adults, may engage additional neural activity during the visualization of facial expressions of emotion, as shown by their enhanced N170 amplitude (e.g., Boutet et al., 2021; Gonçalves et al., 2018b). The present study aimed to expand the knowledge regarding the effects of aging on the N170, further exploring the effect of faces' age. Moreover, we also aimed to investigate if the enhanced N170 amplitude found for older participants is specific to faces or general to other visual stimuli, as well as to expand this research to the P100–N170–P250 complex.

This study was composed of two experimental tasks, to which we proposed two main general hypotheses: we expected to find an enhanced N170 amplitude for older adults in comparison with younger and middle-aged adults (H1), along with higher ERP amplitudes elicited by faces of older adults compared to other stimuli (H2).

4.1. *Face Processing Task*

The results of the Face Processing Task showed that P100 amplitude was similar between groups and conditions. The P100 appears to index the processing of basic visual information (Di Russo et al., 2002; Herrmann et al., 2005), allowing for testing the perceptual degradation hypothesis (Monge & Madden, 2016). According to this hypothesis, the degraded perceptual inputs, resulting from either age-related neurobiological processes or experimental manipulations, lead to errors in perceptual processing that may affect higher-order cognitive processes. Since we did not find significant differences between groups in the P100 amplitude, we suggest that the effects of aging in high-order cognitive processes may start at a later time-windows. These results are consistent with previous findings (e.g., Gonçalves et al., 2018b; Komes et al., 2014).

The results of the N170 are partially consistent with our first hypothesis since older adults had higher amplitudes than younger adults but did not differ from middle-aged adults. This pattern of results replicates previous findings from our group showing that middle-aged adults appear to be at an intermediate level between younger and older adults (Fernandes et al., 2019; Gonçalves et al., 2018b). As their N170 amplitude is neither significantly different from the younger

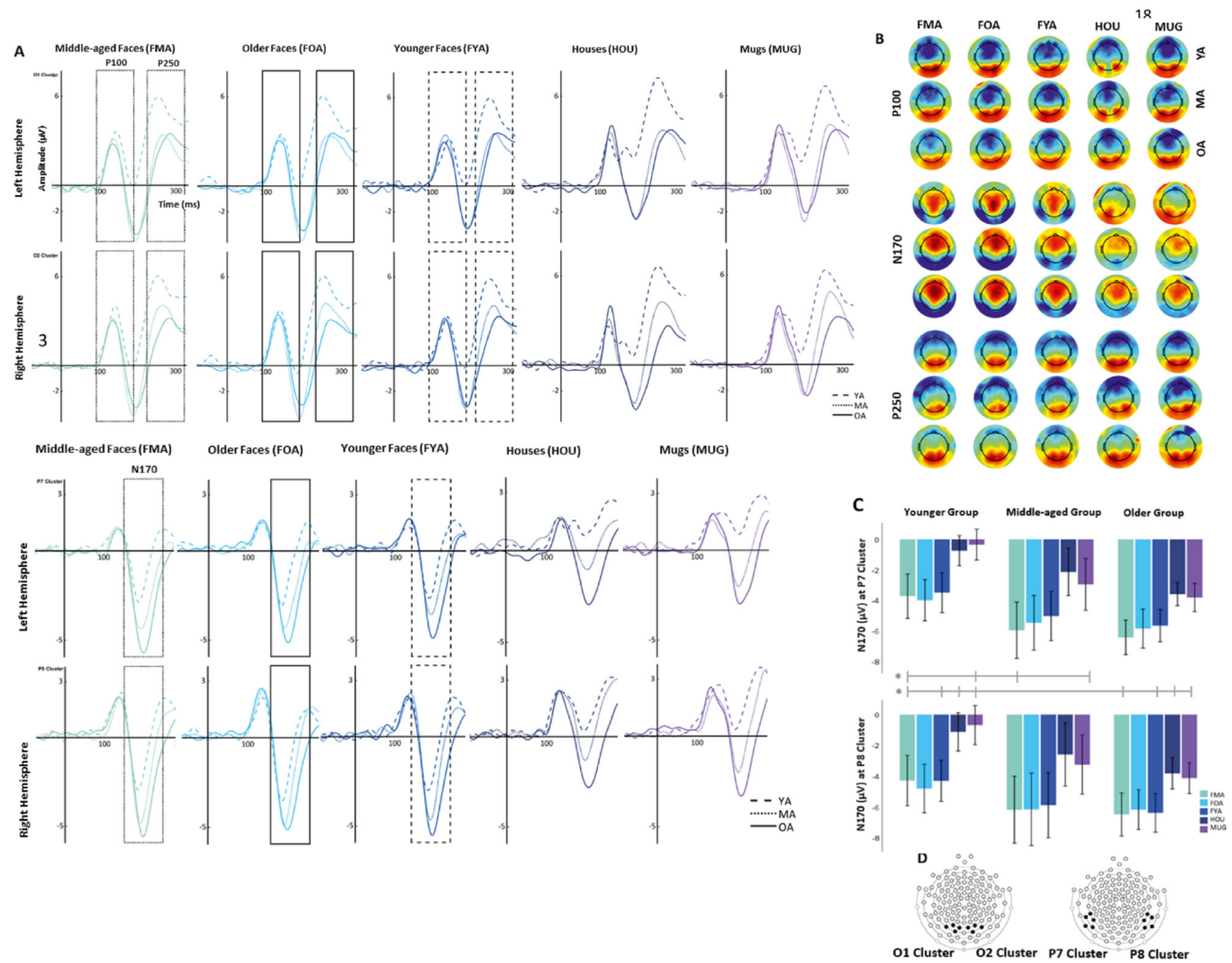

Fig. 3 – A: Grand averages of P100, N170, and P250 amplitudes for younger (YA), middle-aged (MA), and older adults (OA) evoked by each condition. B: Topographical maps for the three ERPs components. C: Means of the N170 peak amplitude (μV) evoked by condition. Error bars indicate 95% confidence intervals and * represent the significant condition*group interaction. D: Electrode locations of O1/O2 and P7/P8 Clusters in the 128-channel HydroCel Geodesic Sensor Net (EGI).

nor from the older adults, such findings suggest that age-related neurophysiological changes in facial and emotional processing may occur gradually across the adult lifespan.

Our results are also consistent with previous research showing that older adults display larger and delayed N170 peak amplitudes, compared to younger adults (e.g., Boutet et al., 2021; Daniel & Bentin, 2012; Fernandes et al., 2019; de Fockert et al., 2009; Gao et al., 2009; Gonçalves et al., 2018b; Liao et al., 2017). In the present study we found that this enhanced amplitude also occurs for non-facial stimuli (houses and mugs), which was also found by a previous study conducted with faces and watches (Boutet et al., 2021). According to these authors, the effects of aging on the N170 may reflect functional changes in distributed networks of the temporal lobe, which show overlapping activation for faces and non-facial visual stimuli (Haxby et al., 2000; Sadeh et al., 2010). Such interpretation is in line with findings that aging leads to dedifferentiation of specialized face networks, resulting in a larger neural activation to process a given stimulus. Such overactivation may result into an increase in amplitude and latency of the ERP time-locked to the processing of those stimuli (Goh et al., 2010; Rossion et al., 2012; Zebrowitz et al., 2016).

Interestingly, the effect of aging on the N170 amplitude and latency is similar to what is observed for inverted faces, known as the face inversion effect. According to this effect, the inversion of stimulus disrupts the recognition of faces more strongly than the recognition of other objects (Farah, Wilson, Drain, & Tanaka, 1995), by interrupting the holistic processing of faces and demanding processing through the sum of their parts (featural processing). According to neuroimaging findings, as inverted faces significantly decrease the response of face-selective brain regions (including the fusiform face area), they recruit the response of other areas selective for non-face objects (Rossion & Gauthier, 2002). This additional neural recruitment will enlarge and delay the N170.

If the aging effect on facial processing shares the same neural basis as the face inversion effect, the results from our study may suggest that the larger N170 found for older adults reflects additional neural resources engaged in the processing

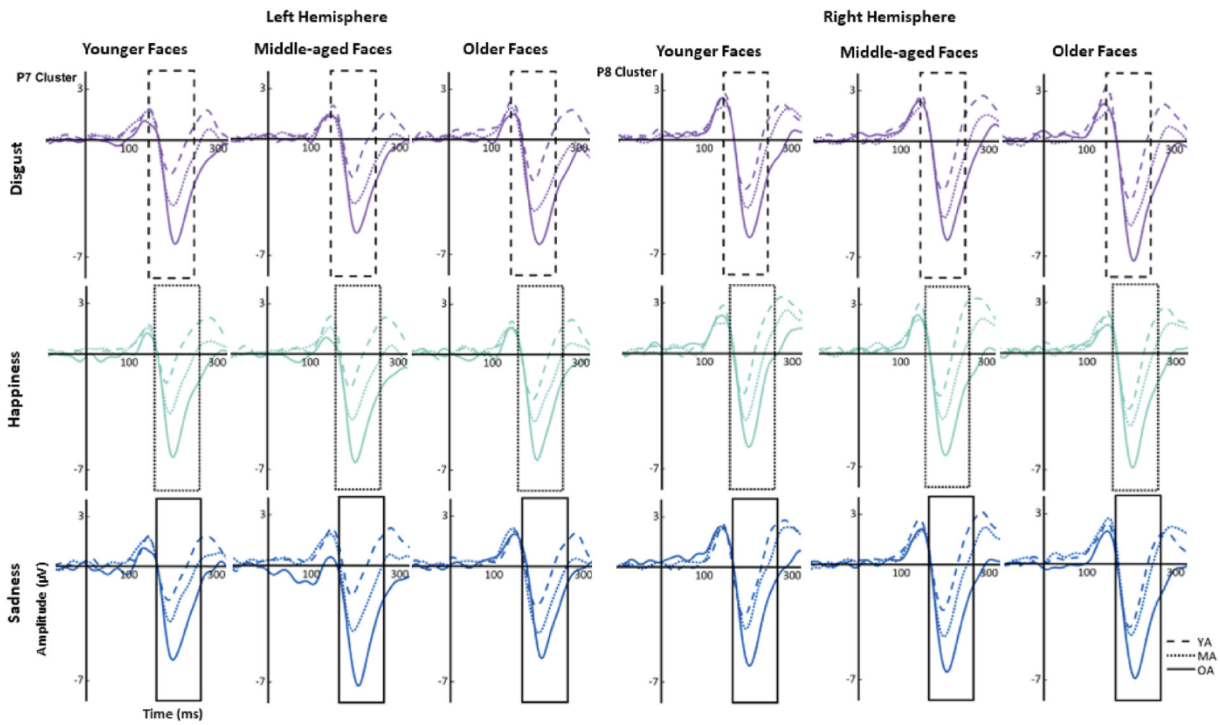

Fig. 4 – Grand-average of N170 peak amplitude (μV) for younger (YA), middle-aged (MA) and older adult (OA) elicited by each condition (younger, middle-aged, and older faces displaying happiness, sadness, and disgust).

of faces and other visual stimuli, possibly resulting from the activation of brain areas selective for faces along with brain regions selective for non-face objects. Such extended recruitment may be elicited by a featural instead of an holistic processing of faces, which may be tested by future studies conducted with neuroimaging techniques and eye-tracking methodologies. Combining neuroimaging and eye-tracking assessments will allow the investigation of visual scanning strategies used by different age groups along with neural processing.

Remarkably, older adults had higher amplitudes than younger adults for all conditions except for older faces, in which younger and older adults did not differ. This result could be in line with the own-age bias (Rhodes & Anastasi, 2012), but the post-hoc analysis revealed a different interpretation. Instead of reduced N170 amplitude for older adults elicited by older (own age) faces, we found an increased N170 amplitude for younger adults elicited by older faces (see Fig. 3C). In this sense, our neural results do not support the own-age bias for neural processing of neutral faces.

Finally, regarding the P250, we found a reduced mean amplitude for older and middle-aged adults compared to younger adults, which was consistent for all conditions. This result is also consistent with the results of previous research (e.g., Bieniek et al., 2013; Chaby et al., 2003; Wiese et al., 2008), including those conducted with facial and non-facial stimuli (Boutet et al., 2021). The neural processes underlying the P250 remain unclear, but they have been associated with the comparison of sensory inputs with those stored in memory (e.g., Tremblay et al., 2014). At this stage of neural processing, a deeper processing of ambiguous stimuli occurs (Latinus & Taylor, 2006), such as the detection of familiarity, the decoding of the emotional content of the face, or the deviations from prototypicality (e.g., Kloth et al., 2017; Schweinberger & Neumann, 2016). Thus, the amplitude of the P250 may be a neural correlate of these processes, and its lower amplitude for middle-aged and older adults may reflect a reduced neural processing at this time-window. For instance, while younger adults may have a deeper processing of the stimuli after their facial decoding, middle-aged and older adults may reduce the later processing (after 170 ms), which would be consistent with the selective engagement hypothesis of aging (Hess, 2006). According to this hypothesis, as aging is associated with decreased cognitive resources, older adults allocate these resources more selectively. As this experimental paradigm does not include a task that requires further processing of the stimuli, such as age, sex, familiarity or emotional identification, the neural processing of these stimuli from older participants could be reduced after the visual processing that happens at a N170 time-window.

4.2. *Emotion identification task*

At a behavioral level, we found that older adults had worse identification of facial expressions of emotion compared to younger and middle-aged adults, which is consistent with the results of two previous meta-analyses (Gonçalves et al., 2018a; Ruffman et al., 2008). Moreover, emotions were better identified when displayed by younger faces, in comparison with middle-aged and older faces, which is also consistent with the results of previous studies (e.g., Ebner et al., 2011, 2012, 2013; Ebner & Johnson, 2009; Riediger et al., 2011; Ziaei et al., 2019).

Regarding significant interactions, we found that younger adults had higher accuracy rates than older adults for emotions displayed by younger and middle-aged faces, but younger and older adults did not differ in the identification of emotions displayed by older faces. As discussed above, this lack of group differences could be suggestive of an own-age bias in the older adults' ability to identify emotions from faces. However, a closer look at our results shows that this effect seems to be explained by lower accuracy rates of younger adults during the identification of emotions displayed for older faces (see Table S1). Interestingly, this result is consistent to what is found for the N170 amplitude in the Face Processing Task, which showed that younger and older adults had similar N170 amplitudes elicited by older faces due to an enhanced amplitude of this ERP component in the younger group.

As reported at supplementary material following our exploratory statistical analysis (see Table S4), we found that older adults had worse performance than younger and middle-aged adults to identify disgust in faces of all ages. This result is against previous meta-analytic findings, which showed that older adults had no impairment at identifying disgust (Gonçalves et al., 2018a; Ruffman et al., 2008). However, our result may be explained by a higher dispersion in the accuracy rates of the older group to this emotional category (independently of the age of the actor), as represented by a larger spread of the kernel density estimation of the violin plots (see Fig. 2).

At a neural level, and consistently to what was found in the Face Processing Task, P100 amplitude was similar between groups and conditions. Regarding the N170, we also found a main effect of the group, showing that older adults had higher peak amplitudes than younger adults. Since these results were consistent with those found for the Face Processing Task, the functional meaning of these findings was discussed in the previous section.

Interestingly, in this task, the main effect of age of actor was consistent with our second hypothesis, as older faces elicited larger N170 amplitudes than younger and middle-aged faces, and middle-aged elicited higher amplitudes than younger faces. As discussed above, this result may reflect an increasing ambiguity of facially expressed emotions throughout aging, due to age-related changes in physical features of the face, such as muscle tissue or wrinkles (Wiese et al., 2013). This increasing ambiguity may require additional neural resources to decode, which may result in an enhanced N170.

Of note, the main effect of age of actor was absent in the Face Processing Task, in which faces (independently of their age) elicited similar N170 amplitudes between them. We propose that such inconsistent findings between both tasks may be explained by the different instructions associated to them. Specifically, the Face Processing Task involved a passive visualization of neutral faces and did not require emotional decoding. On the contrary, the Emotion Identification Task involved the recognition of the emotions displayed by faces of different ages, which may have recruited extra neural resources and lead to an increased N170 for older faces, the most demanding and ambiguous (Wiese et al., 2013).

Also, in contrast with the findings of the Face Processing Task, groups did not differ regarding the amplitude of the P250 in the Emotion Identification Task. We hypothesize that these contrasting results are also related to differences in the demands of both tasks. The P250 appears to be modulated by the salience of the stimuli (Feng et al., 2009), being associated to a deeper processing such as detection of familiarity, decoding of the emotional content present on the face, or deviations from prototypicality (e.g., Kloth et al., 2017; Schweinberger & Neumann, 2016). According to this evidence, the inclusion of an explicit emotion identification task might have increased the salience of the facial stimuli and the engagement of the older participants, resulting in the lack of significant differences between groups observed in this task. Such selective recruitment of neural processing for older adults is consistent with the compensation hypothesis of aging (Hess, 2006), which was discussed in the previous section.

Moreover, the P250 is responsive to the emotional content of the face, having larger amplitudes for emotional expressions compared to neutral faces (Chang et al., 2010; DaSilva et al., 2016). This may explain the lack of condition effects in this time-window for the Face Processing Task, despite the main effect of emotion found in the Emotion Identification Task.

Finally, we also found a main effect of the age of the actor for the P250, showing that older and middle-aged faces elicited lower amplitudes than younger faces. This neural result mirrors the behavioural main effect of age of the actor as emotions were better identified when displayed by younger faces, compared to middle-aged and older faces.

5. Conclusion

The results of both tasks showed that aging affects face and emotion processing, consistent with previous reports. In fact, we have replicated several effects that were punctually investigated in the literature, but the present study offers a comprehensive investigation regarding the effects of age (of the participant and of the actor) in the neural processing of faces and emotional identification of facial expressions of emotion.

We found that aging increases the N170 amplitude, but such increasing is elicited by both facial and non-facial stimuli. On note, this neural change occurs without any age-related differences in the amplitude and latency of the P100, which is considered the earliest component elicited by visual stimuli. Taking into consideration results from previous works, we suggest that the aging effect in the N170 may reflect dedifferentiation in recruiting the activation of brain areas selective for faces. Considering that the aging effect in the N170 mimics the face inversion effect, it can also reveal a featural instead of an holistic processing of facial stimuli.

By including a sample of middle-aged adults, we also found that middle-aged adults were at an intermediate level between younger and older adults as they did not significantly differ from both groups. Such results suggest that age-related neurophysiological changes in the amplitude of the N170 may occur gradually across the adult lifespan.

We did not find an effect of aging in the modulation of the P250 in the Emotional Identification Task, which was present in the Face Processing Task, suggesting that an explicit instruction to identify emotions may have increased older adults' processing of emotional content of the face. Finally, we did not find a modulation of the P100–N170–P250 equivalent to an own-age bias, but we found that older faces elicited larger N170 amplitudes than younger and middle-aged faces. This effect was absent in the task requiring a passive visualization of neutral faces from different ages, having only emerged when the task required the active decoding of the emotional content of the face. This effect may reveal a higher ambiguity of older faces due to age-related changes in their physical features, which hampers the decoding of their emotional content.

Taken together, our results may have an important social implication. They suggest that aging may hamper the neural processing of facial expressions of emotion, and this difficulty may be exacerbated during the identification of emotions from faces of their own-age peers. However, for reasons of geographic distribution, this study only included White participants and White faces as stimuli. This is a limitation of the current study, restricting the generalizability of the results.

Author statement

Carina Fernandes and Fernando Ferreira-Santos were responsible for study conceptualization;
Carina Fernandes, Inês Macedo, and Ana R. Gonçalves were responsible for participants' recruitment, assessment, and data collection;
Carina Fernandes and Mariana R. Pereira were responsible for EEG data processing and treatment;
Fernando Barbosa and João Marques-Teixeira were responsible for funding acquisition and supervision;
Carina Fernandes was responsible for writing the original draft of the manuscript.
All the authors contributed to review & editing.

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Open practices

The study in this article earned Open Data badge for transparent practices. The data for this study is available at: https://osf.io/yka8p/

Declaration of competing interest

The authors have no conflicts of interest to disclose.

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cortex.2023.01.007.

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