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Differential emotional responses to positive and negative visual perception in children and young adults: An electroencephalography study

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ABSTRACT

Currently, the number of children with problems associated with mood disorders and emotion regulation is increasing. However, little is known about the development of emotional responses, especially in the developmental population.

To examine the temporal dynamics of emotional neuronal activation, we presented a subset of standardized emotional pictures from the International Affective Picture System dataset to 45 children and young adult participants. Of these, 15 were children (mean age = 10.0 years, range = 7.1–12.7; 6 boys) and 30 were young adults (mean age = 23.5 years, range = 18.9–33.1; 12 men). We used electroencephalography (EEG) to investigate the spatiotemporal dynamics of emotion processing and measured the brain responses elicited by positive and negative images. Differences in activation patterns were studied using topographic analysis of variance. The study was conducted at Miguel Hernández University in Elche, Spain. Our results show that brain responses move from a high amplitude signal in EEG responses to positive stimuli in children to a high amplitude response to negative stimuli in adults. We confirmed lateralization to the left hemisphere in the processing of positive emotions and to the right hemisphere for negative emotions in both children and young

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adults. We also found differences in the amplitude of the responses to emotional images between female and male participants, although these were significant only in adults ($p < .05$). Our results support and expand the existing knowledge about the differing processes of emotion processing in children and adults.

Introduction

Current neuroscience and psychological science are dedicating great efforts to better understand the nature and development of emotions (Braithwaite et al., 2020; Hoemann et al., 2019; Laurent, 2020; Viana et al., 2020). Whereas some authors assume that emotions are biologically based response mechanisms that guide humans and other animals to adjust their adaptive behavior to the surrounding environment and can be considered "decoupled reflexes" (Adolphs, 2017; Cacioppo & Berntson, 1994; Davidson et al., 1990), others suggest that, for the most part, emotions are social constructs that aid in making sense of incoming sensory data (Barrett, 2017).

What these perspectives agree on is the link between external stimuli (e.g., visual, auditory, sensory) and behavioral responses, mediated by neural circuits. These circuits, shaped by evolution, facilitate adaptive responses to environmental demands. Visual stimuli, for instance, initiates emotional responses when processed through a complex system involving the occipitotemporal cortex, the amygdala, and the orbitofrontal cortex (Hare et al., 2008).

Various techniques have been employed to study physiological reactions to emotions. These include eye tracking (the most popular method), cardiovascular measurements (which produced inconsistent results), and electroencephalography (EEG) measurements, which, although rare, have shown the most robust results (Zhang et al., 2023).

In the pediatric population, a recent EEG study review highlights the paucity of emotional studies in children, indicating the urgent need for further research that considers age and gender-related variability (Bhavnani et al., 2021). Another review reported the same problems in terms of significant differences in the methodology used, but it concurred on changes in emotional stimuli with age, with a decrease in latency and amplitude of EEG waves (Bigelow et al., 2021).

Describing specific studies on emotional responses to visual stimuli by EEG in children demonstrated differences in the processing of positive and negative emotions from very early stages of a few months of age (Grossmann, 2010), in particular, with differences in the amplitude of waves captured by EEG (van den Boomen et al., 2019). In addition, there is interpersonal variability in the development of emotions mediated by various factors, including genetic, environmental (depending on the continued exposure to stimuli of a condition), and even cultural factors (Leppänen & Nelson, 2009).

Emotional processing develops and changes with age. Research in schoolchildren and adolescents shows modifications of amplitude and latency in EEG recordings, with both tending to decrease with age (Batty & Taylor, 2006). The results of behavioral and neuroimaging studies indicate a continuous development of the recognition of emotional expression and the neural regions important for this process throughout childhood and adolescence. However, there are methodological difficulties in the studies that hinder a complete understanding of the mechanisms that produce emotions and how they develop throughout life (Fanselow, 1994; Herba & Phillips, 2004; Mafessoni & Lachmann, 2019).

Even though emotion regulation is a key issue to understanding many mood disorders, we know little about the development of brain organization of emotional responses and the temporal dynamics of emotion processing, especially in the developmental population (Assed et al., 2020; Grossman et al., 2000; Hagstrøm et al., 2020; Nag et al., 2020; Pickard et al., 2020; Rieffe & Terwogt, 2000; Schenkel et al., 2007).

One of the main problems in this field is the difficulty of identifying and classifying emotions (Acheampong et al., 2020; Barrett et al., 2019; Shu et al., 2018). Given that the positive to negative valence dimension is a key organizing factor in modern dimensional models of emotion (Harmon-Jones & Gable, 2008), we should take this biphasic approach into consideration when analyzing fundamental emotions.

Thus, although emotional events vary in intensity, speed, and vigor, they can often be distinguished based on whether they are positive or negative (Arnold, 1960), agreeable or disagreeable, positive or negative (Cacioppo & Berntson, 1994), and pleasant or unpleasant (Lang et al., 1990). This fundamental method may be used to study emotional reactions to visual information (Fanselow, 1994) and, more particularly, to examine the specific spatiotemporal reactions that take place in the brain after viewing complex scenes (Costa et al., 2014; Linden et al., 2012; Waugh & Schirillo, 2012).

In the study of visual emotions, the International Affective Picture System (IAPS) is used; it was developed to provide a set of emotional stimuli to assist in research assessing human emotions and attention (Kujawa et al., 2012). The IAPS includes 823 standardized, emotionally evocative, internationally accessible color photographs. The emotional response to individual pictures can be assessed in three dimensions: valence, arousal, and dominance. Although differences in scoring according to culture have been demonstrated (Huang et al., 2015), it is a widely used and valid method in the study of emotions.

Many studies on the neural mechanisms underlying emotion processing have been performed using functional magnetic resonance imaging (fMRI) or positron emission tomography (PET). However, although these techniques have excellent spatial resolution, their temporal resolution is very poor, in the range of seconds (De Pisapia et al., 2019; Royet et al., 2000; Vink et al., 2014). For that reason, an attractive method for studying the neural mechanisms underlying emotion processing that offers high temporal resolution is EEG.

This method can be easily used in children to identify the time course of emotional reactions. EEG is noninvasive and is particularly suitable to be used across development (Loo et al., 2016; Marshall et al., 2002; Vandenbosch et al., 2019).

It is already known that left frontal brain activity has been associated with the experience of positive emotions in children; negative emotions show greater activation of the right frontal area (Balconi et al., 2015). This frontal asymmetry has been described as mediating emotion (Coan & Allen, 2004). However, studies comparing children and adults are few, and there are no studies using the same paradigms and experimental conditions in both populations. One reason for the scarcity of these studies is the variation in the velocities and amplitudes of EEG waves with age, which makes analysis difficult. Studies performed in children have the added difficulty of localizing the classic signal waves, such as the P300 wave, because it is necessary to consider neurodevelopment in children, which modifies the speed of neuronal conduction due to myelinization (Chevalier et al., 2015). In addition, gender differences have also been demonstrated (Giannopoulos et al., 2022).

The hypothesis of our study was based on the evidence that there are age- and gender-specific modifications in the processing of emotions (Giannopoulos et al., 2022), in our case produced in response to visual stimuli. We also proposed the known hypothesis that there is a lateralization in both children and adults of the brain electrical response measured by EEG according to whether positive or negative images are processed (Coan & Allen, 2004).

Finally, based on previous studies, we hypothesized that there may be a difference in the amplitude of the signal measured in EEG, in response to positive or negative stimuli, and that this amplitude may be different in children and adults (Bigelow et al., 2022).

In short, we examined the temporal dynamics of brain activity by EEG, measured in signal intensity (amplitude), location (topographic), and time (milliseconds), in response to a controlled visual stimulus (images with positive and negative emotional valence extracted from the IAPS in children and young adults).

Method

Participants

This was a cross-sectional study conducted on 45 individuals participating in the EEG study. Of these, 15 were children (mean age = 10.0 years, range = 7.1–12.7; 6 boys) and 30 were young adults (mean age = 23.5 years, range = 18.9–33.1; 12 men).

The participants were neurotypical and upper middle social class (mainly university students or their family members). The research was conducted on a Spanish population with communication in their native language, Spanish. This communication style is characterized by an expressive style, often marked by vivid metaphors and an emotionally rich vocabulary.

The exclusion criteria were having a history of neurological or mental disorders; current medication, drug, or alcohol abuse; and not having normal or corrected-to-normal vision.

All participants and legal representatives were informed about the aim of the study and gave their written consent to participate. A parent accompanied all children to the laboratory.

There were no dropouts or losses of participants in the study. The clinical research ethics committee granted ethical authorization for the current investigation.

Images that could offend the sensibilities of children (e.g., murders, accidents) were avoided. However, parents were informed that some images may be unpleasant. All participants could discontinue the study at any time if they were disturbed by the images or EEG.

Due to the novel characteristics and uncertainty arising from the paucity of studies of these specific characteristics, it was not possible to calculate the sample size. A convenience sample was used, with paired groups (half ratio) of children and young adults, in a consecutive manner until statistically significant results were obtained. This was an initial limitation of our study.

Stimuli and validation

Before starting the EEG studies, we selected and validated the affective stimuli using a stratification procedure. A representative sample of standardized images (144 pictures in total) was preselected from the IAPS dataset (Bradley & Lang, 2017) (https://csea.phhp.ufl.edu/media/iapsmessage.html). This database contains a set of normalized rated images for experimental research on emotion and attention. It consists of a substantial collection of color photographs that are standard, emotionally expressive, and globally accessible and cover a variety of semantic categories from pleasant images (e.g., newborns, adorable animals) to unpleasant images (e.g., scenes of violence and injuries). The preselected IAPS stimuli were selected while taking into consideration both the dimensional (valence and arousal) and discrete (e.g., happiness, anger, fear) ratings available and categorized into four groups according to IAPS ratings, namely very pleasant (valence > 7), pleasant (valence from 5 to 7), unpleasant (valence from 2 to 5), and very unpleasant (valence < 2) images. There were 36 photos in each group. Using a commercial stimulus presentation and experimental design system, images were shown in color with identical brightness and contrast (STIM2; Compumedics, Charlotte, NC, USA).

To avoid potential cross-cultural biases, normative ratings of selected IAPS pictures were first validated in children and adults with similar characteristics to our Spanish study population. In total, 30 children (mean age = 9.36 years, range = 6.00–11.72; 18 boys) participated in the validation procedures. A total of 144 images were presented one by one for 1 s on a 21-inch screen, followed by 3 s of black in random order. Children were instructed to score each picture from 1 to 9 (1 = *unpleasant,* 9 = *very pleasant*), avoiding number 5, and all verbal responses were recorded. The same procedure was performed with 30 young adults (mean age = 23.3 years, range = 20.6–31.3; 17 men). From the initial dataset, we selected 80 images that were reliably rated by all the children and adults for the EEG study (see Appendix). In total, 40 pictures corresponded to positive images (valence > 5; confidence interval [CI] = 95%) and 40 pictures corresponded to negative images (valence < 5; CI = 95%). The participants involved in these validation experiments did not participate in the main experiment.

For the presentation of the images, a 21-inch flat screen was placed at a distance of 1 m from the eyes of the participants and at the same height. This procedure was identical, in the same room and with the same conditions, for all participants and in both phases of the study (image validation and EEG recording).

EEG task

Each image was shown for 500 ms before a 3500-ms period of black screen (Fig. 1). During this time, the participants were required to look at the screen without moving and to evaluate the arousal and valence of their emotional experience, indicating their score verbally. Scores for the images ranged from 1 (*very unpleasant*) to 9 (*very pleasant*), and the entire procedure was recorded. The images, presented using the STIM2 program, appeared randomly and only once. When the images appeared, a pulse was sent to the EEG analysis program to synchronize them.

EEG data acquisition

The commercial 64-channel Quik-Cap (Compumedics) was used, with the placement of electrodes according to the international 10–20 system and the procedure regulated by the International Federation of Clinical Neurophysiology (Klem et al., 1999).

The participants were instructed to remain as immobile as possible, not to blink during image acquisition, and to try to focus their attention on the center of the monitor. We continuously recorded EEG data from 64 sites at a sampling rate of 1000 Hz (FP1, FPZ, FP2, AF3, GND, AF4, F7, F5, F3, F1, FZ, F2, F4, F6, F8, FT7, FC5, FC3, FC1, FCZ, FC2, FC4, FC6, FT8, T7, C5, C3, C1, CZ, C2, C4, C6, T8, REF, TP7, CP5, CP3, CP1, CPZ, CP2, CP4, CP6, TP8, P7, P5, P3, P1, PZ, P2, P4, P6, P8, PO7, PO5, PO3, POZ, PO4, PO6, PO8, CB1, O1, OZ, O2, and CB2) using the international 10–20 system (Klem et al., 1999). The EEG was recorded via cap-mounted Ag–AgCl electrodes and a 64-channel NeuroScan SynAmps EEG amplifier (Compumedics). Prior to data collection, the impedance of the recording electrodes was checked for each participant, and the values remained below 25 kΩ. The recordings were made in a silent space with low illumination.

Before statistical analysis, the EEG signals were filtered with 0.5-Hz high-pass and 45-Hz low-pass filters and re-referenced to a common average reference (CAR). Then, using principal component analysis (PCA) in accordance with industry standards and within the time window (−200 ms, +500 ms) from stimulus onset, all potential motion or eye blinking artifacts were corrected (Kaczorowska et al., 2017).

EEG data in the period (−200 ms, +1500 ms) from stimulation onset were selected for analysis. Topographic analysis of variance (TANOVA), which compares the topographic maps of the EEG record-

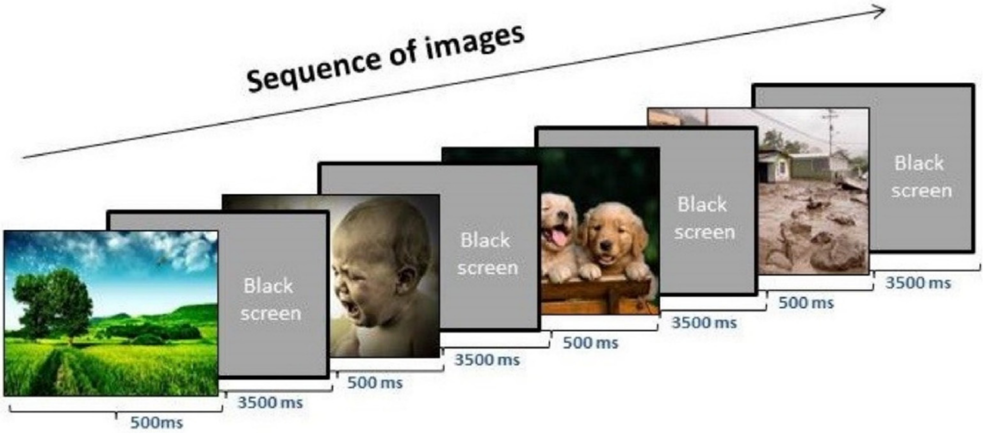

Fig. 1. Time schedule representation of the presentation of images to the participants. Using commercial stimulus presentation software, the stimuli were shown in continuous mode (STIM2; Compumedics, Charlotte, NC, USA).

ing millisecond by millisecond, was used to obtain significant differences in the amplitude of the wave, indicating the time window in which there was a statistical difference in the recorded signal to be analyzed. For each participant, records were divided into two subgroups, positive and negative, according to their valence scores.

We also studied the P300 wave, which is an event-related potential (ERP) that can be registered as a positive voltage deflection with a latency of about 300 ms after stimulus onset in adults (Pritchard, 1981). In the developmental population, it is known to be delayed in time due to myelination. The P3 component may have been distorted due to the lower cutoff frequency of 0.5 Hz. This was a technical limitation in our study. This filtering frequency will be lowered in future studies. The ERP is extracted from the EEG record, and the amplitude of the electrical wave is measured to be studied.

Statistical analysis

We investigated topographic changes in EEG activity (Brunet et al., 2011; Laganaro et al., 2012; Martinovic et al., 2014; Murray et al., 2008) with the power of Curry 7 (Compumedics). This method views the EEG activity of the entire scalp as a finite collection of alternating, spatially stable activation patterns representing a series of steps in the processing of information (Banaschewski & Brandeis, 2007; Schupp et al., 2006). Because it analyzes the overall time course of activity and the entire pattern of brain activation, we chose this over the more conventional approach that is focused on the evaluation of amplitudes and latencies (Skrandies, 1990). Moreover, Curry 7 can identify changes in the underlying sources of activity in addition to differences in amplitude.

To identify the optimum time windows for further dipole analysis, TANOVA was used. A significance level of α = .05 was chosen. The Curry 7 program uses TANOVA to compare EEGs when viewing positive images with EEGs when viewing negative images. The TANOVA indicates the time window with significant differences and the location of the dipole in these windows, which are electrically different (Murray et al., 2008).

In addition, we used dipole source localization. This technique uses a nonlinear multidimensional minimization procedure to estimate the dipole parameters that best explain the observed scalp potentials in a least-square sense. We assumed that EEG signals were generated by only one or a few focal sources. Depending on the degree of parameter flexibility, the dipole source model can be further divided into moving, fixed, and rotating dipoles. We considered a rotating dipole, which consists of two independent dipoles whose orientation is allowed to change over time (Fuchs et al., 1998). For the reconstruction of the head, we used the boundary element method (BEM), which makes it possible to identify the origin of dipoles. Moreover, BEM models work better in portions of the skull that are not spherical such as the temporal or frontal lobes (Vatta et al., 2010). This type of analysis focused on these areas has been used previously in studies on emotions (Coan & Allen, 2004; Gartstein et al., 2020).

Finally, we used standardized low-resolution tomography analysis (sLORETA) to create a graphical reconstruction of the activation of brain areas with visual stimuli (Dattola et al., 2020).

IBM SPSS Statistics was used to conduct the statistical analysis (SPSS 20.0; IBM Corp., Armonk, NY, USA). Data are presented as means ± standard deviations unless otherwise stated, and averages were compared using the *t* test. A *p* value of.05 or below was considered statistically significant.

Results

Selection and validation of IAPS images

The affective ratings of our selected images for Spanish children and adults were strongly correlated with the valence ratings of the North American population (correlation coefficients of.91 for children and.99 for adults). Each image was validated in a prior study, and there were no significant differences between the American and Spanish populations. These results confirm the cross-cultural and cross-age validity of the IAPS images.

Electroencephalography

The participants who took part in the EEG study correctly identified all the presented images. Fig. 2 shows the average values of the total scores for positive and negative images in both children and young adults. There were no significant differences in the scores for positive images between children and adults. However, the scores for negative images were significantly higher in children (2.39 ± 0.60 in children, 1.62 ± 0.577 in adults, $p < .001$).

When we compared the EEG recordings associated with the brain processing of positive and negative images, we found significant differences in the patterns of activity for children and young adults ($p < .05$). Furthermore, the differences were related to age. Fig. 3 shows a representative sample of a 7-year-old child. P300 (vertical green [left] rectangle) is clearly displaced and appears 510 ms after stimulus onset. In addition, the time window with the greatest significant difference between positive and negative stimuli was between 1144 and 1173 ms (vertical blue [right] rectangle). Because our population was in the developmental stage and was in the process of cerebral myelination, response times were longer in children than in adults (Fig. 3).

When we compared the latencies of the P300 wave across age, we found a significant decrease ($p < .01$) in the child population (see Fig. 4A). Furthermore, there was a significant decrease in the time windows, with the greatest significant differences between positive and negative stimuli found in children over time. By contrast, there were no significant differences in the latencies of the P300 wave (261.5 ± 22.3 ms) or in the time windows with significant differences between positive and negative stimuli (543.7 ± 93.8 ms) in adults (Fig. 4B). This suggests that from 19 years of age, the time window for the greatest differences between positive and negative stimuli remained stable between 429 and 554 ms after stimulus onset (Fig. 4).

The TANOVA allowed us to find significant differences in brain functional states for positive and negative stimuli. Our results showed that the distribution of the intracranial dipole sources in the significant time windows provided by the TANOVA was different for positive and negative stimuli in both children and adults. The dipoles corresponding to positive stimuli were located in the left hemisphere, whereas the dipoles corresponding to negative stimuli were located in the right hemisphere. These differences were observed in all the participants, but in the children it was necessary to adjust the time window according to their age. Fig. 5 shows the rotating dipoles for positive and negative stimuli

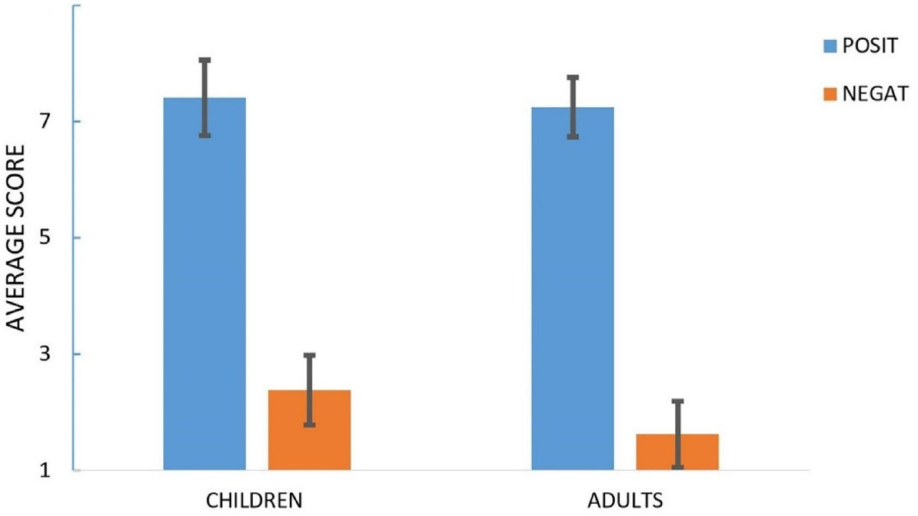

Fig. 2. Comparison of the average scores for positive and negative images in children and adults.

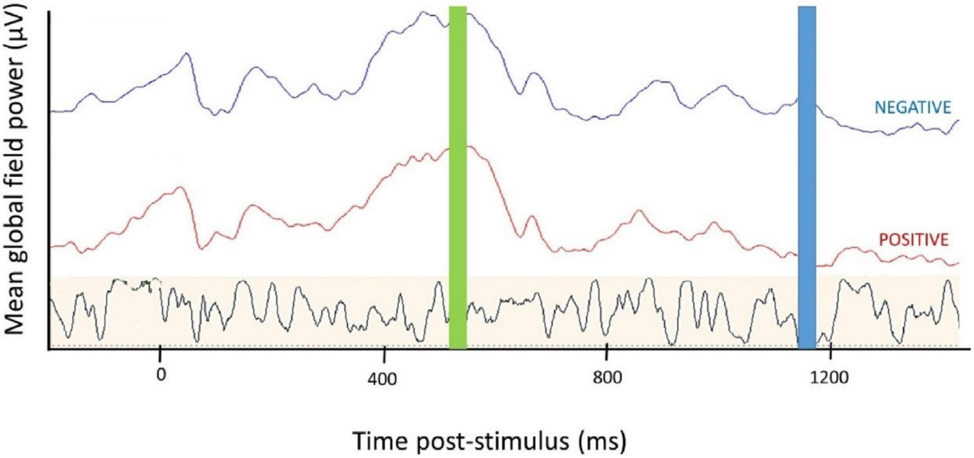

Fig. 3. Time points of significant differences in electroencephalography activity for positive and negative stimuli in a 7-year-child. Topographic analysis of variance, depicting 1.5-s *p* value across time, is shown. Significant *p* values are plotted as vertical rectangles ($p < .05$). The vertical green (left) rectangle shows the displaced P300. The vertical blue (right) rectangle shows the interval with significant differences between positive and negative stimuli. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

using the current density reconstruction that arises from the scalp electric potentials with the sLORETA method in adults (Dattola et al., 2020).

We also studied the amplitude of the EEG recordings in the time windows, with significant differences for positive and negative stimuli (Ruiz et al., 2009; Subha et al., 2010). In children, the average amplitudes for positive stimuli (4.27 ± 1.14 μV) were significantly higher ($p < .036$) (Fig. 6A) than the average amplitudes for negative stimuli (3.46 ± 0.82 μV). However, in adults the average amplitude for negative stimuli (3.79 ± 1.67 μV) was significantly higher ($p < .042$) than the average amplitude for positive stimuli (3.07 ± 1.09 μV) (Fig. 6B). Thus, brain responses shifted from higher responses to positive stimuli in children to higher responses to negative stimuli in adults Fig. 7.

In addition, we analyzed potential differences due to sex. In adults, we found that women had higher amplitudes for negative stimuli (4.27 ± 1.75 μV) than men (3.08 ± 1.32 μV) ($p = .029$). In children, the average amplitude for positive stimuli was also higher in girls (4.50 ± 1.34 μV) than in boys (3.78 ± 0.22 μV), but these differences were not statistically significant ($p > .05$).

Discussion and conclusions

Our results show differences between children and adults in emotion processing in response to emotionally valenced visual stimuli, in this case IAPS images. Brain responses were different, from a large amplitude signal in EEG responses to positive stimuli in children to large amplitude responses to negative stimuli in adults. We also confirmed lateralization in the processing of positive to left hemisphere and negative to right hemisphere emotions in both children and young adults.

We found a temporal difference in the appearance of the P300 waves and the waves where emotional response to visual stimulus was produced. Both waves appeared earlier in time with increasing age.

One of the main issues related to the study of emotions in different age groups concerns the images or stimuli used. Although most studies in this domain analyze emotional responses to facial expressions, our study examined the responses induced by more complex images. Nonetheless, we could not use the same images for children and adults. For example, some negative images used in adults, such as images of murders or violence, could offend the sensibilities of children. On the other hand, some images that are usually scored positively in adults, such as pictures of babies, are neutral for

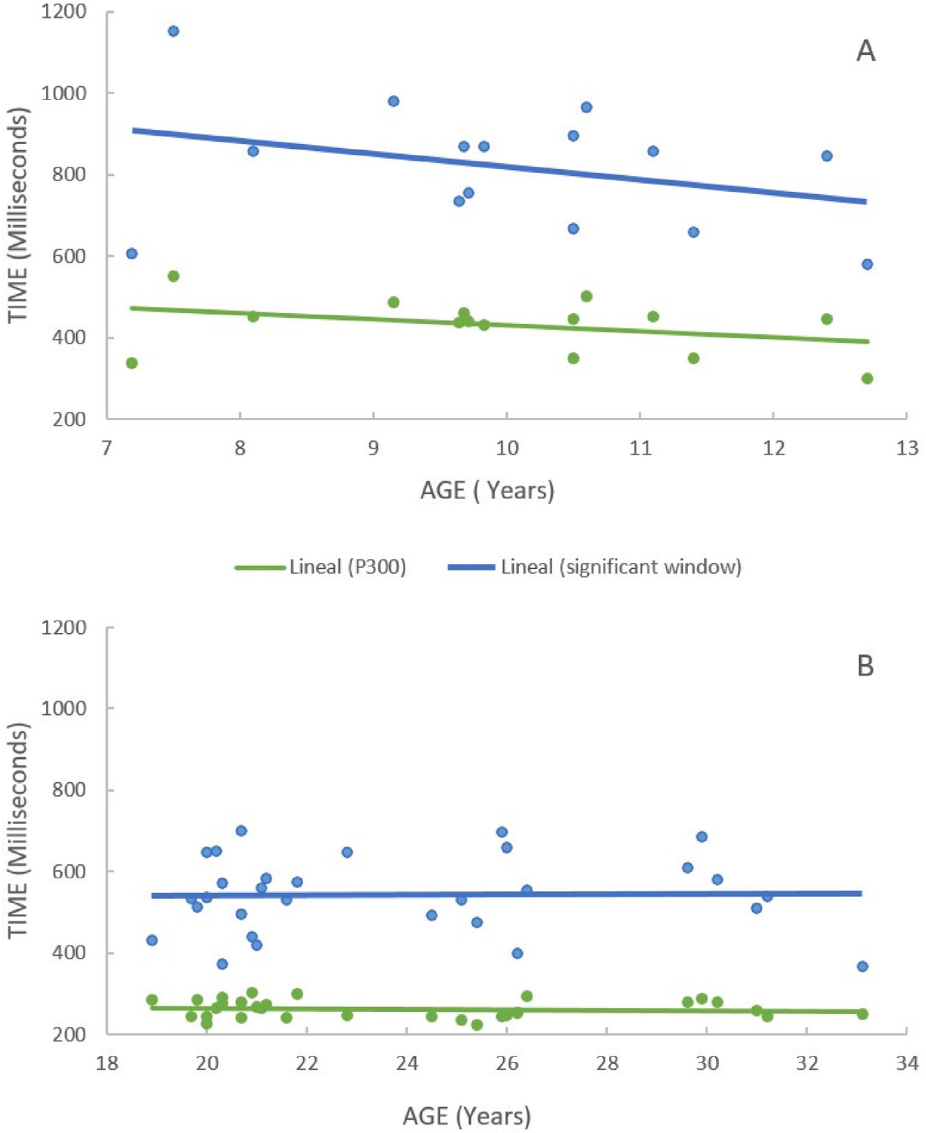

Fig. 4. Evolution of P300 and significant post-stimulus time window for positive and negative stimuli in relationship with age: (A) children; (B) adults. Note that this is a cross-sectional study, so each patient is presented at one point, but there is no longitudinal follow-up of the same patient.

most children, who prefer images of animals, fireworks, and the like. As a result, prior selection and validation of the set of images to be used in each specific population was required. In this framework, the selected IAPS pictures used in this study covered a wide range of affective content and included both positive and negative images that were rated reliably by all children and adults. However, although the subjective scores for the positive images were very similar in children and adults, children tended to assign a higher score (more positive or pleasant) to images with potentially disagreeable or negative content. This could be due to the fact that the images presented were not so

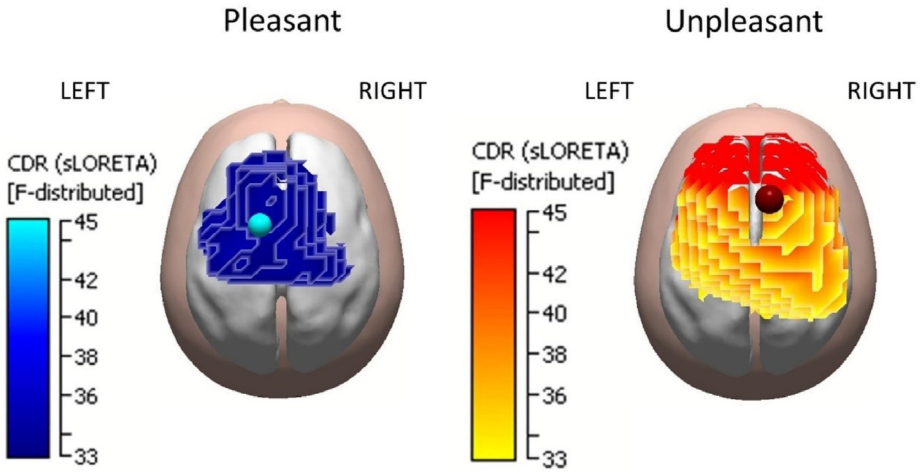

Fig. 5. Reconstruction of the head and rotating dipoles in the time window (429–554 ms) for adults. Rating was divided into two groups according to subjective punctuation and Cartesian coordinates of the rotating dipole for each group. CDR, current density reconstruction; sLORETA, standardized low-resolution tomography analysis.

unpleasant, but we also need to consider the possibility of less emotional reactivity to negative stimuli (Sharp et al., 2006).

Results show that the amplitudes of brain responses were higher to positive stimuli during childhood, and then these responses were higher to negative stimuli during adulthood. These differences according to age indicate that there may be important differences in emotion processing in children and adults. We postulate that this could fulfill evolutionary adaptive functions. The literature on ERPs suggests that there is an evolution of emotional reactivity to emotional stimuli and an increased efficiency in the selection of attention to emotional stimuli with age. (Dickey et al., 2021).

Our emotions are designed to be useful for adaptation to the environment. The fact that pleasant (positive) emotions produce greater signal amplitudes in children could be related to learning and adaptive processes. By contrast, adults have greater wave amplitudes for negative (unpleasant) images, which indicates a propensity to pay attention to, learn from, and use negative information more than positive information (Vaish et al., 2008). These effects may be due to synaptic pruning that occurs throughout life that produces improved ways of processing neural information (Sowell et al., 2001; Steinberg, 2005).

The results indicating differences in signal intensity to visual emotional stimuli with age are of particular interest to psychologists and educational psychologists. This suggests that children may be more receptive to positive emotions and therefore that learning and professional practice should adopt a positive approach, as advocated by many educational theories. However, at an older age, the greater electrical intensity produced by negative stimuli indicates that we must be alert to external threats to our mental and physical well-being. This is not the case with children, who benefit from the protection afforded by their parents.

The changes found in the latencies of the time windows with the greatest significant differences for positive and negative stimuli in children could be related to a relatively slower brain processing speed for complex emotions. The delays observed in the P300 wave for younger children support this finding and suggest that it could be associated with changes in myelination that continue, perhaps, as late as 30 years of age (Barriga-Paulino et al., 2015; Overbye et al., 2018; Riggins & Scott, 2020). Myelination progressively increases with age and then degenerates slowly, especially in older adults (Bawa, 1981; Chevalier et al., 2015). These findings highlight the need for and difficulty of studying emotional reactivity and brain processing differences in children by age groups.

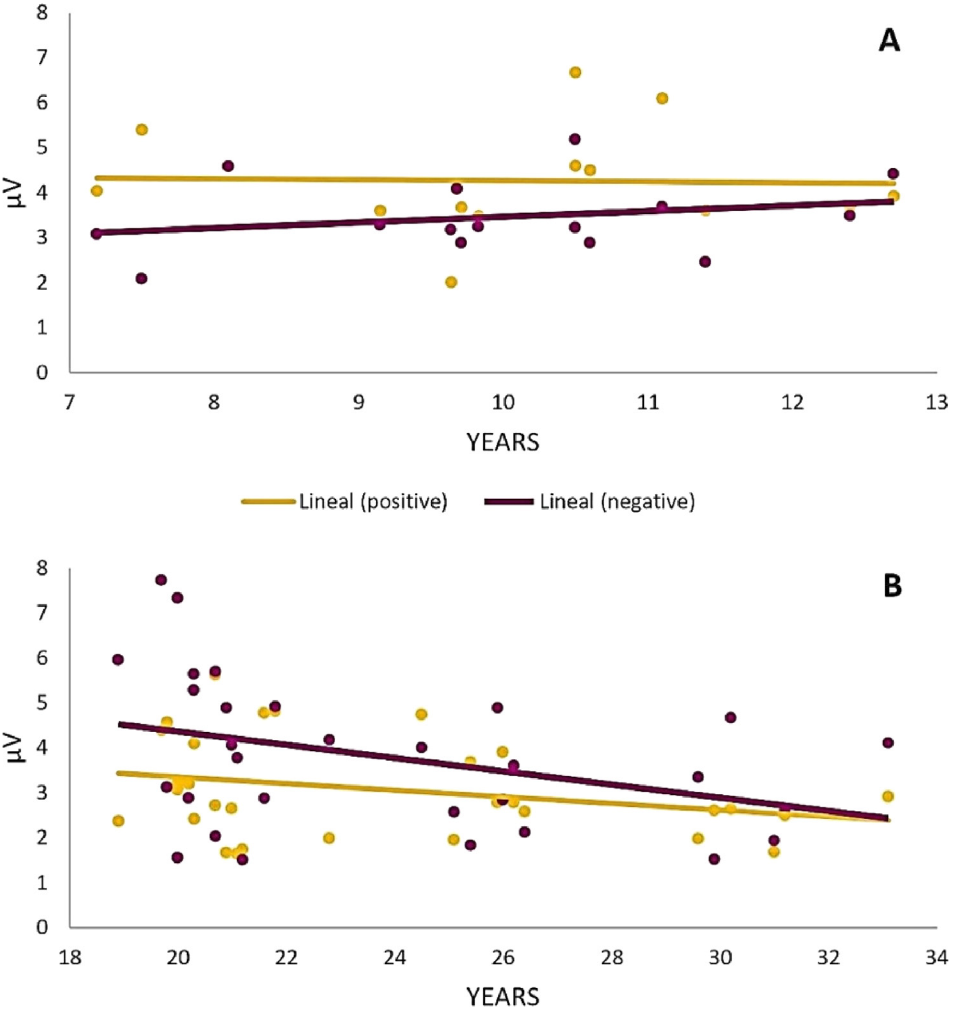

Fig. 6. Amplitude of electroencephalography responses for the significant time windows in function of age: (A) children; (B) adults. Note that this is a cross-sectional study, so each patient is presented at one point, but there is no longitudinal follow-up of the same patient.

Our results showed the distribution of the intracranial dipole sources in the significant time windows. We also found right lateralization with negative visual stimuli and a preferential activation of the left hemisphere for positive emotions found by others in both children and adults (Balconi et al., 2017; Bawa, 1981).

When we split children and adults by sex, we found that women generally had greater EEG signal amplitudes. This could reveal an advantage of women in processing emotional expressions (Collignon et al., 2010; Hampson et al., 2006) and could be linked to sex differences in brain anatomy and cognition (De Bellis et al., 2001, Lee et al., 2005). The primary caretaker hypothesis contends that women have developed characteristics that improve the likelihood that their babies will survive because of their evolutionary position as primary caregivers (Hampson et al., 2006), but we must stress that this is not a straightforward discussion. This gender difference occurs in the Spanish population, and sociocultural or gender roles may alter the results depending on the study population (Leppänen & Nelson,

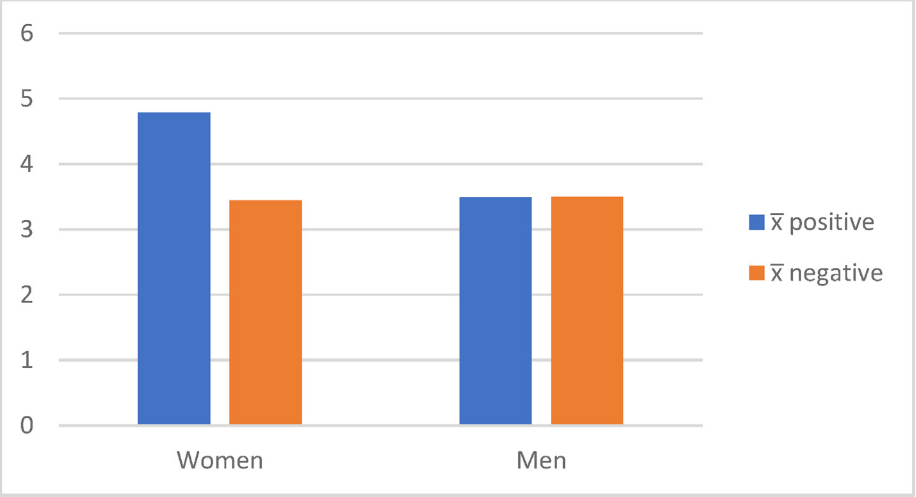

Fig. 7. Mean signal intensities between men and women in response to positive and negative stimuli. Differences were statistically significant ($p < .05$). Positive mean = 4.79, 95% confidence interval [3.95, 5.62]. Negative mean = 3.49, 95% confidence interval [3.01, 3.92].

2009). In addition, hormonal factors may produce changes in emotion processing. To avoid confounding these data, we did not include adolescents in our study. In this context, the ability to recognize emotional states facilitates "reading" the feelings of others, which could be crucial to predicting actions and optimizing social interactions and behavioral reactions.

Although more studies with a larger number of participants and a broader age range are still needed, these results could be useful to better understand issues associated with emotion processing.

A limitation of the current study is that it did not assess the emotional response of each individual participating in the study. Thus, there may be a disparity between the individual's personal assessment and the value assigned to the visual stimulus. For example, an individual may have a negative personal experience with a pet, which could influence that individual's emotional response to the stimulus. Likewise, this was a cross-sectional study, so we cannot generate causality in the changes of electrical patterns with age.

Furthermore, the study of the brain signal amplitudes and the time windows significant for processing emotional stimuli, together with the spatial location of the EEG potentials observed during emotional processing, could be useful to provide a comprehensive explanation of the role of each hemisphere in the processing of emotional information.

CRediT authorship contribution statement

María Dolores Grima-Murcia: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Francisco Sanchez-Ferrer:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Eduardo Fernandez:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Project administration, Methodology, Formal analysis, Data curation, Conceptualization.

Data availability

Data will be made available on request.

Appendix A

Full list of International Affective Picture System images used in the study with children:

1030, 1040, 1050*, 1120, 1201, 1202*, 1275*, 1280, 1280*, 1300*, 1302, 1410*, 1441*, 1460*, 1463*, 1595*, 1601*, 1610*, 1620*, 1710*, 1722*, 1750*, 1811, 1812*, 1920*, 1930, 1932, 1999, 2070*, 2091*, 2100*, 2120*, 2130, 2151, 2154, 2165, 2190, 2301, 2311, 2314, 2320, 2340, 2345*, 2347, 2410, 2456*, 2457*, 2458*, 2501, 2650*, 2660, 2688*, 2715, 2770, 2780, 2791, 2810*, 2840, 2900*, 3022*, 3230*, 3280, 3500, 4603, 5020*, 5030, 5410, 5450*, 5470*, 5480*, 5621, 5829, 5831*, 5910*, 5940, 6190, 6230*, 6250, 2*, 6300*, 6370*, 6510*, 6570, 1*, 7000, 7010, 7079*, 7090, 7100, 7130, 7150, 7170, 7250*, 7287, 7325*, 7330*, 7380*, 7390, 7400*, 7430*, 7451*, 7476, 7502*, 7510*, 8030*, 8031*, 8193*, 8260*, 8330, 8380, 8420*, 8461, 8490*, 8496*, 8503*, 8510*, 8620*, 900*, 9001*, 9031*, 9050, 9150, 9250*, 9260, 9280, 9291*, 9295*, 9320*, 9340*, 9341, 9360*, 9395*, 9421*, 9468, 9470, 9480*, 9490*, 9495*, 9560*, 9561*, 9582, 9594, 9600*, 9611, 9635, 9800*, 9940*.

Full list of International Affective Picture System images used in the study with young adults:

1052, 1201, 1300, 1333*, 1440*, 1441*, 1460, 1595*, 1602*, 1610*, 1640*, 1710*, 1720*, 1750*, 1850, 1920*, 1942*, 2000, 2010, 2039, 2040*, 2050*, 2055*, 2057, 2058, 2060, 2070, 2080*, 2092*, 2095*, 2110*, 2150*, 2154*, 2205, 2217, 2240, 2260*, 2278, 2302, 2320*, 2340*, 2342*, 2347*, 2392, 2442, 2457, 2500, 2515, 2530*, 2590, 2594*, 2605, 2694*, 2703*, 2716, 2718, 2800*, 3000, 3001*, 3010*, 3015*, 3022, 3030, 3053*, 3131*, 3170*, 3180, 3191*, 3216, 3261, 3266*, 3301*, 3350, 3360, 3530*, 4090, 4100, 4220, 4255, 4598, 4635, 5210*, 5250*, 5410*, 5662*, 5760, 5825*, 5830*, 5833*, 6010*, 6020, 6200*, 6220*, 6313*, 6350*, 6410, 6520*, 6563*, 6836*, 7079*, 7130, 7361, 7477, 7488, 7515, 7580*, 8080, 8118, 8170*, 8190*, 8231*, 8251, 8370*, 8420*, 8470, 8496*, 8499*, 8501, 8502, 8600, 9001, 9006, 9040*, 9042, 9046, 9075*, 9102, 9182, 9183*, 9185*, 9187*, 9252*, 9325*, 9405*, 9412*, 9413*, 9417, 9433*, 9452*, 9470*, 9570*, 9599, 9622, 9940*.

*Selected images for electroencephalography recording.

Appendix B. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2025.106208.

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