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Interaction between Emotion and Cognition: Electrophysiological Correlates of Emotional Meaning Processing

Field of Study: Psychology (M-PSI/01)

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Contents

Introduction

1. The relationship between cognition and emotion

1.1.Emotion and cognition: A dynamic relationship

1.2.Studying the interplay between cognition and emotion

1.3.Emotional development and emotional meaning

1.4.Electroencephalography (EEG)

1.5.Event-Related Potentials in Emotional Processing

1.6.Cognition and Emotion: Resting-State EEG

2. The integration of emotions into reading processes: EEG correlates in children

2.1.Background

2.2.The current study: aims and hypothesis

2.3.Method

2.3.1. Participants

2.3.2. Materials

2.3.3. Procedure

2.3.4. EEG recordings and preprocessing

2.3.5. Statistical analysis

2.4.Results

2.5.Discussion

3. The relationship between Resting-state EEG, emotional dimensions, and cognitive performance in children

3.1. Resting-State EEG

3.2.Theta/Beta Ratio (TBR)

3.3. Frontal Alpha Asymmetry (FAA)

3.4. The Current Study: aims and Hypothesis

3.5. Method

3.5.1. Participants

3.5.2. Materials

3.5.3. Procedure

3.5.4. EEG recordings and preprocessing

3.5.5. Statistical analysis

3.6. Results

3.7. Discussions

3.7.1. Correlations between resting-state EEG and behavioral measures

3.7.2. Correlation between LPP and FAA

Conclusion

Appendix A. Correlations between questionnaires and cognitive tasks

Appendix B. Mean, Standard Error and Standard Deviation of FAA and TBR

Appendix C. Correlations between TBR (grouped by frontal, central, and parietal electrodes) and emotional questionnaires and cognitive performance

Appendix D. Correlations between EEG resting-state measures (FAA and TBR) and EQi:YV

Appendix E. Correlations between EEG resting-state measures (FAA and TBR) and AQC

Appendix F. Correlations between EEG resting-state measures (FAA and TBR) and cognitive tasks

Introduction

This work aims to investigate the interaction processes between cognition and emotion in primary school children, focusing on linguistic processes from a neurophysiological perspective. Cognition and emotion are two key aspects of development that dynamically influence each other. It is widely acknowledged that cognitive functions are the basis of learning processes and that emotions significantly influence cognitive processes.

Emotions can generally be described as discrete or coherent responses to significant events. The concept of emotion differs from other concepts such as feelings (which mainly concern the personal experience associated with the emotion), moods (which are affective states of longer duration but generally less intense), and the concept of affectivity (a broader term encompassing all emotional phenomena).

Cognition refers to the basic and complex forms of knowledge and awareness, including perception, attention, memory, language, and executive functions, abilities that enable individuals to carry out tasks and interact with the world.

The first chapter of this thesis focuses on the scientific literature on emotion and cognition, emphasizing their inseparability in achieving a deeper understanding of mental processes and behavior. It also highlights the central role of language, concepts, and words as fundamental organizing elements of thought and action. Emotional words are linked to embodied emotional concepts; therefore, studying their neural correlates through psychophysiological techniques such as electroencephalography is relevant.

The second chapter examines how emotional words can differentiate from non-emotional words at the electrophysiological level. Specifically, event-related potentials are used to study the

electroencephalographic response to emotional and neutral words during an emotional categorization task in primary school children.

Finally, the third chapter investigates the possible relationships between spontaneous brain activity measured by resting electroencephalography and emotional and cognitive measures collected in children. In particular, two electrophysiological indices that have been variously indicated as informative on cognitive and affective processes are used, namely the ratio between theta and beta waves and frontal alpha asymmetry.

Keywords: ERP; Resting-State EEG; Emotional words; primary school children; language.

Chapter 1

1. The relationship between cognition and emotion

1.1.Emotion and cognition: A Dynamic Relationship

Understanding human behavior and mental health cannot be separated from understanding the complex interactions between cognition and emotion (Uniyal, 2024). Cognitive functions, like perception, attention, memory, language, and executive functions, allow us to interpret sensory input and environmental signals to prepare complex behavioral responses (Anderson, 2005). Similarly, emotions significantly influence behavior by providing essential information about internal and external states, thus constituting another fundamental human experience (Liu et al., 2009). Therefore, emotion and cognition govern human behavior by guiding – among other things - decision-making, relationships, and well-being. Traditionally, cognition and emotion have been considered two opposing entities (Dennis, 2010; Shackman et al., 2015). Indeed, humans tend to experience cognition and emotion as fundamentally different; while emotion is imbued with pleasure or pain that can be easily felt in the body, cognition often appears devoid of a hedonistic tone and somatic characteristics (Okin-Singer et al., 2017). These differences in phenomenological experience and peripheral physiology have led many researchers to treat emotion and cognition as distinct mental faculties (Okon-Singer et al., 2015). The most widespread conception regarding the interaction between cognition and emotion considers emotional states potentially detrimental to the expression of cognitive potential (Okin-Singer et al., 2017). Indeed, emotion dysregulation is often cited as a transdiagnostic construct that plays a key role in childhood, adolescent, and adult psychopathology (Paulus et al., 2021). Neuropsychological studies have shown that when emotional functioning is impaired, social reasoning and decision-making can also be severely impaired (Damasio et al., 1991). Positive and negative emotions serve a regulatory function, so reduced or impaired emotional reactivity can negatively impact behavioral control (Seo & Barrett, 2007). Therefore, adequate

cognition can only occur when there is an efficient and functional connection with emotions (Damasio, 1994). Indeed, neuroscience data suggest that emotion and cognition are integrated, coordinated, and complementary (Grey & Burges, 2004). A range of emotions, cognitive processes, and contexts must be assessed to delineate how emotion-cognition integration occurs and predict how this interaction influences behavior. Specific emotional states can differentially influence information processing, and cognitive control can modulate various emotional experiences (Gray, 2001).

According to Scherer (2005), emotions have several components. The cognitive component (appraisal), the neurophysiological component (bodily sensations and perceptions), the motivational component (action tendencies), the motor expression component (facial and vocal expression), and the subjective feeling component (emotional experience) are considered the most important (Scherer, 2005). Furthermore, researchers adopt two main perspectives in studying emotions: discrete and dimensional (Russell, 2009). An example of the discrete approach is the cognitive-motivational-relational theory (Lazarus, 2000), which identifies each emotion through specific cognitive contents and appraisal properties called "core relational themes.” In contrast, the dimensional approach considers that emotions can be defined along a continuum of multiple dimensions (Laborde, 2016). The most widely used model has two main dimensions: valence and arousal (but see also Imbir et al., 2019; Yani-de-Soriano & Foxall, 2006). Valence indicates the hedonic tone (i.e., pleasant to unpleasant), while arousal refers to emotional intensity and ranges from low to high (Feldman–Barrett, 1998). The discrete approach, therefore, focuses on how specific emotions can influence or be influenced by cognitive processes. In contrast, the dimensional approach seeks to identify, for example, appropriate levels of emotional valence and arousal in relation to task demands (Laborde, 2016). As for cognitive functions, a macro-distinction divides them into higher-order functions, which exert top-down control on behavior, and functions that are instead based on more automatic and bottom-up driven processes (Diamond, 2012). Higher-order functions can be further defined as executive functions such as inhibition, working memory, and cognitive flexibility (Miyake &

Friedman, 2012), which are fundamental for complex mental phenomena such as planning, reasoning, and decision-making (Collins & Koechlin, 2012). Differently, more automatic cognitive functions are instead studied in the context of attentional processes in tasks that do not generally require the mental manipulation of new information (Laborde, 2016). For example, it has been demonstrated that emotional stimuli can automatically attract attention, resulting in improved processing of emotionally significant information (Vuilleumier & Driver, 2007). Emotional stimuli, compared to neutral ones, can enhance memory consolidation processes (Phelps & Sharot, 2008), as demonstrated by an enhancement in retrieval performance (Kensinger & Corkin, 2003), although some studies have questioned this effect (Kensinger et al., 2007). The integration of emotion and cognition involves distinct processes that can influence each other in selective ways (Gray, 2004). Specific emotions can enhance some cognitive functions while impairing others, leading to either opposition or mutual support, depending on the situation and context (Dennis, 2006). In line with this view, the affective evaluation hypothesis suggests that executive control and affective functions are reciprocally regulated to direct and control behavior (Luu & Tucker, 2004).

1.2.Studying the interplay between cognition and emotion

Generally, researchers rely on three macro-theoretical models to study the interaction between cognition and emotion. The first two models consider the cognition-emotion interaction unidirectional, while the third is a dynamic bidirectional model (Bell, 2012). For the first model, emotions influence cognitive functions by organizing thought and action (Cole et al., 2004). By manipulating the emotional content of the experimental situation, the effect on cognitive functions and performance is explored (Richard & Gross, 2000). In contrast, the second model considers how cognition influences emotion. In this case, individual cognitive characteristics and/or cognitive strategies significantly affect – for example - emotional regulation abilities (Ochsner & Gross, 2005, 2008). These two models are widely used because of their simplicity and because they effectively

describe fundamental characteristics of the interaction between cognition and emotion. However, the third model, representing a dynamic bidirectional relationship between emotion and cognition, is considered the most reliable (Bell, 2012). Indeed, bidirectional interactions between emotion and cognition can be observed – among others - in perception, memory, decision-making, and social behavior (Uniyal, 2024). Cognition shapes an event's meaning and emotional intensity, while emotions influence attention, memory, and decision-making. For the cognitive appraisal theory, for example, the personal meaning of events is based on cognitive interpretations and emotional reactions (Lazarus, 1991). Another example is the hypothesis of Zelazo and collaborators (Zelazo & Cunningham, 2007). According to these authors, executive functions can be differentiated into cold and hot, depending on the goals and the emotional consequences of the decision-making process. Furthermore, when problem-solving is focused on regulating emotions, executive functions coincide with emotional regulation (Zelazo & Cunningham, 2007; Bell, 2012). In line with this view, Gray and colleagues (2004) explained that cognition and emotion are highly integrated and not completely separable during information processing under some conditions (Gray, 2004). Neuroimaging and electrophysiological studies can help delineate this complex interplay at the neural and temporal levels. The dorsolateral prefrontal cortex (dlPFC) and the medial prefrontal cortex (mPFC) contribute to regulating emotions through top-down control. These areas would, therefore, be part of a dorsal system responsible for cognitive control (Luu et al., 1998). At the same time, the amygdala influences cortical and other subcortical regions and, consequently, attentional and memory processes (Phelps & LeDoux, 2005). The amygdala and other limbic regions, brainstem structures, and orbitofrontal areas constitute a ventral system that underlies emotional arousal and motivational processes (Dolan, 2002). Finally, the anterior cingulate cortex (ACC) and the ventromedial-prefrontal cortex (vmPFC) are indicated as key regions in the intermediacies between the ventral and dorsal systems and, consequently, in the interaction between cognition and emotion (Botvinick et al., 1999; Roy et al., 2012). Traditionally, it was argued that activation of areas involved in cognitive control was

accompanied by affective suppression during cognitive processing. In contrast, affective activation was coupled with cognitive suppression during the processing of emotions, thus making emotion and cognition cerebral separate processes (Bush et al., 2000). These observations were derived from functional studies, but this simplification has been overcome (e.g., Hass et al., 2006; Bell, 2012). Similarly, Yonelinas and Ritchey's (2015) model proposes interactions based on activation/deactivation mechanisms of the amygdala and hippocampus to explain the different properties and the behavioral performances for emotionally and non-emotionally memories (Yonelinas & Ritchey, 2015). It is important to note that neuroimaging studies demonstrate that core emotional and cognitive processes are co-localized in the brain (Shackman et al., 2011), and electrophysiological research has shown that prototypical cognitive control signals co-vary systematically with emotional traits and states (Cavanagh & Shackman, 2015). Recently, Pessoa has proposed a change of perspective (Pessoa, 2018; 2019). The author proposes to "eliminate" the distinction between cognition and emotion, overcoming - among other things - the conceptual segregation of emotion from perception, motivation, and cognition, conceptualizing emotion in terms of large-scale neural network interactions. Indeed, brain areas would give rise to psychological functions in terms of properties emerging from interactions between brain regions working together as functional systems (Grossberg, 2018). Instead of describing phenomena with standard interaction approaches (for example, for the extinction of fear memories, each brain region corresponds to a correlate such that the amygdala would be linked to valence, the medial PFC to regulation, the hippocampus to context, ...), it would be necessary to focus research efforts on the multivariate dynamics of brain data. Cognitive and emotional processes are intrinsically dynamic and interconnected. Emotions do not result from isolated activations of specific brain areas but large-scale network interactions that form functionally integrated systems. A brain dynamics-focused approach might be based on the notion of neural networks of attractors in which activity levels converge toward an equilibrium (Hopfield & Tank, 1986; Yu et al., 2020). Indeed, the brain does not simply react to

sensory stimuli. Sensory signals are incorporated into ongoing processing involving brain and body states, such that the same stimulus exerts very different effects depending on the context. Thus, studying "isolated systems" (e.g., the amygdala alone or with some target areas) is only the first step in understanding emotional processing during complex behaviors. Furthermore, it is suggested that, in evolutionary terms, survival benefits from circuits that can form in a combinatorial fashion because of their flexibility.

From what has been said, it follows that the conception of brain functioning in relation to behavior must partly abandon the idea of hierarchical organization of brain areas and mental functions in favor of a heterarchical conception, shifting the problem towards the understanding of interregional coordination, or how signals from multiple regions evolve collectively (Tognoli & Kelso, 2014). Instead of focusing exclusively on causality as an intrinsic goal of explanations in brain functions, Pessoa proposes a research path in which to develop formal tools that describe and allow the prediction of the multivariate structure of brain data. Unraveling the brain circuits involved in cognition-emotion interactions is essential to understanding cognitive and emotional processes, how they influence behavior, and, above all, designing effective mental health interventions.

Also, developmental psychology has traditionally considered emotional and cognitive development separately (Blankson et al., 2012), and only recently have there been attempts to integrate these processes conceptually (e.g., Dennis, 2010; Blankson et al., 2012). For example, attentional control processes have been hypothesized to influence cognition and emotion across development (Bell, 2012). Attentional control is necessary for resolving conflict between thoughts, feelings, and responses and, therefore, for developing self-regulation of both emotional and cognitive processes (Rueda et al., 2005). Longitudinal data from cognitive and emotional developmental psychology highlight dense interconnections between cognitive maturation, emotional regulation, and psychosocial adjustment (Eisenberg et al., 2010; Zelazo & Carlson, 2012). For example, the benefits of incorporating cognition and emotion into childhood interventions to promote positive

socioemotional functioning have been highlighted (Riggs et al., 2006). As our knowledge advances, we will have more opportunities to predict the development of affective and other disorders and, more generally, improve human well-being and experience.

1.3.Emotional development and emotional meaning

The scientific debate on emotional development's nature and its fundamental characteristics is ongoing. Emotional development generally refers to the ability to develop or regulate and "sculpt" affective states, depending on the reference theory, based on innate, individual, social, and cultural characteristics (Hoemann et al., 2019). Some theories support the idea that all humans have an essential set of basic emotions that are distinguishable by individual biological and behavioral processes (Colombetti, 1995). For instance, Ekman (2003) and Ekman & Friesen (1978) have been very influential with their studies on facial expressions, developing a list of basic emotions that are universal and not culturally determined. At the same time, children learn to experience and perceive emotions in ways specific to their culture, which occurs in the early stages of development (Holodynski & Friedlmeier, 2006).

Emotional development is a key achievement for maturation and involves – among others – the ability to understand and control emotions. The understanding of emotions is the ability to recognize and label one's and others' emotions, connect them to situations, understand their causes, identify the rules of manifestation, and recognize the disparities between external manifestations and experienced emotions (Denham, 1998). In line with the multilevel and multisystemic view of emotions, emotional control involves emotional reactivity and emotion regulation (Thompson et al., 2008). Emotional reactivity is the reaction to emotion and includes subjective feelings, behavioral manifestations, and bodily responses. Emotion regulation involves monitoring and modifying emotional reactions' temporal dynamics and intensity (Thompson, 1994). Therefore, emotion regulation is related to how individuals influence their emotions, such as how they experience them and how they express them

(Gross, 1998; Lavi et al., 2019). Emotion regulation processes can be spontaneous, natural, unintentional, and relatively effortless processes that determine changes in the properties of an emotional response (Gyurak et al., 2011). Difficulties in spontaneous regulation have been positively related to vulnerability to depression (e.g., Ehring et al., 2010) and negatively associated with anxiety levels (Etkin et al., 2010). Also, problems in voluntary emotional regulation are associated with behavioral and mood disorders (Calkins & Keane, 2004; Dennis & Hajcak, 2009). For example, it has been observed that children who have suffered maltreatment show emotional dysregulation both in terms of greater emotional reactivity and in terms of a reduced ability to spontaneously and voluntarily modulate the emotional experience (e.g., Lavi et al., 2019). Although explicit and implicit forms of emotion regulation can be distinguished, they have porous boundaries and are somewhat interconnected. From an evolutionary perspective, emotion regulation represents the intersection between cognitive and affective capacity development and offers a unique opportunity to better understand their interaction (Hajcak et al., 2010).

It is common to find externalizing and internalizing problems of adaptation in association with difficulties in emotional and cognitive processing (Martel et al., 2007). Indeed, longitudinal studies have provided convincing evidence of the relationship between cognitive and emotional maturation and psychosocial adaptation (Cartensen et al.,1999). Cognition is crucial in regulating emotional experiences (Vuilleumier & Driver, 2007). Emotion regulation is supported by cognitive processes such as attention and executive functions (e.g., working memory and inhibitory control). The neurobiological basis of emotional regulation indicates that cortical networks involved in attention and working memory play a fundamental role in emotion regulation and other aspects of motivated behavior (Etkin et al., 2015). A simple strategy to reduce the influence of a negative emotion is attentional avoidance, that is, shifting attention away from the source of distress to something else (Gross, 2015). Another strategy is cognitive reframing and reappraisal, which requires the maintenance of a goal or regulatory model and depends on a working memory circuit that includes

the lateral prefrontal cortex (PFC) and the posterior parietal cortex (PPC) (Rolls, 2013). Indeed, individual differences in working memory capacity have been shown to predict successful reappraisal (Etkin et al., 2015). Emotion and cognition are, therefore, intrinsically linked to physiological and behavioral regulation processes (Lamm et al., 2006). Sometimes, emotion and cognition can be in opposition. For instance, this can happen in particularly emotionally intense moments, and consequently, the ability to control thought and behavior can be lacking (Drevets & Raichle, 1998). However, emotion and cognition are more frequently understood as integrated processes aimed at satisfying individual needs. This does not only apply to positive emotions. From the early stages of development, negative emotions can facilitate cognitive processes, such as attention and learning (Dennis, 2010). Therefore, emotions are adaptive if well-regulated (Frijda, 1986). Based on the overlaps between cognitive and emotional control, these dimensions may fall into a single dimension of control. However, at least in early childhood, these processes could be separate, albeit related. This would be supported by evidence indicating that emotional control emerges earlier than cognitive control during development (Blair, 2002). Furthermore, some evidence indicates that emotional control, at least during development, can be viewed as a construct distinguishable from the constructs of emotional understanding, cognitive control, and cognitive understanding (Blakson et al., 2012; Leerkes et al., 2008). Despite this, it is essential to remember that a better understanding of emotions is positively correlated with emotional regulation capacity (e.g., Wang et al., 2020).

A recent proposal integrates constructed emotion theory with constructivist rationalism to explain how emotional development may overlap with the development of emotion concepts (Hoemann et al., 2019). Rational constructivism postulates fundamental learning mechanisms to explain conceptual development and change. Primitive proto-conceptual representations are modified by learning language and symbols. In addition, Bayesian inductive learning would implement prior knowledge and other information to revise beliefs. Finally, forms of constructive thinking, such as analogy, explanation, and imagination, would allow the formation of new theories (Hoemann et al.,

2019). It is important to emphasize that intersubjectivity is intrinsic to emotional development. For this reason, emotions develop as products of social and cultural reality in which language plays a significant part (Ratner, 1989). Interactions between humans contribute to the development of emotional categories as a form of shared regulation based on maintaining the balance of body systems. In this context, children must learn that various situations involving different bodily sensations and actions can be grouped into the same goal in a context-specific way. This goal can be physiological, concrete, or even psychological. Children learn these categories with the help of words spoken by caregivers and other humans around them. Emotional words are, therefore, a powerful tool for the cultural transmission of emotional concepts.

Furthermore, emotional words are linked to embodied emotion concepts, and learning emotion words, like all words, supports children's ability to impose functional similarities on objects, actions, and events that are perceptually dissimilar. Building semantic and lexical representations of words requires that concepts are associated with words or phrases (Morgan et al., 2020). Interestingly, data in the literature highlight how newborns understand the meaning of some words spoken by caregivers and strangers as early as six months after birth (Bergelson & Swingley, 2018). Learning a new emotional word may be an opportunity to impose higher-order regularities, provided that it is associated with a pattern of sensory and motor changes in a specific situation. Words play an organizational role in thoughts and actions because they support the formation of concepts during childhood (Hoemann et al., 2019). For this reason, studying the processing of emotional words is a fundamental part of the study of affect organization (Briesemeister et al., 2014; Citron, 2012).

In addition, the brain continuously formulates predictive models; this explanation of how the brain works is generally called predictive coding (Clark, 2013). These predictions aim for physiological efficiency, anticipating and preparing the body's needs for action (Wolpert et al., 2013). Therefore, the brain continuously constructs embodied ad hoc concepts to guide action and satisfy contextual and physiological goals (Barret, 2017). Several aspects of emotional concepts are embodied and

culture-specific and change over time as children update their internal model of the body in the world through social learning and language (Hoemann et al., 2019). This approach has the advantage of explaining the improvements observed in children by introducing emotional intelligence training. Indeed, a deeper understanding of emotional concepts and words, focusing on the multifaceted nature of emotional experience, adds flexibility to the child's internal model, allowing for more personalized predictions. Emotional understanding of oneself and others is an essential component of children's social cognition, and the lack of this ability has been implicated in atypical development and problematic behaviors (Dunn, 2005). However, it is unclear how learning emotional concepts would differ from learning other categories of concepts. Investigating whether and how emotional words differ from others and what qualities determine this differentiation is essential. Furthermore, the idea of embodied emotional concepts highlights the need to examine emotional experiences' physiological foundations. Indeed, neuroimaging and physiological research methodologies, including electroencephalography, can provide critical insights into how emotions manifest physically. More generally, psychophysiological research has confirmed that the processing of emotional content causes changes in a wide range of measures, including heart rate and skin conductance (Bradley & Lang, 2000). This issue is not only of academic interest but also has significant implications for mental health treatments, human-computer interaction, and biofeedback technology (Chang, 2024). The interaction between emotions and physiological responses is bidirectional and complex (Quadt et al., 2022). Schachter-Singer suggests that the same physiological response can lead to different emotions, and this would depend both on the characteristics, e.g., the intensity of physiological arousal and the cognitive interpretation of the physiological state (Schachter & Singer, 1962). This suggests that mental processes are integral to the emotion-physiology relationship since the brain's interpretation of bodily states can shape the emotional experience. Scherer (2001) further suggests that the valence of experience depends on how it is interpreted. This would at least partly account for incongruent emotional experiences, where a theoretically negative experience, such as excessive

physical exertion during a demanding workout, can become a positive and rewarding experience. According to Larsen et al. (2017), positive and negative emotions are not necessarily extremes of a continuum but can coexist in an emotional experience. People often tolerate discomfort because they have important long-term goals, and motivation plays a key role. Indeed, human emotions reveal intent and desire, motivating social interactions, empathy, and collaboration. Motivation is commonly defined as the tendency to act to obtain a reward or to avoid punishment. The self-preserving appetitive system determines, for example, the search for food and the care of offspring and is accompanied by pleasant affective states. The protective defense system coordinates withdrawal and defense against nociceptive agents and is associated with the experience of unpleasant affects (Schupp et al., 2006). Emotion and motivation are closely linked concepts, as both depend on the organism's and its environment's relationship. Emotions are action dispositions that prepare the organism for avoidance or approach. The preparation and organization of appropriate behavioral responses require rapid information extraction from the environment. Selective attention mechanisms ensure the priority processing of relevant objects, events, or places. In passive attention, the power to capture attention derives from simple stimulus qualities such as intensity or novelty. In active attention, priority processing reflects the intentional effort to search for selected stimuli based on instructions and intentions. Emotional stimuli direct attentional resources, and motivated attention depends on evolutionary qualities and is, therefore, more evident for stimuli with high evolutionary significance. Pessoa suggests that emotional and motivational signals are integrated with executive functions to effectively incorporate value into behavior development (Pessoa, 2009). Indeed, emotion and motivation can influence decision-making processes by introducing biases in preferences and the overall perception of a given situation (Loewenstein et al., 2001).

The traditional conceptualization of valence (positive/negative) has played a key role in studying emotions but has also introduced some limitations. For example, Russell's (1980) dimensional model has allowed researchers to categorize emotions systematically and make them quantifiable. This has

undoubtedly facilitated scientific research by developing tools such as the Affective Norms for English Words (ANEW; Bradley & Lang, 1999), with important implications for clinical and research practice. At the same time, it has introduced some limitations, such as an excessive simplification of emotions. Emotions are not always clearly positive or negative, as shown by neuroimaging studies in which emotions of different valences are not traceable to positive and negative brain regions (Lindquist et al., 2012). Thus, we can suggest that experiences are not simply "good" or "bad" but result from the interaction of multiple affective, cognitive, and motivational systems.

In summary, emotional development involves the acquisition of key knowledge about affective states and the ability to monitor and control them. Emotional development involves building emotional concepts supported by emotional words, which provide a critical window for studying affective experience. Emotional concepts are embodied concepts, and for this reason, psychophysiology, understood as the study of the bodily manifestations of emotional states in close relationship with mental processes, represents a fundamental complement to accurate research in the field of emotions.

1.4.Electroencephalography (EEG)

Electroencephalography (EEG) is a noninvasive neuroimaging technique that records the brain's electrical activity using electrodes placed in a cap on the scalp. Each electrode is defined with letters representing the area in which it is positioned (e.g., F = frontal; P = parietal), odd numbers for the left electrodes, even numbers for the right ones, and the letter "z" indicates the midline electrodes. The electrodes are positioned according to the international reference system (Jasper, 1958; Xia & Hu, 2019; see **Fig.1**). Typically, electrode impedances should be kept below 10 KΩ to reduce artifacts and have less noise in the recording. The record of each channel involves measuring the active channel, the reference, and the ground electrode. Voltage fluctuations at each electrode site reflect a differential measurement between the active and reference electrodes, amplified and recorded as an EEG trace.

Therefore, the active electrode should be placed where the voltage changes, and the reference should be neutral. However, there is no absolute neutral position, so all recordings are bipolar. It is important to note that EEG data can be re-referenced without loss of information, and a popular reference in the scientific literature involves using the average of all electrodes. Furthermore, dealing with artifacts is essential because they can add significant random variation to the data (e.g., lateral or roving eye movements and muscle tension). Indeed, a central aspect of correctly processing electroencephalographic data concerns their pre-processing. Electroencephalographic data require numerous operations, such as filtering, analysis of independent components (ICA), and rejection of channels and parts of the trace that present anomalous activity peaks.

EEG signal reflects extracellular currents generated by synchronized afferent input to cortical neurons. These neurons are organized in layers whose apical dendrites are oriented perpendicularly to the scalp's surface (primarily pyramidal neurons from layer V) (Luck, 2014; Jackson & Bolger, 2014). The signal (+ or –) of EEG deflections depends on the location (superficial or deep) and type of synapses (excitatory or inhibitory) (Niedermeyer & da Silva, 2005). By synchronizing the signal with a response or external stimulus and averaging it over many trials, it is possible to extract neural activity specifically related to the sensory, motor, or cognitive event that evoked it (Sanei & Chambers, 2022). These signals are called event-related potentials (ERPs; **Fig.2**). Therefore, EEG activity synchronized (time-locked) with the presentation of stimuli may represent sensory processing, selective attention, decision-making, or other cognitive operations. ERPs have a very low voltage compared to the background EEG; that is, they are masked by background activity and noise. Averaging is the key procedure to reduce noise, as the average of random activity tends to zero as the number of repetitions increases (Luck, 2014). Polarity, latency, scalp distribution, and functional aspects define ERP components. For example, the N170 component has a relatively negative polarity and a latency of approximately 170 milliseconds from stimulus presentation. This component probably has the superior temporal gyrus (STS) and the fusiform gyrus as its main generators, and it

is sensitive to structural aspects of faces, including emotions (Rossion & Jacques, 2008). ERPs' latencies, amplitudes, and peaks can vary between populations (e.g., typical and clinical populations). Typically, short-latency components occur within 50 milliseconds and may depend on stimulus properties. Medium-latency components occur within about 250 milliseconds and may represent the effect of stimulus properties on attentional mechanisms. Finally, late components occur after 250–300 milliseconds and are more sensitive to task demands and other cognitive processes (e.g., Luck, 2014).

Fig. 1. International 10–20 System for electrode placement (Adapted from Xia & Hu, 2019)

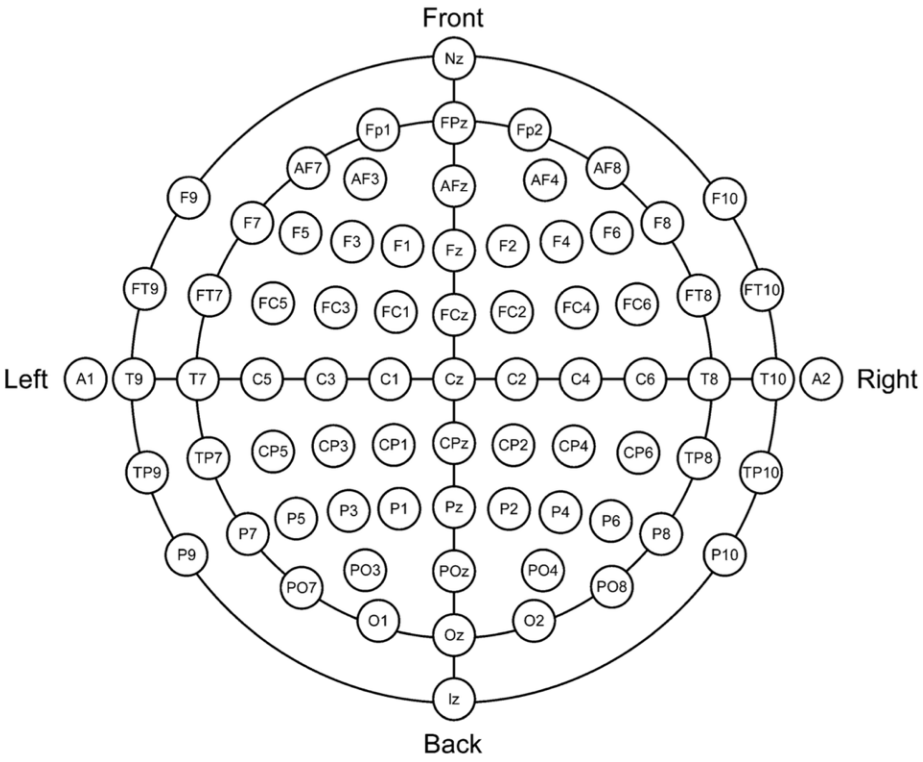
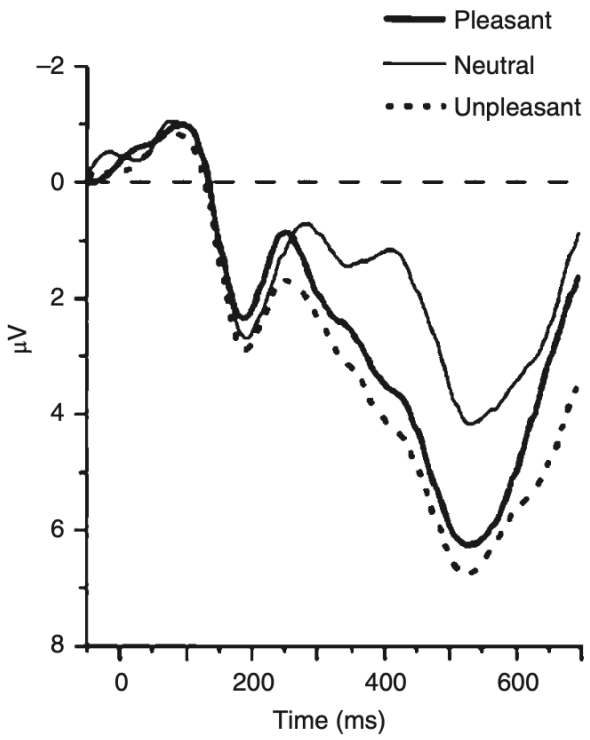


Fig.2. Example of event-related potentials during viewing pleasant, neutral, and unpleasant visual stimuli (Adapted from Sanei & Chambers, 2022)



The spontaneous EEG activity was generally classified according to the frequency bands. Spontaneous EEG activity is divided into five frequency bands: delta (δ, < 4 Hz), theta (θ, 4–8 Hz), alpha (α, 8–13 Hz), beta (β, 13–30 Hz), and gamma (γ, > 30 Hz) (but see also Sanei & Chambers, 2022). With the increased frequency, the EEG rhythms are prone to be characterized with a lower amplitude (Hughes, 1994; Lu & Hu, 2019; **Fig.3**). Different frequency bands have been associated with mental states and functions. For example, the alpha frequency band traditionally indicates a relaxed state without attention or concentration and is maximal in the posterior regions during the resting state with eyes closed (Sanei & Chambers, 2022). When switching from a resting state to an active waking state (e.g., by opening the eyes), the predominance of this frequency band in the posterior regions is reduced or disappears (see our data sample in **Fig.4**).

Fig. 3. Rhythmic EEG activity patterns (Adapted from Lu & Hu, 2019)

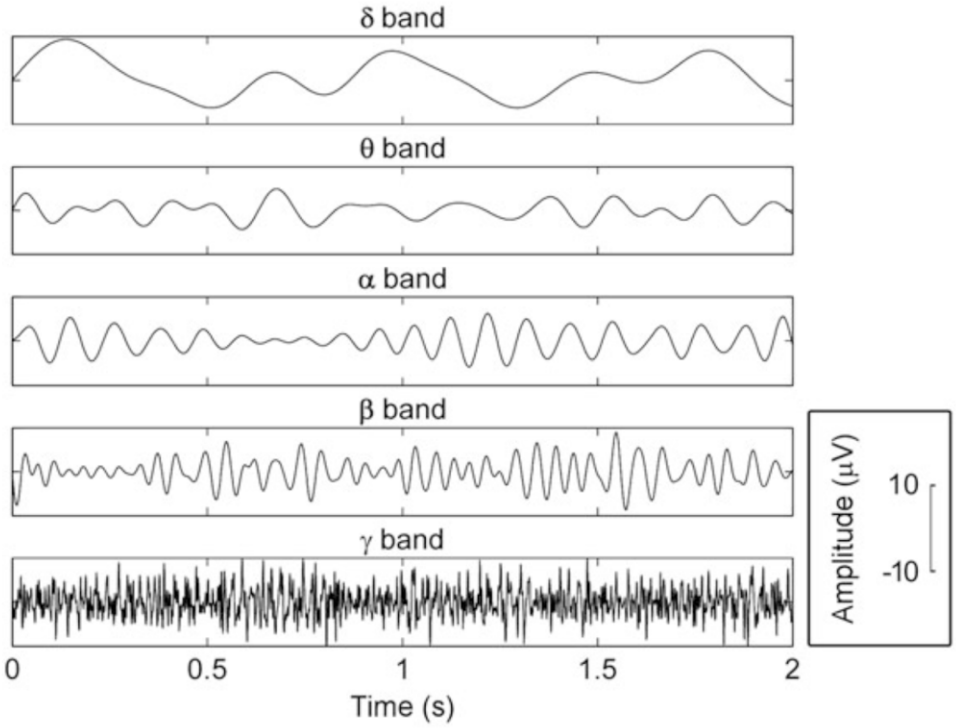
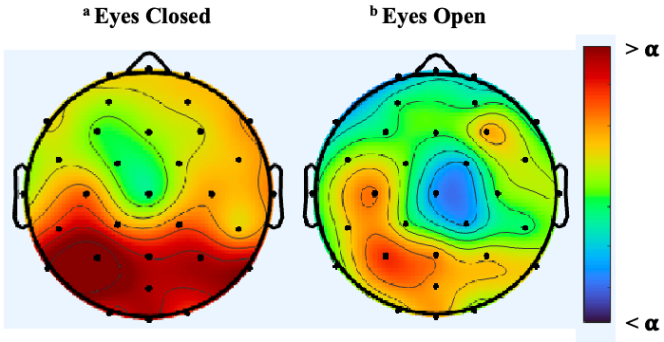


Fig.4. Alpha band power during resting state with a) eyes closed and b) eyes open. Data are extracted from one participant of our studies for illustrative purposes (EEGLAB, v.2024.2.1; MATLAB, v.R2024a).



After almost a hundred years since the first recording of human brain electrical activity (Berger, 1929), today, EEG is an established technique in clinical and research settings supported by the scientific and professional community around the world (Bringas-Vega et al., 2022; Mushtaq et al., 2024). EEG has had a substantial impact on clinical diagnosis: it contributes to the diagnosis of epilepsy and sleep disorders, among others. There are established standards and automated analysis approaches for some clinical applications, and EEG has proven successful for mass screening of brain dysfunction (World Health Organization, 2023). EEG has been widely used to explore fundamental questions in mental processing, including the study of cognition and emotion. In scientific research, EEG has several advantages: i) it measures brain activity directly and non-invasively; ii) it can also be used with neonates and non-communicative populations (e.g., sleep and vegetative states); iii) it has a high temporal resolution (in the order of millisecond); iv) it is a relatively reliable technique; v) it has a relatively low cost; vi) there is a vast knowledge of different EEG components. The disadvantages are: i) the modest spatial resolution and the inverse problem (anatomical localization of activity generators); ii) the need for many trials to extract evoked potentials; iii) the sensitivity to artifacts (e.g., movements); iv) some components overlap; v) long-term recordings can be difficult (especially with special populations and/or children). Integrating EEG with new technologies, including virtual reality and artificial intelligence, holds unprecedented promise for studying and integrating the digital and physical worlds (Suhaimi et al., 2020).

1.5.Event-Related Potentials in Emotional Processing

As highlighted, scientific research can gain several advantages from using ERPs. Several studies have indicated that emotional stimuli automatically capture attention for pleasant and unpleasant stimuli (Bradley et al., 2001). Generally, the hypothesis that emotion directs attention and facilitates subsequent processing has been described as "motivated attention" (Bradley et al., 2003). Emotional

stimuli receive more processing resources, and their facilitated processing was studied by ERP modulations (Hajcak et al., 2010). The amplitude and latency of ERP components provide information about the strength and time course of the underlying neural processes. Emotions influence both early (< 300 ms) and late (> 300 ms) ERP components and these modulations depend on the types of stimuli (e.g., pictures, faces, and words), the task, and the age of the participants (e.g., Skrandies, 2004; Bao et al., 2024). However, it is worth noting that such emotional modulations have been observed more consistently in later ERPs during development (Pegg et al., 2019; Dickey et al., 2021). As mentioned, emotion processing is dynamic, involving both reactivity and regulation and retrieving emotional information. The transition from childhood to adulthood is characterized by a gradual decrease in neural reactivity to emotional stimuli and increased efficiency of attentional systems. The ability to regulate emotions would also show improvements, although ERP research on developmental changes in emotion regulation is still limited, highlighting a critical direction for future research (Dickey et al., 2021). Alterations in emotionality have transdiagnostic implications, underscoring the importance of understanding developmental changes in emotion processing and regulation to advance knowledge of developmental psychopathology (Mathews & MacLeod, 2005). There is compelling evidence that emotion-related ERPs are sensitive to early alterations associated with depression risk (Kujawa & Burkhouse, 2017). EEG studies have generally reported increased amplitudes of ERP components in anxious children, even when they did not differ from typically developing children at the behavioral level (Wauthia et al., 2016). Therefore, ERP data could facilitate early detection of risk for developing psychopathology and inform early intervention and prevention efforts.

An example of an ERP related to emotional experience is error-related negativity (ERN). This negative deflection occurs approximately 100 ms after an incorrect response and represents error processing (Falkenstein et al., 2000). Emotional experience modulates the ERN, and anxious children show a larger ERN, while anxiolytic drugs reduce this amplitude (Johannes et al., 2001; Ladouceur

et al., 2006). The P2 component is an ERP characterized by a positive peak that occurs approximately 200ms after a stimulus is presented (Crowley & Corlain, 2004). Several studies have indicated that the P2 has a distribution fronto-central on the scalp (Schacht & Sommer, 2009; Citron, 2012). This ERP component is generally associated with arousal-related perceptual mechanisms (Kissler et al., 2006), with P2 being larger for emotional words than for neutral ones (e.g., Wang et al., 2019). Another ERP modulated by emotional stimuli compared to neutral ones during different tasks is the early positive negativity (EPN) (Schupp et al., 2006). This component develops between 150 and 300 ms, and highly arousing stimuli elicit a greater negativity than less arousing stimuli of the same valence (Schupp et al., 2004). However, this modulation would not reflect solely emotional arousal but is presumably associated with other perceptual variables. Indeed, the EPN is greater for images of people than for objects and images with an object displayed in the foreground than for more complex scenes (Schupp et al., 2006). A component that has been tested in several studies with emotional words is the N400. The N400 is a relative negativity with a peak around 400 ms after stimulus presentation, larger at centro-parietal sites with a slight bias for the right hemisphere (Kissler et al., 2006; Lau et al., 2008). The N400 is considered to be related both to lexical and semantic processing (Yao et al., 2016) and to information integration during the post-lessical stage (Kutas & Federmeier, 2010), with increasing amplitudes for difficulties in semantic access or integration (Lau et al., 2008). Several studies have indicated that emotional words induce a smaller FN400 (Frontal N400) than neutral words during lexical-decision tasks (Yao et al., 2016; Li & Wang, 2022).

Probably, the most prominent ERP component associated with emotional processing is the Late Positive Potential (LPP). In general, the LPP is more positive for emotional stimuli than neutral ones (Cuthbert et al., 2000) and is reduced by strategies of reappraising emotional stimuli in more neutral terms (Dennis & Hajcak, 2009). LPP reflects attentional processes, indicating facilitated attention toward emotional stimuli, and has been reported as a likely marker for the study of emotional and behavioral dysregulation (Dennis, 2010). Indeed, there is some evidence that LPP may represent a

possible marker of emotional regulation (Hajcak et al., 2014; Hajcak & Foti, 2020). Furthermore, the LPP modulations following emotional stimuli are not necessarily accompanied by improvements or visual perception deterioration (Brown et al., 2012). LPP modulation for emotional stimuli seems relatively stable over time and does not appear to habituate to repeated stimulus presentations (Codispoti et al., 2006). Task relevance also modulates LPP. For example, LPP amplitudes are increased for emotional stimuli relative to neutral ones when task-relevant compared to when they are not (Schupp et al., 2007). Furthermore, Hajcak and colleagues (2006) showed that the amplitude of the LPP may not depend on the difficulty of the task. Consistently, it has been shown that the difficulty of the competing task does not significantly alter the amplitude of the LPP during the viewing of emotional and neutral pictures (Hajcak et al., 2007).

Adults with anxious attachment styles showed greater LPPs for unpleasant images than adults with low scores on attachment anxiety (Ziber et al., 2007). In line with these findings, in a study in which adolescents passively read emotional and neutral words, a significant greater modulation of the LPP was found in adolescents with PTSD compared to control adolescents for socially threatening words (Klein et al., 2019). This finding has been interpreted as an attentional bias towards threatening stimuli in adolescents with PTSD. Indeed, increased focused attention on potentially threatening stimuli is consistently demonstrated for anxiety disorders (Bar-Haim et al., 2007). For example, Shackman et al. (2007) presented emotional visual stimuli to physically abused children and a control group. Compared to controls, abused children showed greater attention to threatening visual emotional cues (faces), as shown by ERP and SCR (Skin conductance response) modulations. In addition, the degree of attention to threatening stimuli was mediated by the relationship between physical abuse and children's reported anxiety. The authors interpreted these results by arguing that extreme emotional experiences may promote vulnerability to anxiety by influencing the development of attentional regulation skills (Shackman et al., 2007). In a recent study, McLean et al. (2020) investigated the relationship between internalizing problems (anxiety and depressive symptoms) and emotional

reactivity measured by LPP. In this work, preschool children passively viewed emotional and neutral pictures while EEG activity was recorded. In addition, the children's mothers completed the Child Behavior Checklist. Results showed that differences in LPP for emotional versus neutral pictures at anterior recording sites within 700 ms of stimuli presentation were associated with internalizing symptoms. The authors concluded that children with greater LPP for emotional pictures may be at greater risk for internalizing problems, potentially due to greater emotional reactivity (McLean et al., 2020).

Although it seems that P2/EPN and LPP modulations in passive viewing contexts are similar, when paying attention to the emotion, effects were observed primarily for the LPP, suggesting that the cognition/attention-emotion interaction changes over time (Schupp et al., 2006). These findings also suggest that some top-down mechanisms (e.g., task relevance) operate together with bottom-up mechanisms of emotional salience. Indeed, modulation of the LPP may depend on both attentional mechanisms and initial appraisals of stimuli, as well as on emotional reappraisal instructions and previously learned information (Hajcak et al., 2010). However, it is important to highlight that LPP could more generally reflect the significance of the stimulus in appetitive and aversive motivational terms. In this regard, Bradley (2009) discusses how LPP could be a neural response that generally indicates the significance of stimuli detected in the environment. For instance, LPP has been examined in response to several stimuli, such as drug-related stimuli (e.g., Franken et al., 2008). An increased LPP response to drug-related stimuli was observed in cocaine abusers, and LPP amplitude predicted cocaine craving. Consistent with motivational theory, LPP is more positive for one's face and name, for the faces of one's relatives, and for the face of one's partner (Tacikowski & Nowicka, 2010; Grasso & Simons, 2011; Burdwood & Simons, 2016). Although these studies broaden the understanding of the LPP, they cannot assess its discriminant validity, and further studies are needed to define the LPP more precisely.

The nature of developmental changes in EEG components can hardly be considered linear and may vary between ERPs and experimental contexts. For example, ERN amplitudes may increase with age (Davies et al., 2004) and decrease in older adults (Mathewson et al., 2005). The increased LPP positivity for emotional stimuli increases from childhood to adolescence (Chronaki et al., 2018) and decreases from adolescence to adulthood (Deng et al., 2019). Adolescents have higher LPP positivity than adults, regardless of emotional conditions (Bondy et al., 2018). Furthermore, the distribution of EEG activity on the scalp and the putative neural sources of ERPs changes with age (Dennis, 2010; Skrandies, 2014). In particular, the topographical distribution of the LPP in early and middle childhood is more diffuse across the time course of processing, with more positive LPPs at posterior, central, and anterior sites (Hua et al., 2014; Solomon et al., 2012). These differences in ERP distribution may be partly driven by still-developing reciprocal projections between subcortical and prefrontal regions. Subcortical limbic regions develop nonlinearly, while prefrontal areas tend to grow in a linear pattern that continues into early adulthood. Thus, potential asymmetries in the developmental trajectories of cortical and subcortical regions could contribute to the discrepant findings for ERPs from childhood to adolescence (Dickey et al., 2021). However, studies in the literature have overlooked crucial issues and specific populations. For example, studies on children with emotional stimuli have focused primarily on faces and pictures, neglecting emotional words (Yeh et al., 2023).

A recent study by Bao and colleagues (2024) using emotional and neutral words in cohorts of young adults and older adults showed how emotional words modulate ERPs differently between these populations. LPP modulations were observed during a lexical decision and an emotional categorization task. For the emotional categorization task, authors found modulations in the P2 and LPP in young adults, while in older adults, they found only LPP modulations between around 550 and 700 ms (Bao et al., 2024). In a study with children/adolescents, Skrandies (2014) analyzed the electrophysiological correlates of the connotative meaning of words defined by semantic differential

on three dimensions: "evaluation," "power," and "activity." The authors reported modulations in very early time windows around 100 - 200 ms that depended on the semantic class of the word. These results contrast with those previously reported and must be interpreted cautiously. First, evidence supports that very early ERP components do not differentiate emotional and neutral words in implicit and explicit tasks on emotional words (i.e., distinguishing the orientation of lines superimposed on words, indicating the type of word, indicating its emotional content; Schindler et al., 2020). Second, the experimental task was quite different and requires the memorization of the words presented. Finally, the participants (N=19) had significant age differences (11 - 15 years). In another study conducted on adolescents and adults, Yeh and collaborators (2023) investigated the EEG correlates of the processing of emotional words differentiated by valence and divided into emotion-labeling words (e.g., sadness) and emotion-laden words (e.g., gift) in a valence categorization task. The authors observed a modulation of the late positive potential (LPP), with more positive responses for emotion-label words than emotion-laden words and a more positive LPP for adolescents than adults. Both adolescents and adults showed a greater LPP modulation for negative versus positive valence words. The unbalanced modulation between the two valences has been attributed to the enhanced processing of negatively emotionally labeled words. The results could be explained by the density hypothesis, which suggests that positive valence has more similar characteristics (higher density) for emotional concepts than negative valence (Unkelbach et al., 2008). Furthermore, emotion-labeled words may reactivate emotional states from nonspecific and multiple memories. In contrast, emotion-laden words may activate a given event or object with specific contexts (Yeh et al., 2023). The latest results support the differential effects of negative and positive valence in ERP modulations for emotional stimuli. This aspect may have significant repercussions, particularly concerning clinical research. Indeed, studies on child psychopathology reflect the different ERP modulations by valence, with differences for internalizing/externalizing disorders and between different types of disorders (Chronaki, 2016).

In summary, although both early and late ERPs show sensitivity to emotional versus neutral stimuli, the effects are more consistent in late ERPs, such as the LPP. ERP data support that development from childhood to adulthood is characterized by overall decreases in neural reactivity to emotional stimuli and increased efficiency of emotion processing. Similarly, greater emotional regulation abilities would emerge with age. Studying LPP modulations reactively and as functions of regulatory instructions could be particularly fruitful for clinical research. ERP research could benefit from a careful analysis of the relationships with behavioral and self-reported data and the combination with other physiological and electrophysiological measures (i.e., frequency bands). An example could be the study of the association between LPP modulations and EEG frontal asymmetry, which have been shown to index affective style.

1.6.Cognition and Emotion: Resting-state EEG

EEG allows the continuous measurement of the brain's electrical activity, which can be expressed in electrocortical rhythms (Buzsáki et al., 2012). A technique used throughout life with typical and atypical populations involves measuring EEG activity during resting states (Anderson & Perone, 2018). In particular, the activity is measured in multiple sessions or in the same ones that alternate a resting state with eyes closed and eyes open (observing a fixation cross) without the participants performing any cognitive task. The study of the EEG at rest allows to investigate the synchronized activity of neurons through the study of the power of the frequency bands (Buzsáki, 2006). The power can be absolute (for example, for intervals 8-13 Hz – alpha) or relative to other frequency bands (for example, 8-13/1-50 Hz). The duration of resting EEG sessions and the length of EEG segments used in analyses vary widely, from a handful of seconds (Tomalski et al., 2013) to a few minutes (Benasich et al., 2008). It is important to note that indicating brain activity as resting can be partly misleading. Indeed, most of the brain's energy consumption can be attributed to spontaneous activity similar to

that at rest (Raichle & Mintun, 2006; Zhang et al., 2019). However, the functional significance of networks active at rest remains partly elusive (Anderson & Perone, 2018). The analysis of resting EEG can provide important information on individual developmental dynamics, which is underlined by changes in frequency power during brain maturation. For example, EEG studies on brain maturation have shown that beta and alpha activity increases as children grow, and delta and theta activity decreases (Clarke et al., 2001). Changes in neural patterns shown in resting EEG data from childhood to adulthood may be related to synaptic pruning, incomplete myelination, and expanding connectivity during development (Kaminska et al., 2019). For example, Whitford et al. (2007) showed that resting EEG power was related to gray matter volume in corresponding brain regions. Changes in the resting theta band have also been associated with language abilities in children, showing that maturation (decrease) of theta oscillations is positively related to children's language abilities (Lum et al., 2022). Frequency band estimation is also the basis for calculating several indices related to cognitive and emotional aspects. Some studies (e.g., Perone et al., 2018; Clarke et al., 2019) have linked individual slow /fast wave ratio (e.g., theta/beta ratio - TBR) to individual performance in tasks involving executive functions. Indeed, a high TBR is considered to reveal poor top-down control over bottom-up processes (Putman et al., 2014). In contrast, low TBR levels, especially frontal, have been associated with better executive function abilities (Perone et al., 2018). Consistent with Marshall et al. (2004) – who showed that institutionalized children presented high theta levels and low beta levels – Audet & La Mare (2011) showed that socially deprived orphans had higher levels of inattention and hyperactivity. These observations support the notion that everyday experiences during childhood have a considerable impact on brain development. Even risk factors such as preterm birth have been associated with higher slow-wave powers independent of socioeconomic status during childhood (Harmony et al., 1990). However, little is known about what links resting-state brain activity to cognitive performance or how everyday experiences, such as parent-child interactions, might impact brain maturation, as reflected in frequency bands. Perhaps the

most fruitful use of TBR has been concerning ADHD research. Indeed, children with ADHD have increased slow-wave activity and reduced beta activity (Clarke et al., 2011). Thus, a high TBR ratio is considered a marker of ADHD (Clarke et al., 2003; see also Arns et al., 2011). Given the characteristic hyperarousal present in ADHD, it has been hypothesized that TBR reflects cortical arousal. However, subsequent research has reported that this association is imprecise. Indeed, in a study by Barry et al. (2004), TBR did not correlate with electrodermal activity, a measure of central nervous system arousal. Instead, subsequent work has emphasized a link between alpha and central nervous system arousal (Barry et al., 2005). Higher levels of alpha reflect a state of low cortical arousal and decreased attention (Klimesch, 2007).

Strong evidence for an association between TBR and cognitive functions comes from studies correlating frequency bands with known ERP components (e.g., Nakao et al., 2013). Clarke et al. (2019) correlated TBR with P300 amplitude and latency. In general, participants with better performance in cognitive tasks also had shorter P300 latencies, while amplitude was more influenced by energetic factors associated with the task situation (Donchin, 1981). The authors found a positive correlation between P300 latency and TBR but no correlation between TBR and P300 amplitude. The interpretation of these results points to rethinking TBR as an index of central nervous system processing (Clarke et al., 2019). However, central nervous system processing is a rather broad concept encompassing several aspects of brain functioning and will require further investigation. Furthermore, it has been observed that the frontal slow/fast wave ratio may reflect the top-down frontal cortical regulation of subcortical affective approach drive (Putman et al., 2010). Indeed, higher TBR over the frontal area has been associated with weaker inhibitory control on emotional faces and a motivational imbalance between reward and punishment in the Iowa Gambling Task (Schutter & Van Honk, 2005; Putman et al., 2010). Therefore, TBR has also been suggested as informative of affective experience and regulation (Zhang et al., 2019). Although the two proposed positions (TBR as a measure of the central nervous system processing capacity and TBR as an indicator of affective

experience) might seem contradictory, it is still possible to reconcile them from the perspective of the interaction between cognition and emotion. In this regard, we have already reported how better cognitive abilities determine better emotional regulation and emotions, if well-regulated, are essential for efficient cognitive functioning.

A second relevant index of resting EEG activity is frontal alpha asymmetry (FAA), considered a measure of affective style and/or a trait indexing motivational tendency to approach or withdraw from positive and negative emotions (Davidson, 1998; 2004; Lopez-Duran et al., 2012). The observation underlying the study of FAA is that alpha power is inversely proportional to brain activity (Im et al., 2022). Typically, FAA is calculated by subtracting the natural logarithm of left hemisphere alpha power from right hemisphere alpha power; therefore, higher FAA scores indicate more activation in the left hemisphere. Relative left frontal activity is associated with an approach to positive emotions, and relative right frontal activity with withdrawal from negative emotions (Wang et al., 2020). Approach to positive emotions and withdrawal from negative emotions are the outcomes of spontaneous emotion regulation. Indeed, several studies indicate that resting FAA is associated with spontaneous emotion regulation (Harmon-Jones & Gable, 2018; Perone & Vaughan, 2024). In line with this perspective, reduced left frontal EEG activity is observed in depression (Thibodeau et al., 2006), and direct manipulation of the left prefrontal cortex, for example via transcranial magnetic stimulation (excitatory rTMS), reduces depressive symptoms (O'Reardon et al., 2007). Consistently, a recent study (Im et al., 2022) showed that trauma-exposed children and adolescents had more negative FAA than non-trauma-exposed children and adolescents, consistent with studies in adults (Mayer et al., 2015). Thus, these findings suggest that trauma-exposed children may experience higher levels of baseline physiological arousal than those without trauma exposure, providing preliminary psychophysiological evidence that early trauma exposure may be associated with increased cortical activity in the right hemisphere, indicative of greater trait-level avoidance (Im et al., 2022). Furthermore, Perchtold et al. (2019) showed that greater paranoia proneness was associated

with less left-lateralized activation, as measured by FAA. In this case, FAA was measured during attempts to invent alternative appraisals for anger-evoking interpersonal situations. The authors reported that greater right-lateralized activity during cognitive reappraisal efforts might impair individuals' ability to develop effective alternative interpretations for anger-evoking interpersonal situations, and this impaired ability may partly contribute to greater paranoid ideation (Perchtold et al., 2019).

In summary, TBR and FAA are considered informative measures regarding cognitive and emotional aspects. FAA seems to more robustly reflect emotional regulation and motivational characteristics, while TBR seems more related to cognitive abilities. However, as we have previously reported, cognition strongly influences emotional processes and vice versa. Therefore, further studies considering how emotion and cognition influence each other are needed to clarify how TBR and FAA may reflect on behavior.

Chapter 2

2. The integration of emotions into reading processes: EEG correlates in children

2.1.Background

Emotions are a fundamental part of everyday contexts, and they are crucial for the adaptive challenges necessary to select appropriate behaviors in a social environment (Battaglia et al., 2021). It is well-documented that emotions profoundly affect cognitive functions (Pessoa, 2009; Tyng et al., 2017). The scientific literature often reports that emotions can be detrimental to cognition (De Houwer & Tibboel, 2010; Padmala et al., 2011). However, emotions can also improve various aspects of cognition and behavior, demonstrating the complex influence of emotions on different cognitive processes (Pessoa et al., 2012; Dolcos et al., 2017). Gray and colleagues (2002) argued that cognition and emotion are highly integrated, becoming inseparable during information processing (Gray, 2004; Gray et al., 2002). These observations highlight the critical importance of associating emotions and cognition during experimental studies (Kauschke et al., 2019).

In psychological sciences, emotions are mainly studied by categorizing them (e.g., sadness, happiness) or searching for dimensions underlying emotional processes (Russell, 2009). The first approach seeks to understand, for example, the effect of a specific emotion on a behavioral aspect and/or adaptive functioning (William & DeSteno, 2008). Regarding the second approach, although several models have been proposed (e.g., Yani-de-Soriano & Foxall, 2006; Imbir et al., 2019), it is often reported that valence and arousal are the dimensions that explain most of the variance in emotional reactions to stimuli (Lang et al., 1997; Russell, 2003). Several electroencephalographic (EEG) studies have reported modulations of brain activity (event-related potentials – ERPs) by experimentally controlling the emotional content of stimuli – for example, words - during cognitive tasks (Wang et al., 2019; Bao et al., 2024) with partly contrasting results (Yao et al., 2016). With their high temporal resolution, ERPs are appropriate for studying the temporal dynamics of processes

involved in processing emotional words. Indeed, several works showed that the ERP effects of emotional words are evoked by controlling valence and arousal (Citron, 2012; Citron et al., 2013).

Traditionally, word processing has been divided into two main phases: lexical and post-lexical (Seidenberg et al., 1992; Bao et al., 2024). Lexical processing is a fast and automatic word recognition process in which orthographic input is associated with mental lexical representations to access syntactic and semantic information of words. In contrast, post-lexical processing is a slower and more controlled process that combines word information with contextual knowledge – to make decisions based on task demands (Coronel & Federmeier, 2014). It is important to note that previous ERP studies have shown that the emotional features of words influence both the lexical and post-lexical phases during word processing (Citron, 2012; Ku et al., 2020). The lexical phase is associated with earlier ERP components (i.e., P2/EPN), while the post-lexical phase is related to later components (i.e., LPC, LPP). In addition to lexical and post-lexical phases, word processing during reading involves a pre-lexical phase (Jończyk, 2016). Very early processes (within 200 ms of stimulus onset) can be influenced by visual or graphic features of verbal stimuli and are, therefore, much less interesting in studies of emotional word processing (Imbir et al., 2019). However, modulations in very early ERP components (e.g., P1, N1) have been observed in experimental tasks using emotional words, with larger amplitudes for emotional words than for neutral words (e.g., Hofmann et al., 2009; Bayer et al., 2018). Although emotions influence both early (< 300 ms) and late (> 300 ms) ERP components, these modulations depend – among others - on the task and the age of the participants (e.g., Skrandies, 2004; Bao et al., 2024). In addition, it is worth noting that emotional modulations have been observed more consistently in later ERP components (Pegg et al., 2019; Dickey et al., 2021; Schindler et al., 2023).

In a recent work by Bao et al. (2024), ERP modulations for emotional words were investigated in young and older adults. The authors used an implicit task (lexical decision) and an explicit task (emotional categorization). The results showed different effects in relation to the age group of the

participants and concerning the task investigated. The P2, N400, and LPP modulations were observed in the lexical decision task for the young adult group. As expected, nonwords produced a more negative N400 than words, while P2 was more positive for emotional than neutral words. In contrast, the LPP was more positive for neutral than emotional words. The older adult group also showed a more negative modulation of the N400 for nonwords than for words. Furthermore, emotional words produced more negative amplitudes than neutral words for both the N400 and the LPP. As for the emotional categorization task, the authors observed different effects in the two different age groups. The young adult group showed a modulation of P2 and LPP (more positive) for emotional words compared to non-emotional words. The older adult group only showed a more positive LPP for emotional words than neutral words.

First, the fact that participants of different age groups produced different results is not surprising since, as already highlighted, there are significant changes in electroencephalographic correlates with age (e.g., Chronaki et al., 2018; Deng et al., 2019). Also, the fact that implicit and explicit tasks produced different results is unsurprising. While explicit emotional tasks involve categorizing stimuli by valence (e.g., neutral vs. emotional), implicit emotional tasks require categorizations unrelated to the emotional content of the words, such as the lexical decision (words/nonwords) of the presented stimuli. It is important to underline that goal-oriented top-down mechanisms influence explicit tasks. Therefore, in these tasks, participants consciously evaluate the emotional content, which implies using greater attentional resources to be directed toward emotional stimuli (Delaney-Busch et al., 2016). Differently, in implicit tasks, bottom-up effects are mainly involved, for which the processing of the emotional features of words is more automatic and less dependent on the task at hand (Citron, 2012). Therefore, explicit tasks require greater cognitive resources for processing emotional words and a deeper processing of emotional features. Based on this, a less positive LPP in the lexical decision task for emotional words compared to neutral words implies a simpler integration of the information necessary to solve the task, facilitated by the implicit processing of the emotional valence

of words. Differently, a more positive LPP for the emotional categorization task suggests a more elaborate processing of emotional words than neutral words about the task. This is supported by a centro-parietal distribution of the LPP for the implicit task and a more fronto-central distribution for the explicit one (Bao et al., 2024).

2.2.The current study: aims and hypothesis

Our study aimed to investigate the ERP correlates of emotional word processing in primary school children. Children completed an emotional word categorization task in which they had to explicitly indicate the valence of the words (neutral vs. emotional). Using the high temporal resolution of ERPs, we aim to investigate the emotional effects of reading and categorizing emotional words with respect to neutral ones in children. Although studies in the literature report a consistent modulation of late ERPs for emotional stimuli compared to neutral ones (such as a more positive LPP due to a greater engagement of attentional processes towards emotional stimuli), we also noted the lack of studies that have investigated the electrophysiological correlates during the presentation of emotional words in children (Yeh et al., 2023). For this reason, we decided to opt for a data-driven statistical analysis (see the Statistical Analysis paragraph). A second aim was to investigate the reaction times of responses to words in the experimental conditions. We hypothesized an emotional effect with shorter reaction times for emotional words than neutral ones. Indeed, general effects of emotionality as a processing advantage for emotional compared to neutral information have been shown for various stimuli, including words (Yap & Seow, 2013; Goh et al., 2016). The explanation for these biases should be understood in an evolutionary framework since quickly paying attention to emotional stimuli is essential for survival (Baumeister et al., 2001; Vaish et al., 2008).

2.3.Method

2.3.1. Participants

A total of 20 children (9 females, 11 males) aged between 7 and 9 (mean = 8.4; standard deviation = 0.68) participated in recordings of EEG. Data from 5 participants were excluded from the analyses due to insufficient valid epochs. Therefore, the final sample consisted of 15 participants (6 females, 9 males; mean age = 8.6; standard deviation = 0.50). The participants were healthy (no history of neurological or psychiatric problems) and had normal visual function. The use of psychoactive medication at the time of testing or in the twelve months prior to testing was also an exclusion criterion. The inclusion/exclusion criteria were screened via interviews with teachers and parents. Additionally, children completed the One Minute Reading Test (OMRT; Sartori et al., 1995) to check for reading problems (mean = 69.4; standard deviation = 7.93).

None of the children had a diagnosis of dyslexia or other learning disabilities at the time of the experiment. All children had Italian as their first language and regularly attended schools. All parents gave written informed consent, and all children gave oral consent during the experiment. This study procedures were approved by the Ethics Committee of the University of Foggia and met the ethical standards of the 1964 Declaration of Helsinki (World Health Organization, 2013).

2.3.2. Materials

We selected 50 words (25 neutral and 25 emotional words) from the Italian adaptation of the Affective Norms for English Words (ANEW) (Montefinese et al., 2014; Montefinese et al., 2013; Bradley & Lang, 1999). From this database, we extracted the average affective assessment of the words (9-point Likert scale) of both valence (from 1 – very unpleasant, to 9 – very pleasant) and arousal (from 1 – very calm, to 9 – very aroused). Furthermore, we extracted the subjective indices of the words (9-point Likert scale) of familiarity (from 1 – unfamiliar, to 9 – very familiar), imageability (from 1 –

unimaginable, to 9 – very imaginable), and concreteness (from 1 – abstract, to 9 – very concrete). All the words used are in the Elementary Lexicon database used to extract the word frequency (Marconi et al., 1993). It is important to report that the ratings of emotional words were obtained from a large sample of young Italian university students (Montefinese et al., 2014). Indeed, an Italian database of emotional words validated in children does not exist. However, Sylvester et al. (2016), using the BAWL (Berlin Affective Wordlist), showed that children between the ages of 6 and 12 process affective lexical semantics similarly to adults (Sylvester et al., 2016). Word lists were assembled by empirically maximizing differences among the emotional dimensions under study (valence and arousal; *affective/subjective indexes*) and by balancing the lists across categories of the main linguistic variables (frequency, length, orthographic neighbors, mean frequency of orthographic neighbors, contextual rules, doubles, consonant clusters, bigram frequency; *objective indexes*) and the main *subjective indexes* (familiarity, imageability, concreteness; see **Table 1** – Subjective and Objective indexes of neutral and emotional words used in the experiment).

Table 1. Subjective and Objective indexes (mean and standard deviation) of neutral and emotional words used in the experiment.

	Neutral (SD)	**Emotional** (SD)
Valence	5.16 (0.26)	5.17 (2.44)
Arousal	4.52 (0.32)	6.13 (0.33)
Familiarity	7.37 (0.75)	7.34 (0.94)
Imageability	8.01 (0.43)	8.06 (0.50)
Concreteness	8.04 (0.49)	7.82 (0.66)
Frequency	53.08 (49.26)	62.80 (65.36)
Length	6.68 (1.65)	6.36 (1.58)
Number of Orthographic Neighbors	5.20 (5.48)	4.88 (4.19)
Mean Frequency of Orthographic Neighbors	13.94 (20.66)	11.57 (15.99)
Contextual Rules	0.56 (0.77)	0.52 (0.65)
Doubles	0.44 (0.65)	0.20 (0.41)
Consonant Clusters	0.52 (0.59)	0.56 (0.65)
Bigram Frequency	9.50 (0.43)	9.37 (0.55)

The words were predominantly nouns (24 nouns and 1 adjective for both neutral and emotional words), and most were paroxytone (21 paroxytones and 4 proparoxytones for neutral words; 23 paroxytones and 2 proparoxytones for emotional words). Neutral and emotional words had similar valence (mean valence neutral words = 5.17, standard deviation = 0.2; mean valence emotional words = 5.16, standard deviation = 2.4). The neutral words had valences between 4.5 and 5.5, while the emotional words had valences between 2.2 and 8.6 (14 negative words between 2.29 to 3.91, and 11 positive words between 6.70 to 8.60), but none of the emotional words had valences between 4 and 6. Intermediate valence values indicate that a word has been classified as neither positive nor negative.

Words differed in arousal ($t = -17.484$; $p < 0.001$), with neutral words having an arousal ranging from 3.61 to 4.94 (mean = 4.52; standard deviation = 0.31), while emotional words had an arousal ranging from 5.57 to 6.88 (mean = 6.13; standard deviation = 0.33). ANCOVA with arousal as the dependent variable, the category of the words (emotional or neutral) as a fixed factor, and the objective and subjective indexes of the words as covariates also showed a significant difference in arousal for the category of words ($F_{1,37} = 234.537$; $p<0.001$). On the contrary, no significant effects were found for familiarity ($F_{1,37} = 0.089$; $p = 0.767$), imageability ($F_{1,37} = 1.945$; $p = 0.171$), concreteness ($F_{1,37} = 0.280$; $p = 0.600$), frequency ($F_{1,37} = 0.923$; $p = 0.343$), length ($F_{1,37} = 0.954$; $p = 0.335$), orthographic neighbors ($F_{1,37} = 1.017$; $p = 0.320$), mean frequency of orthographic neighbors ($F_{1,37} = 1.281$; $p = 0.265$), contextual rules ($F_{1,37} = 1.224$; $p = 0.276$), doubles ($F_{1,37} = 0.148$; $p = 0.702$), consonant clusters ($F_{1,37} = 0.483$; $p = 0.491$), and bigram frequency ($F_{1,37} = 0.224$; $p = 0.639$).

2.3.3. Procedure

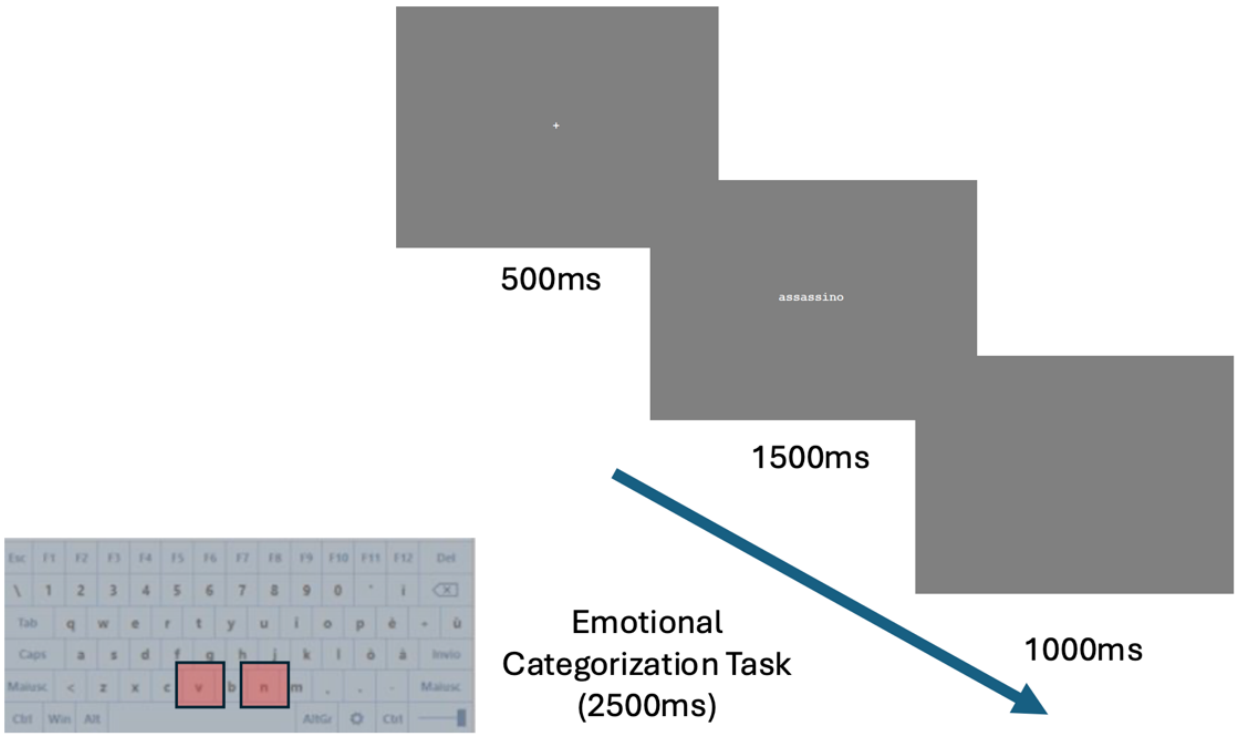
The children were recruited in collaboration with school offices. Each school institute involved in the project signed a bilateral agreement with the University of Foggia, thus formally regulating the research personnel and instrumentation admitted to the institute, the activities included in the

agreement, and the persons responsible. After the agreement signature, the project was presented in detail to the teachers of the classrooms involved to explain the procedure of the project deeply and agree with them about the scholastic timing to dedicate to the experimental sessions and the modalities of distribution of written informed consent to the parents. Participants and their parents received written information about the study goals, experimental procedures, and confidentiality. Parents were asked to provide written informed consent, and minors provided oral assent to participate in the study. Before the experimental session, a licensed psychologist ensured the children were willing to carry out the tasks and calm when facing the experiment. The school institute provided an adequate space for the experiment sessions.

This study involved administering an emotional word categorization task to a group of primary school children during EEG recording. The task involves presenting 50 words divided into neutral words (25 words) and emotional words (25 words). Participants had to indicate whether the words were neutral or emotional by pressing two keys on the keyboard (V, N). The keys to indicate the categories of the words were randomized among participants. Each trial had a total duration of 3000 ms and involved the presentation of a fixation cross (500 ms), followed by the emotional or neutral word (1500 ms), followed by a black screen (1000 ms). Participants had a maximum of 2500 ms to indicate the word's valence. The task was administered to the computer via E-prime (Version 3.0.3.31). The children sat in a quiet room in front of a 14-inch screen at a distance of 60 cm. They were asked to concentrate on the tasks while avoiding eye movements, blinking, and unnecessary movements. The words were presented at the center in non-capitalized, white letters on a black background (see **Fig. 5** – Illustration of a Single Experimental Trial). Words are presented in a pseudo-randomized order, avoiding the same category of stimuli being presented for more than two consecutive trials. The stimuli were presented in a single block, preceded by a practice block of five training trials. The duration of the task was approximately five minutes. EEG activity is recorded during the task, and reaction times and accuracy are measured.

In addition to recommendations for ERP studies (e.g., Keil et al., 2014; Picton et al., 2000; Maby, 2016), we followed the recommendations reported by Brooker et al. (2020) for EEG data collection in children (Brooker et al., 2020).

Fig. 5. Illustration of a Single Experimental Trial

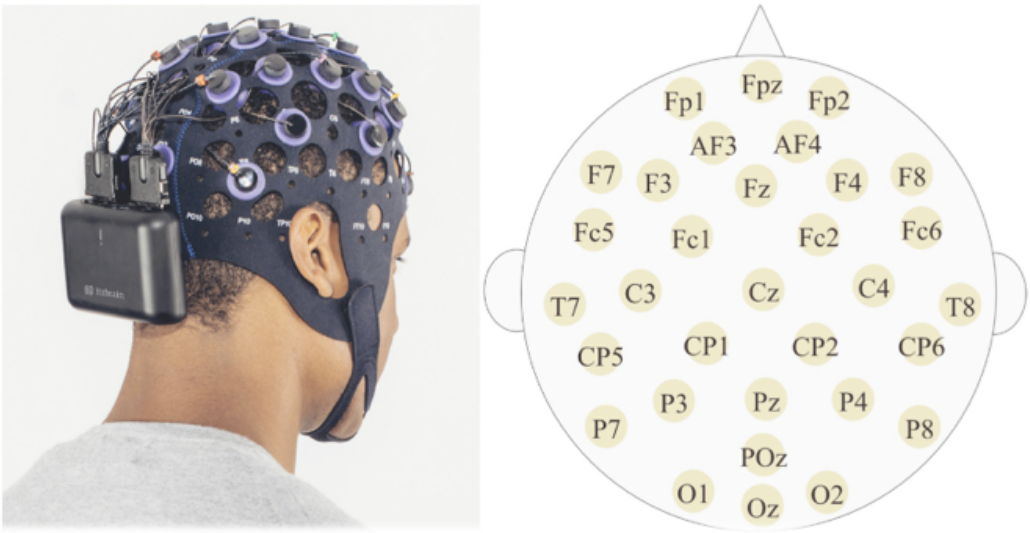


2.3.4. EEG recordings and preprocessing

The electroencephalogram was recorded with the EEG-32-Versatile™ system (Bitbrain, Spain; see **Fig. 6** – BitBrain EEG-32 channels). This system uses 32 water-based electrodes (i.e., humid sponges) placed on an electrode cap arranged in the 10 to 20 system (Homan et al., 1987; Acharya et al., 2016).

For reference, we used the left earlobe and the channel AFz for the ground. All data was streamed via Bluetooth to the computational unit using Bitbrain proprietary software and backed up to an internal SD card to avoid data loss due to the wireless connection. The signals were recorded using a sampling frequency of 256 Hz with a resolution of 64 bits. During the recordings, the skin-sensor impedance was kept in the appropriate range through the real-time impedance monitoring feature of the acquisition software. The EEG signal was preprocessed using the EEGLAB toolbox (version 2024.2.1; Delorme & Makeig, 2004) on the MATLAB platform (version R2024a).

Fig. 6. BitBrain EEG-32 channels.



The data were filtered with 0.5 - 30 Hz bandpass filters (Zhang et al., 2023; 2024) and cleaned using the EEGLAB Clean Raw Data plugin (Klug et al., 2022; Megías et al., 2018; Piazza et al., 2016). The rejected channels by Clean Raw Data software were reconstructed using the spherical interpolation method (Perrin et al., 1989). Participants with more than three channels removed were excluded from analyses. Independent component analysis (ICA) was performed using FastICA (Hyvarinen, 2009;

Hyvarinen & Oja, 1997) and ICLabel (Pion-Tanachini et al., 2019; Pernet et al., 2021) in EEGLAB to correct artifacts (e.g. blinks and eye movements) (Gramann, 2024). We then re-referenced the EEG data using the averaging method (Picton et al., 2000; Marshall et al., 2002; Perez-Edgar & Fox, 2003). Epochs were segmented from 100 ms before to 1000 ms after the onset of the stimuli and were rejected if they contained an artifact signal below/above ±100 μV. The number of valid epochs was calculated for each participant and experimental condition. Participants with at least 10 valid epochs per condition were included in the analyses (e.g., Brooker et al., 2020; Ralph et al., 2020). This process resulted in the exclusion of 5 participants, for a total of 15 participants included in the analyses. Finally, epochs of EEG data in the same condition and each electrode for every participant were averaged to obtain a stable ERP waveform, with baseline correction from 100 to 0 ms preceding the onset of the target stimuli.

2.3.5. Statistical analysis

We analyzed the effect of emotionality on reaction times and the accuracy rate between conditions using paired t-tests. Given the lack of EEG studies using emotional words in primary school children (Yeh et al., 2023), we decided to implement a data-driven analysis via ANOVA in EEGLAB with permutation statistics ($p < 0.05$) and False Rate Discovery (FDR) correction considering all electrodes and the entire epoch, with the type of words (emotional, neutral) as within factor. The data-driven approach involves performing a large number of comparisons with corrections for multiple comparisons to remove or mitigate the increased likelihood of false discoveries inherent in performing many tests. Although this approach may result in the loss of some statistical power, it is particularly useful and appropriate with ERP data, especially when there are few a priori hypotheses (Maris & Oostenveld, 2007; Groppe et al., 2011). Permutation testing is similar to parametric hypothesis testing, except that permutation testing uses a distribution derived from permuting

observed scores, whereas parametric tests assume that the population has a specific distribution (e.g., normal). Although ERPs are likely to be sufficiently normally distributed, a nonparametric test provides extra assurance, especially when the number of participants is small (Groppe et al., 2011). As a general rule, Manly (1997) suggests using 1000 permutations for an alpha level of 5%. FDR-based correction is a powerful method for correcting for multiple comparisons. The FDR correction procedure is comparable to the Bonferroni correction in highlighting effects in the data. This is especially true if the FDR procedure rejects hypotheses using conventionally low alpha levels (i.e., 5%); in these cases, false discoveries are much lower than correct rejections (Groppe et al., 2011). After identifying the electrodes that were significantly different between the emotional and neutral word conditions with the first analysis reported above, we implemented a point-by-point analysis with permutation statistics ($p < 0.05$) and FDR correction in EEGLAB on the significant electrodes to identify clusters of temporal points significantly different between the conditions (neutral and emotional words) in the time range from -100 to 1000 ms.

All analyses were performed using the EEGLAB toolbox (version 2024.2.1; Delorme & Makeig, 2004) on the MATLAB platform (version R2024a) and JASP (version 0.19; JASP Team, 2024).

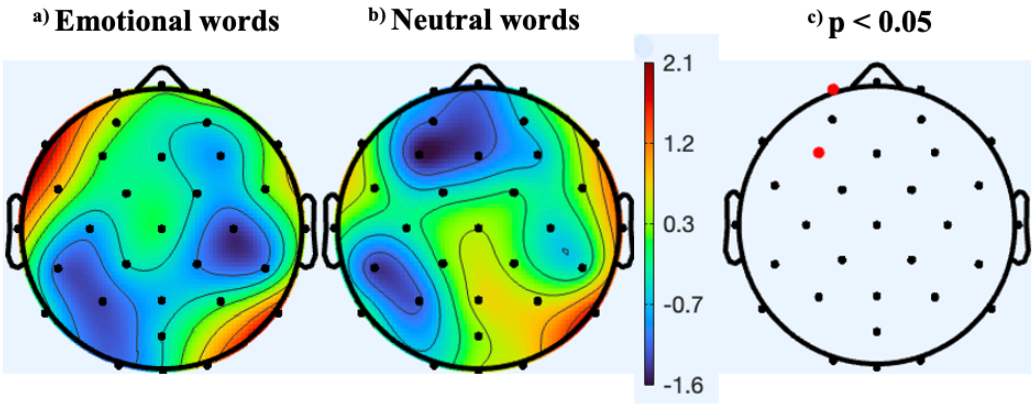
2.4.Results

Behavioral Results: For behavioral data, we applied outlier correction (±3 SDs) on RTs for each child. A paired-sample t-test showed no significant differences in reaction times between neutral and emotional words (mean neutral = 1035.39, emotional = 1035.38; standard error neutral = 46.2, emotional = 57.3; $t = 0.0006$; $p = 1$). Conversely, the paired t-test for accuracy rate showed a significant difference between neutral and emotional words (mean neutral = 85.87%, emotional = 38.67%; standard error neutral = 3.80, emotional = 6.91; $t = -4.612$; $p < 0.001$; total accuracy mean

= 62.3%, standard error total = 2.22, t = 5.515; p < 0.001), indicating a significant tendency for children to judge the words as neutral.

ERP results: Data from the 15 participants with at least 10 valid epochs per condition were used to perform ERP analyses in EEGLAB. The number of valid epochs used for the analysis did not differ between conditions (mean emotional = 14.7, neutral = 16.2; standard error emotional = 3.765; neutral = 4.057; t = 1.08; p = 0.291). ANOVA with permutation statistics (p < 0.05) and FDR correction, with the type of words (neutral, emotional) as within-subject factor, and considering all electrodes and the entire epoch, yielded two electrodes that significantly differed between the neutral and emotional word presentation conditions. These electrodes were Fp1 and F3 (see **Fig. 7** - Topographic maps for the presentation conditions of a) emotional and b) neutral words. c) Electrodes with significant differences between conditions; p < 0.05, in red, Fp1, F3).

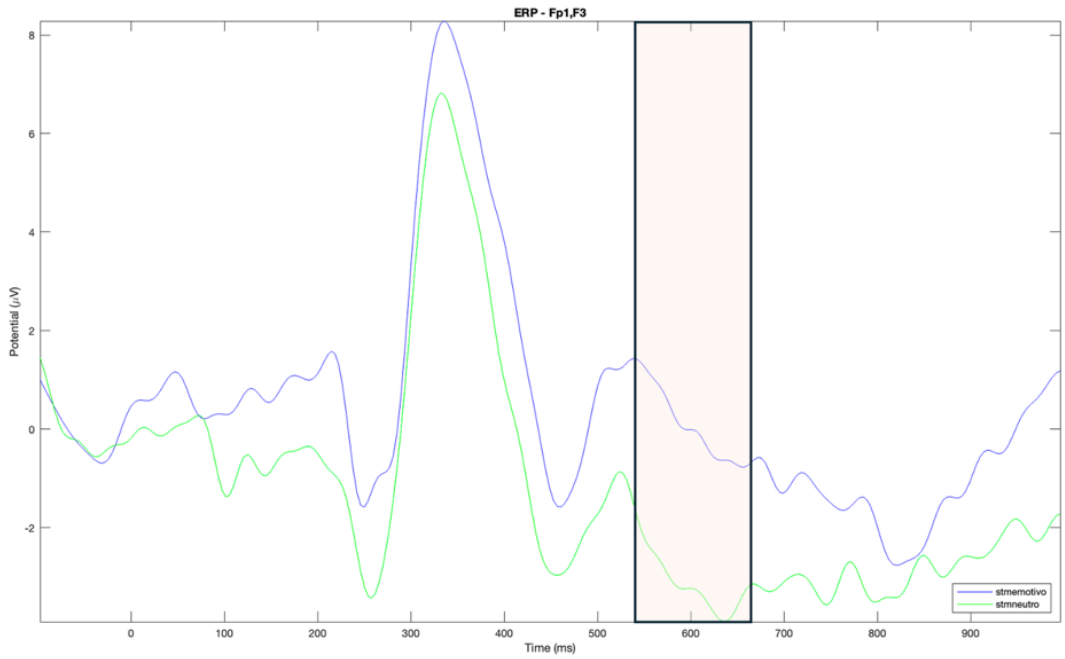
Fig. 7 - Topographic maps for the presentation conditions of a) emotional and b) neutral words. c) Electrodes with significant differences between conditions (p < 0.05, in red; Fp1, F3).

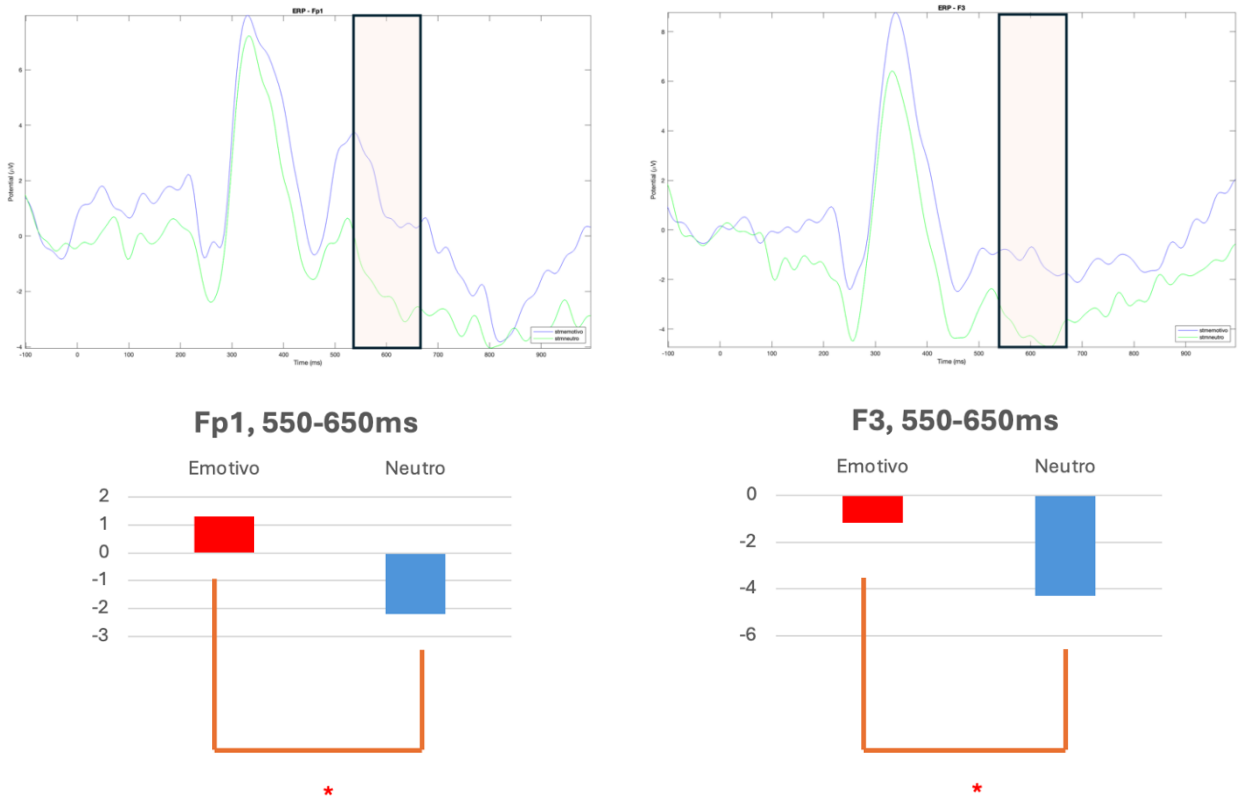


We then applied the permutation analysis (p < 0.05) with FDR correction and the type of words (neutral, emotional) as within-subject factor, only on the significant electrodes between -100 and 1000

ms, observing significant differences in a cluster of points between 550 and 650 ms (see **Fig. 8** - Top: ERPs from -100 to 1000ms for electrodes Fp1 and F3; bottom: ERPs from -100 to 1000ms for electrodes Fp1 and F3 individually and extractions of the mean ERPs between 550-650ms for the emotional and neutral words conditions; blue lines: emotional words condition, green lines: neutral words condition; significant differences between -100 and 1000ms highlighted in pink). These significant differences indicate a more positive LPP for the emotional words' presentation condition than for the neutral words' presentation condition for electrodes Fp1 and F3. We then extracted the mean values of the ERPs for both conditions separately and for both electrodes in the time interval between 550 and 650 ms for further analysis (see Chapter 3).

Fig.8. Top: ERPs from -100 to 1000ms for electrodes Fp1 and F3; bottom: ERPs from -100 to 1000ms for electrodes Fp1 and F3 individually (blue lines: emotional words condition, green lines: neutral words condition; significant differences between -100 and 1000ms highlighted in pink) and extractions of the mean ERPs between 550-650ms for the emotional and neutral words conditions.





2.5.Discussion

This study aimed to investigate the ERP modulations of emotional words compared to neutral words in a sample of primary school children engaged in an explicit emotional word categorization task. The results showed a greater positivity in two frontal electrodes (Fp1, F3) between 550 and 650 ms, referred to as a greater LPP (e.g., Hajcak & Dennis, 2009), for the emotional word presentation condition compared to the neutral word presentation condition. Contrary to expectations, reaction times did not differ between emotional and neutral words. However, children's performance for words differed in accuracy rate, with emotional words having a lower accuracy rate than neutral words.

These results are consistent with previous literature indicating a more positive LPP for emotional stimuli than neutral stimuli, including words (Hajcak & Dennis, 2009; Bao et al., 2024). A more positive LPP indicates a greater engagement of attention mechanisms towards stimuli with emotional

content (McLean et al., 2020; MacNamara et al., 2022). Our results also align with previous scientific literature, indicating that ERP modulations for emotional stimuli are more consistent in late components than early ones (Pegg et al., 2019; Dickey et al., 2021; Schindler et al., 2023). Indeed, in our sample, the difference between ERPs in response to emotional and neutral words was significant in the time interval between 550 and 650 ms. Our results add substantial evidence to the scientific literature regarding the modulation of the LPP during explicit emotional categorization tasks for emotional words compared to neutral words for primary school children.

However, our results are not aligned with studies reporting faster reaction times for emotional stimuli than for neutral ones. This unexpected effect in our data may be due to the poor accuracy of our sample in identifying words as emotional. The accuracy rate for emotional words was significantly lower than for neutral words. Children tended to judge the words as more neutral, which may have led to bias in reaction times. This accuracy result may limit observations made on ERP modulations. However, it is also important to point out that since word categorization was based on previous average ratings, it is inevitable that there is some variability in how different children perceive different valences. This problem may also affect linguistic studies with adults more generally (Delaney-Busch et al., 2016). Our accuracy data partially mirror those reported by Delaney-Busch et al. (2016), who noted that some individuals classify a relatively small proportion of words as emotional compared to neutral words. Individual experiences may lead participants to classify words into emotional categories that differ from the standard ones (González-Villar et al. 2014). Furthermore, several studies reported the distribution of the LPP as a maximum in the centro-parietal electrodes. In our results, the differences were significant in two frontal electrodes. These differences in the scalp distribution could be due to the age of the participants and the demands of the decision-making task they were engaged in (Bao et al., 2024). Literature reports that ERP distributions on the scalp can change with age, with a more diffuse distribution in children (Brooker et al., 2020).

Furthermore, some work report that LPP distribution can also be more concentrated in frontal sites (Foti et al., 2009; McLean et al., 2020; MacNamara et al., 2022; Bao et al., 2024).

Our study has some limitations. Although our data-driven analysis is motivated by the lack of studies investigating emotional words in children, it may have underestimated some differences in other ERP components (Groppe et al., 2011). For example, in a recent work, Bao and colleagues (2024) reported significant effects for emotional words compared to neutral words in an emotional categorization task in the P2 and LPP time window. However, these effects were present in the young adult group, while in the older adult group, emotional words only modulated the LPP component in a time window similar to the one reported in our work (Bao et al., 2024). However, it is important to note that our results are not directly comparable with those of Bao et al. (2024) because our task was slightly different. In our case, the children had to indicate whether the words were emotional or neutral. In contrast, in the study of Bao et al. (2024), the participants had three choices (positive, negative, neutral). The second limitation of our research concerns using words validated by young Italian university students (Montefinese et al., 2014). To our knowledge, no validated databases of emotional words exists for Italian children. This aspect indicates a critical direction for future research. However, it is important to highlight that Sylvester et al. (2016), using the BAWL (Berlin Affective Wordlist), reported that children aged 6–12 years judged words at the affective and semantic levels similarly to adults (Sylvester et al., 2016). A third limitation of our study concerns the failure to differentiate analyses for words with different valence (positive and negative) compared to neutral words. This limitation of our work offers an essential direction for future research. We used negative and positive words as emotional words for our work, but these categories of words could not be analyzed separately. Indeed, our goal was to evaluate the general effects of words' emotionality through ERP. This allowed us to reduce the administration time and the task's difficulty, which aligns with the guidelines for conducting EEG studies in children (Brooker et al., 2020). Delaney-Busch and colleagues (2016), in a study with young adults and emotional words, highlighted how the modulation

of the LPP was affected by both valence and arousal, depending on the experimental task. In particular, the authors highlighted that during the semantic categorization of words, the LPP showed a greater positivity for high-arousal words than low-arousal words but no effect for valence. Differently, during the emotional categorization task, the LPP was more positive for negative than positive and neutral words (Delaney-Busch et al., 2016). A more positive LPP for unpleasant words than pleasant words paired for arousal can be interpreted differently. First, it may represent a tendency of the negative motivational system to respond more intensely than the positive motivational system (Ito et al., 1998). However, it is also possible that such negativity bias reflects the greater ease of discrimination of negative words compared to neutral and positive words, depending on the context and situation (Delaney-Busch et al., 2016). It is important to underline that future studies should deepen this topic about emotional words in children. It has been noted that, concerning psychopathology, the response to negative and positive stimuli can be different. For example, negative stimuli are reported to elicit greater responses in anxiety disorders, while the advantage of positive stimuli could be reduced in depressive disorders (Bauer et al., 2021; Dell'Acqua et al., 2022).

Studies integrating emotion and cognition can provide additional information compared to studies considering these aspects separately. For example, it has been reported that differences or lack of differences in inhibition abilities found in patients with various psychopathologies compared to control subjects change depending on the emotional content of the stimuli (Battaglia et al., 2021). This aspect raises two fundamental issues: i) the possibility of identifying more subtle differences between patients and control participants that cannot be highlighted through classic cognitive tasks in which the emotional content of the stimuli is not controlled; ii) there is also the possibility that differences highlighted with classic cognitive tasks between patients and control subjects can instead be smoothed out in experimental paradigms that control the emotional characteristics of the stimuli, highlighting the possibility of using emotional signals to facilitate cognitive functions. This further raises the need to deepen investigate neural responses to emotional stimuli during cognitive tasks in

typical participants and their relation to the different nature of the stimuli (faces, images, and words). In other words, understanding how brain responses can be informative of risk and psychopathology cannot ignore an in-depth analysis of typical functioning in different situations and contexts. For these reasons, it is desirable to develop standardized materials that allow for the systematic and replicable evaluation of the characteristics of neural responses during cognitive tasks that include emotional components. Examining normative models of neural markers for emotion-cognition integration must be completed carefully, considering individual differences relevant to developing mood and behavioral problems. These are all fundamental steps for developing assessment batteries of cognition/emotion integration in emotional processing whose psychometric properties are known.

Chapter 3

3. The relationship between Resting-state EEG, emotional dimensions, and cognitive performance in children

3.1. Resting-State EEG

Resting EEG is a common and widely used technique to study brain activity. This non-invasive technique can be used across the lifespan and with special populations (e.g., infants and patients with Alzheimer's disease), demonstrating great versatility. EEG activity is recorded while participants remain relaxed without performing tasks (e.g., observing a fixation cross or having their eyes closed). Although in some cases recordings from specific sites are used (e.g., mainly central electrodes for the study of ADHD; for a review, see Arns et al., 2011), many studies use the signal recorded from all sites (Anderson & Perone, 2018). The most used measure in resting EEG studies is the absolute or relative power of frequency bands (e.g., delta, theta, alpha, beta, and gamma), i.e., the synchronized activation of neurons at a given frequency (Buzsáki, 2006). Generally, the more neurons that fire synchronously at the same frequency, the greater the power (Izhikevich, 2003). Synchronous neural activity is not limited to behaviors such as cognitive tasks but also occurs spontaneously, independently of stimulation (Barry et al., 2007). Typically, neurons that synchronize on fast frequency bands are located in circumscribed brain areas, while those that synchronize on slower bands tend to be more distant (e.g., Girard et al., 2001; Jensen et al., 2014). This relationship between frequency and distance could be explained by conduction delays between distant neurons, which prevent reliable synchronization at high frequencies (Anderson & Perone, 2018). Importantly, studies have shown that power in frequency bands changes during development at all scalp recording sites (Miskovic et al., 2015). For example, delta and theta activity decreases, and alpha and beta activity increases with age (Clarke et al., 2001; Barry et al., 2004). A recent review (Anderson & Perone, 2018) showed that, in general, power in frequency bands decreases with age, and in parallel,

functional networks become more organized. Both of these changes could be linked to structural changes in the brain during development. Although it is unclear what causes these age-related changes, synaptic pruning and myelination are among the main candidates (Smit et al., 2012). Synaptic pruning and myelination mechanisms likely favor the emergence of more efficient neural networks.

As we mentioned, resting activity is also called spontaneous activity, and it is actually an active state characterized by high energy expenditure (Raichle & Mintun, 2006). For example, Damoiseaux et al. (2006), using functional magnetic resonance imaging (fMRI), identified ten brain networks active during "resting" phases. Surprisingly, little is known about spontaneous brain activity measured by resting EEG, particularly in early and middle childhood (Anderson & Perone, 2018; Lum et al., 2020). Some works have studied the resting activity of ERPs recorded during the performance of cognitive tasks (e.g., Nakao et al., 2013; Clarke et al., 2019). Nakao et al. (2013) observed a negative correlation between the amplitude of the N2 at a frontal site and the delta, theta, and beta frequency bands. The N2 is an ERP component that occurs approximately 200 ms after stimulus presentation, and its greater amplitude indicates greater attentional control (Espinet et al., 2012). From this work, it emerges that resting-state EEG activity is related to attentional control during the performance of cognitive tasks. However, the scientific literature on resting-state EEG is lacking, as there is no theory linking resting-state brain activity with brain activity during a task or performance, nor is there a theory linking it to real-world behavior. It has been proposed that spontaneous synchronized activity reflects the basic functional organization of the brain that supports perceptual, motor, sensory, and higher-order processes (Lum et al., 2022). If this is the case, it is reasonable to expect that resting state EEG indices are correlated with measures experienced during cognitive activities, such as reading skills and intelligence, as well as emotional processes.

3.2. Theta/Beta Ratio (TBR)

Although early studies had indicated the theta/beta ratio as a neural signal of cortical arousal, more recent studies hypothesize that this ratio represents cognitive processing abilities (Clarke et al., 2019). Indeed, several studies have strongly associated alpha activity with cortical arousal (Barry et al. 2004, 2005). The literature has given wide prominence to the theta/beta ratio as a diagnostic tool for ADHD, although with partly conflicting results (Lenartowicz & Loo, 2014). Perone et al. (2018) reported that the theta/beta ratio at rest could be associated with executive control processes. In particular, lower levels of the theta/beta ratio were associated with better executive functions (Perone et al., 2018). The significance of the theta/beta ratio has not been yet fully elucidated. However, it has been proposed that a high value is related to poor top-down regulation of bottom-up brain processes (Putman et al., 2014). These observations are consistent, as tasks involving executive control engagement may require the application of rules to favor voluntary responses over automatic stimulus-driven responses. Clarke et al. (2019) studied the theta/beta ratio and its relation to the P300 component, finding that a greater P300 latency was associated with a higher theta-beta ratio. This work is consistent with the previous studies cited, as a shorter P300 latency has been associated with higher scores on cognitive tests (McGarry-Roberts et al., 1992). Based on these results, the authors concluded that the theta/beta ratio could be a measure of the processing capacity of the central nervous system (Clarke et al., 2019). However, further studies are needed to understand more precisely the associations between the theta/beta ratio and cognitive functions. In fact, "processing" is a comprehensive concept that can include many aspects of the functioning of the central nervous system. The slow-wave/fast-wave ratio has also been explored as a correlate of emotional regulation processes. In particular, a higher TBR is associated with psychological disorders related to poor attentional skills (Arns et al., 2011). This observation was motivated by asserting that the theta/beta ratio could reflect cortico-subcortical interactions necessary for efficient affective processing (Knyazev, 2007). Assuming that a high theta/beta ratio is associated with attentional problems and

that attentional control is related to affective processing, the theta/beta ratio could also be informative concerning individual affective characteristics (Tortella-Feliu et al., 2014). Therefore, the theta/beta ratio's role is still unclear in the literature, with partly contrasting results (e.g., Dennis & Solomon, 2010; Goodman et al., 2013).

3.3. Frontal Alpha Asymmetry (FAA)

A relevant measure in resting-state EEG research is frontal alpha asymmetry (FAA). This index has been associated with several aspects of individual behavior and functioning, including affective state and motivational tendencies to approach and withdraw (Davidson, 2004; Lopez-Duran et al., 2012). The use of the FAA in experimental research is based on the observation that alpha power is inversely related to brain activity (Im et al., 2022). Since FAA is the difference between the natural logarithm of the activity recorded in the right hemisphere minus that recorded in the left hemisphere, a more positive FAA indicates greater alpha activity in the right hemisphere and, therefore, greater activation of the left hemisphere. The more positive FAA is associated with approach to positive emotions, while the more negative FAA is associated with withdrawal from negative emotions (Wang et al., 2022). For example, in depression, a reduced EEG activity of the left hemisphere is observed (Thibodeau et al., 2006). In addition, approaching or withdrawing from emotions relates to spontaneous emotional regulation (Harmon-Jones & Gable, 2018). Studies have reported an association between emotional regulation and spontaneous EEG activity, with an increase in left frontal activity indexed by FAA associated with a more efficient emotional regulation (Jackson et al., 2003; Tortella-Feliu et al., 2014; but see also Goodman et al., 2013). For these reasons, the FAA has been hypothesized as an informative measure concerning individual affective states and emotional processes. In this context, FAA is considered a useful measure for the study of typical and psychopathological development since deficiencies in emotional self-regulation processes are associated with the risk of internalizing

and externalizing problems during childhood (e.g., anxiety and depression; Allen & Reznik, 2015). In developmental terms, it has been observed that FAA switches from right-lateralized to more left-lateralized in the transition from infancy to childhood (Perone & Vaughan, 2024). However, early exposure to disadvantageous situations, as well as the restoration of more advantageous situations during development, can modify the lateralization tendencies of FAA (e.g., McLaughlin et al., 2011; Lusby et al., 2016), demonstrating a possible tight coupling between children's daily emotional experience and brain dynamics. Further research is needed to precisely delineate the trajectory of FAA across the lifespan and the role of individual and developmental factors that shape its course (Perone & Vaughan, 2024). The FAA may reflect top-down frontal cortical regulation of subcortical areas involved in emotional processing, such as the amygdala (Ray & Zald, 2012). For example, Zotev et al. (2016) showed that during the thought of happy memories, left frontal alpha power and amygdala activation increased temporally correlated. However, further research is needed as frontal alpha activity is more likely to be part of broader and more complex dynamics of interactions between different cortical areas (Zotev & Bodurka, 2020). Furthermore, two meta-analyses have questioned the role of resting FAA as a marker of individual traits and dispositions (Wacker et al., 2010; Kuper et al., 2019). These data underline the need to study further the role of resting FAA as an indicator of individual affective processes.

3.4. The current study: aims and hypothesis

The current study used resting-state EEG to examine the relationship between spontaneous neural oscillatory activity (i.e., TBR & FAA) and some emotional dimensions and cognitive performance in primary school children. In particular, children’s affectivity was investigated with two questionnaires: the Emotional Quotient Inventory Youth Version (EQi:YV) and the Alexithymia Questionnaire for Children (AQC). Instead, the cognitive performance investigated were working memory (Digit span

backward), reading comprehension (MT Reading Comprehension Test), reading fluency (One Minute Reading Test), and nonverbal fluid intelligence (Colored Progressive Matrices). It is important to highlight that the study of the relationships between resting-state EEG and emotional and cognitive measures is particularly lacking in primary school children (Lum et al., 2020). However, based on previously reported findings on FAA, we hypothesized a positive correlation between FAA and self-reported emotional experiences (e.g., higher emotional quotient, lower levels of alexithymia). Given the lack of evidence directly relating alpha power to higher-order cognitive functioning in children (e.g., Maguire & Schneider, 2019), we hypothesized no correlation between FAA and cognitive measures. Instead, based on what was reported in research on TBR, we hypothesized a negative relationship between TBR and children's self-reported emotional measures. Furthermore, we also hypothesized negative relationships between TBR and measures of working memory and reading, while we expected weaker relationships with fluid intelligence as measured by Raven's matrices (Lum et al., 2022). Previous studies have reported inconsistent relationships between frequency bands and cognitive and reading abilities. The conflicting results are particularly evident in the age group investigated in this study (i.e., primary school children), which appears to be under-investigated (Lum et al., 2020). Indeed, most research has focused on the study of linguistic features in younger children or infants and on the use of single frequency bands rather than indices that may be more informative concerning related mental processes, such as the TBR (e.g., Brito et al., 2016; Lum et al., 2020). Although relationships between theta bands and working memory (Maguire & Schneider, 2019) and language (e.g., lexical-semantic retrieval during sentence comprehension in Beese et al., 2017; sentence repetition in Lum et al., 2020) have been found, these relationships have not always been confirmed (e.g., Cantiani et al., 2019). Finally, the relationships between nonverbal IQ and resting EEG have been mostly reported as inconsistent (e.g., Kwok et al., 2019; Lum et al., 2020). For these reasons, we decided to investigate the relationships between spontaneous oscillations, self-reported emotional characteristics, and cognitive functions in a group of primary school children using two

measures of spontaneous activity that have been little investigated in this age group, but which are variously informative concerning cognitive and emotional functioning, namely the TBR and the FAA.

The final aim of this work was to investigate the relationship between ERP and resting-state EEG. A subsample of this study (N=20) also completed the emotional word categorization task reported in Chapter 2 (see the Results section of Chapter 2). Following the recommendations of Hajcak et al. (2010), we investigated the possible relationship between the significant ERP components reported in Chapter 2 (LPP for emotional and neutral words) and FAA. Based on previous studies (e.g., McLean et al., 2020), we hypothesized that a more positive LPP in the emotional versus neutral words presentation condition would be related to a more negative FAA.

Scientific literature reports that LPP modulations could be informative regarding individual affective characteristics (e.g., Dickey et al., 2021). However, LPP modulations have mainly been investigated in a general and historical context of opposition between emotion and cognition, presumably leading studies to focus on how cognitive components can modify affective experiences (Dennis, 2010). In particular, cognitive strategies to suppress emotions were often investigated, such as re-evaluating the meaning of a stimulus in a more positive sense or shifting attention away from the emotional stimulus. This methodology cannot completely reveal the nature of affective experience about emotion-cognition integration because it fails to elucidate processes that occur too rapidly or subtly to be expressed in overt behavior (Dennis, 2010). The LPP reflects facilitated attention to emotions, such that it is more positive in response to emotional stimuli than to neutral ones (Cuthbert et al., 2000; Zaho et al., 2018; Li & Wang, 2022) and is reduced following the use of cognitive emotion control strategies such as reappraisal, which reduces the negative emotional impact of unpleasant stimuli (Dennis & Hajcak, 2009). Finally, LPP effects have been studied most often for emotional pictures, while EEG studies in children with emotional words are almost absent (Yeh et al., 2023).

3.5. Method

3.5.1. Participants

A total of 40 children (16 females, 24 males) aged between 7 and 9 (mean = 8.45; standard deviation = 0.59) participated in recordings of EEG. Data from 6 participants were excluded from the analyses due to insufficient valid epochs. In addition, data from 4 participants were excluded from the analyses for Positive Impression and Inconsistency indices higher than 16 and 9 on the Emotional Quotient Inventory: Youth Version, respectively. Therefore, the final sample was 30 participants (12 females, 18 males; mean age = 8.43; standard deviation = 0.56). A subgroup of this sample (N=20) also completed the emotional word categorization task described in Chapter 2 (see the Participants Section of Chapter 2). The participants were healthy (no history of neurological or psychiatric problems) and had normal visual function. The use of psychoactive medication at the time of testing or in the twelve months prior to testing was also an exclusion criterion. The inclusion/exclusion criteria were screened via interviews and/or questionnaires to teachers and parents. None of the children had a diagnosis of dyslexia or other learning disabilities at the time of the experiment. All children had Italian as their first language and regularly attended schools. All parents gave written informed consent, and all children gave oral consent at the time of the experiment. This study procedures were approved by the Ethics Committee of the University of Foggia and met the ethical standards of the 1964 Declaration of Helsinki (World Health Organization, 2013).

3.5.2. Materials

Emotional Quotient Inventory: Youth Version (**EQi:YV**; Bar-On, 1997; Fancello & Cianchetti, 2024) - The EQi:YV is based on Bar-On's model of emotional and social intelligence, which was the theoretical basis of the same adult questionnaire (EQ-i, Bar-On, 1997). The children's version of the questionnaire calculates a total emotional intelligence quotient (EQ) and separate scores for the

Intrapersonal, Interpersonal, Adaptability, Stress Management, and General Mood scales. In addition, the questionnaire has two control scores, namely the Positive Impression score and the Inconsistency Index. The questionnaire contains 60 items and uses a 4-point Likert-style format (from "not true" to "very true"). The Positive Impression scale was introduced to identify subjects who wish to give an exaggeratedly positive image of themselves (cut-off > 16). Instead, calculating the Inconsistency Index allows us to estimate the consistency in the subject's responses (cut-off > 9). The Intrapersonal scale estimates how well subjects understand their emotions, can express them, and can communicate their feelings and needs. The Interpersonal scale measures how much the respondent has satisfying interpersonal relationships. The Adaptability scale indicates how flexible subjects are and how they can manage changes positively. The Stress Management Scale estimates how calm and impulsive test subjects are and how they react emotionally to stressful situations. The General Mood scale indicates how optimistic the respondents are. Finally, the Total EQ scale measures the general level of emotional intelligence. Higher scores indicate better affectivity depending on the factors investigated.

Alexithymia questionnaire for children (**AQC**; Rieffe et al., 2006; Di Trani et al., 2018) - The AQC consisted of 20 items on a 3-point Likert-style scale (from "not true" to "true"). The questionnaire is based on the adult questionnaire for alexithymia (20-item Toronto Alexithymia Scale; TAS-20) developed by Bagby et al. (1994). Alexithymia can be described as a limited or problematic ability to identify and communicate one's feelings. High levels of alexithymia are often associated with physical health problems and negative moods (Rieffe et al., 2006). In addition to a general Alexithymia score, the questionnaire allowed the calculation of three partial scores: i) Difficulty in identifying feelings - measures the ability to recognize and differentiate one's emotions; ii) Difficulty in describing feelings - measures the ability to communicate the emotions felt verbally; ii) Externally oriented thinking - measures the tendency to focus on concrete and external facts rather than on thoughts, emotions or internal states. Higher scores indicate worse affectivity, depending on the area investigated.

Test of reading comprehension **(MT Task**; Cornoldi & Colpo, 2011) - The MT test consists of independent reading of two short passages (news and informational), followed by 12 multiple-choice questions. Higher scores indicate better performance on the reading comprehension test.

Coloured Progressive Matrices (**CPM**; Raven, 1998) - The Raven's Progressive Matrices Test is a well-known fluid intelligence measure that involves solving 36 matrices organized in three sequences. Each matrix presented is incomplete and can be completed by indicating one of the six missing pieces proposed below it. Higher scores indicate better intelligence and reasoning skills.

Digit span backward (**Working Memory**; Wechsler, 2006) - In this working memory test, sequences of numbers are read aloud, and the participant is asked to repeat them in reverse order. The sequences become increasingly complex (2 to 8 elements per level; 2 sequences for each level). The score was calculated as the sum of the number of correct sequences repeated.

One-Minute Reading Test (**OMRT**; Sartori et al., 1995) - The OMRT instrument assesses reading fluency through one-minute isolated words reading aloud test. The score is counted as the number of words read correctly per minute, representing the performance index.

3.5.3. Procedure

The children were recruited in collaboration with school offices. Each school institute involved in the project signed a bilateral agreement with the University of Foggia, thus formally regulating the research personnel and instrumentation admitted to the institute, the activities included in the agreement, and the persons responsible. After the agreement signature, the project was presented in detail to the teachers of the classrooms involved to explain the procedure of the project deeply and agree with them about the scholastic timing to dedicate to the experimental sessions and the modalities of distribution of written informed consent to the parents. Participants and their parents received written information about the study goals, experimental procedures, and confidentiality.

Parents were asked to provide written informed consent, and minors provided oral assent to participate in the study. Before the experimental session, a licensed psychologist ensured the children were willing to carry out the tasks and calm when facing the experiment. The school institute provided an adequate space for the experiment sessions.

In this study, we administered emotional questionnaires and cognitive tests to a group of primary school children. In a separate session, we measured resting-state EEG for four minutes (2 minutes eyes open and 2 minutes eyes closed). A small group of these children (N = 20) also completed an emotional word categorization task during the EEG recording (see the Method Section of Chapter 2).

Children completed emotional questionnaires (EQi:YV and AQC) and cognitive tests (MT Task, CPM) in small group sessions separately from the individual sessions in which they completed the working memory task and the OMRT. In another individual session, children underwent resting-state EEG. For the EEG resting-state session, the children sat in a quiet room in front of a 14-inch screen at a distance of 60 cm. Children underwent two resting-state EEG sessions (eyes open and closed), each lasting two minutes. The children looked at a fixation cross on the computer screen for two minutes and then remained with their eyes closed for another two minutes during the EEG recording.

In addition to recommendations for EEG studies in adults (e.g., Keil et al., 2014; Picton et al., 2008), we followed the recommendations reported by Brooker et al. (2020) for EEG data collection in children (Brooker et al., 2020).

3.5.4. EEG recordings and preprocessing

The electroencephalogram was recorded using the EEG-32-Versatile^{TM} system (Bitbrain, Spain). This system uses 32 water-based electrodes (i.e., humid sponges) placed on an electrode cap arranged in the 10 to 20 system (Homan et al., 1987; Acharya et al., 2016). For reference, we used the left earlobe and the channel AFz for the ground. All data was streamed via Bluetooth to the computational unit

using Bitbrain proprietary software and backed up to an internal SD card to avoid data loss due to the wireless connection. The signals were recorded using a sampling frequency of 256 Hz with a resolution of 64 bits. During the recordings, the skin-sensor impedance was kept in the appropriate range through the real-time impedance monitoring feature of the acquisition software. The EEG signal was preprocessed using the EEGLAB toolbox (version 2024.2.1; Delorme & Makeig, 2004) on the MATLAB platform (version R2024a).

The data were filtered with 0.5 - 30 Hz bandpass filters (Xue et al., 2020) and cleaned using the EEGLAB Clean Raw Data plugin (Klug et al., 2022; Megías et al., 2018; Piazza et al., 2016). The rejected channels by Clean Raw Data software were reconstructed using the spherical interpolation method (Perrin et al., 1989). Participants with more than three channels removed were excluded from analyses. Independent component analysis (ICA) was performed using FastICA (Hyvarinen, 2009; Hyvarinen & Oja, 1997) and ICLabel (Pion-Tanachini et al., 2019; Pernet et al., 2021) in EEGLAB to correct artifacts (e.g., blinks and eye movements). We then re-referenced the EEG data using the averaging method (Picton et al., 2000; Marshall et al., 2002; Perez-Edgar & Fox, 2003). Segments containing residual muscle movements or other artifacts greater than ± 100 uV were rejected prior to further analysis. Frequency analysis was performed using the EEGLAB Spectral Analysis plugin (eegstats ver. 1.3; Miyakoshi, 2022) to compute the EEG data's power spectral density (PSD). This step involves applying a Fast Fourier Transform (FFT) spectral analysis technique to estimate the power spectrum (2 seconds epochs, 1 second overlap) (Li et al., 2020; Marcu et al., 2024). We extracted the theta (4 - 6.5 Hz), alpha (7.5 - 11.5 Hz), and beta (12 - 17.5 Hz) bands based on the power distribution in children (Barry et al., 2004; Vuga et al., 2008; Lopez-Duran et al., 2012). The FAA, defined as the difference between the natural logarithm of the right alpha power minus the natural logarithm of the left alpha power, was calculated for electrode pairs F3/F4, Fp1/Fp2, AF3/AF4, and F7/F8. We also calculated the TBR, which is defined as the ratio of the theta frequency bands to the beta frequency bands. All segments (eyes open and eyes closed) were collapsed for

analysis. Because of the non-normal distribution, power density values and ratios were log-normalized (van Albada & Robinson, 2007; Putman et al., 2010). The number of valid epochs was calculated for each participant and each condition (eyes open and closed). Participants with at least 60 valid epochs (at least 30 for eyes open conditions and 30 for eyes closed conditions) were included in the analyses (Anderson & Perone, 2018; Lum et al., 2022). This process resulted in the exclusion of 6 participants.

3.5.5. Statistical analysis

We performed correlation analyses using Pearson's r or Spearman's rho in case of ordinal variables or violations from normality (Bishara & Hittner, 2012; Putman et al., 2010). We first tested the association between the results of the emotional questionnaires and the cognitive tasks. Then, we explored the correlations between the resting EEG values (FAA and TBR) and the emotional and cognitive measures. Based on the work of Putman et al. (2010), for TBR analyses, we first selected electrodes of interest in the frontal (F3, Fz, F4), central (C3, Cz, C4), and parietal (P3, Pz, P4) regions. We averaged the TBR of these electrodes to obtain a single estimate of TBR for the frontal, central, and parietal electrodes. We then performed correlation analyses between these three electrode groupings and the emotional and cognitive measures. Furthermore, we repeated the correlations between TBR for all electrodes individually and emotional and cognitive measures for exploratory purposes.

Subsequently, we performed correlation analyses between the significant ERP differences obtained in the emotional word categorization task (see the Results section of Chapter 2) and the FAA measured on the same participants (Hajcak et al., 2010). From the total sample, we extracted the ERP and FAA values of the 15 participants who had also completed the previously reported emotional words categorization task (see the Method section of Chapter 2). In particular, we extracted separately the

mean ERPs in the neutral and emotional words conditions for the electrodes that produced significant differences in the emotional categorization task (Fp1, F3) in the time interval between 550 and 650 ms (see the Results section of Chapter 2). In these ranges, we calculated the difference between the mean ERP amplitude for emotional words and the mean ERP amplitude for neutral words in each child (McLean et al., 2020). Finally, we correlated the differences in ERPs between emotional and neutral words with FAA measured on frontal electrode pairs (Hajcak et al., 2010).

All analyses were performed using the EEGLAB toolbox (version 2024.2.1; Delorme & Makeig, 2004) on the MATLAB platform (version R2024a) and JASP (version 0.19; JASP Team, 2024).

3.6. Results

Behavioral Results: The means and standard deviations of the behavioral results are reported in **Table 2.** (Mean and standard deviation of behavioral results). As expected, the Emotional Quotient measured by the EQi:YV correlated positively with all subscales (Intrapersonal: $r = 0.747$, $p < 0.001$; Interpersonal: $r = 0.449$, $p = 0.015$; Stress Management: $r = 0.655$, $p < 0.001$; Adaptability: $r = 0.511$, $p = 0.005$; General Mood: $r = 0.464$, $p = 0.011$). Furthermore, the General Mood subscale correlated with the Intrapersonal subscale ($r = 0.392$, $p = 0.035$) and the Stress Management subscale ($r = 0.381$, $p = 0.041$). Alexithymia levels measured by the AQC correlated positively with the AQC subscales of Difficulty Identifying Feelings ($r = 0.815$, $p < 0.001$) and Difficulty Describing Feelings ($r = 0.786$, $p < 0.001$). Levels of alexithymia were negatively correlated with emotional quotient ($r = -0.416$, $p = 0.028$) measured by the EQi:YV, and with the intrapersonal ($r = -0.595$, $p < 0.001$) and general mood ($r = -0.530$, $p = 0.004$) subscales measured by the EQi:YV. These correlations are consistent because lower levels of alexithymia in children are associated with better emotional profiles at EQi:YV. Consistently, the AQC Difficulty Identifying Feelings subscale correlated negatively with the Emotional Quotient ($r = -0.456$, $p = 0.015$) of the EQI:YV scale and with the Intrapersonal ($r = -$

0.533, p = 0.002) and General Mood (r = -0.597, p < 0.001) subscales measured by the EQi:YV. Finally, the AQC Difficulty Describing Feelings subscale correlated negatively with the Emotional Quotient (r = -0.433, p = 0.021) and the Intrapersonal subscale (r = -0.659, p < 0.001) measured by the EQi:YV. Regarding cognitive measures, only working memory correlated positively with the MT comprehension task (rho = 0.485, p = 0.010), showing that better working memory skills corresponded to better text comprehension. Again, the correlation found is consistent since the contribution of working memory to reading comprehension performance has been documented (Artuso & Palladino, 2016; 2022; Palladino et al., 2001). Furthermore, we observed a negative correlation trend between alexithymia levels measured by the AQC and performance on the Raven matrices (r = -0.344, p = 0.068), which could indicate that higher levels of alexithymia are associated with lower fluid intelligence. The other correlations were not significant (see **Appendix A.** Correlations between questionnaires and cognitive tasks).

Table 2. Mean and standard deviation of behavioral results

	Mean	Std. Deviation
Intrapersonal	12.552	4.983
Interpersonal	38.276	4.079
Stress management	29.345	7.093
Adaptability	28.759	5.221
General Mood	46.034	7.213
EQ	108.931	12.870
Difficulty identifying feelings	5.862	3.533
Difficulty describing feelings	6.310	3.339
Alexithymia	18.483	5.629
Externally oriented Thinking	7.448	2.339
MT Task	14.650	3.526

CPM	31.467	2.389
Working Memory	3.037	1.091
OMRT	61.321	11.438

Correlations between resting-state EEG and behavioral measures: The number of valid epochs for the eyes-open resting-state condition was 51.46 (standard error = 1.631), and for the eyes-closed condition was 49.06 (standard error = 1.868). The total mean number of epochs entered into the analysis was 101.06 (standard error = 3.179). The number of epochs entered into the analysis did not differ between the eyes open condition and the eyes closed condition ($t = 1.183$; $p = 0.241$). The mean values and standard error for the FAA and TBR are reported in **Appendix B** (Mean and Standard Error FAA and TBR).

We found no significant correlations between the TBR for the grouped frontal, central, and parietal electrodes and the emotional and cognitive measures (see **Appendix C.** Correlations between TBR grouped by frontal, central, and parietal electrodes, emotional questionnaires, and cognitive performance). On the contrary, as far as exploratory analyses are concerned, the results indicated that TBR measured in CP1 and CP2 negatively correlated with the Stress Management subscale of the EQi:YV (CP1: $r = -0.412$, $p = 0.026$; CP2: $r = -0.376$, $p = 0.044$; see **Fig. 9** - Correlations between TBR and Stress Management), indicating that better stress management was associated with lower TBR. Furthermore, FAA measured in F7/F8 showed a trend towards significance with the Stress Management ($r = 0.333$, $p = 0.078$) and General Mood subscales of the EQi:YV ($r = 0.333$, $p = 0.077$), indicating a weak positive relationship between these measures (see **Fig. 10** - Correlation between FAA (F7/F8), Stress Management and General Mood). Other correlations between emotion questionnaires and resting-state EEG measures were not significant (see **Appendix D.** Correlations

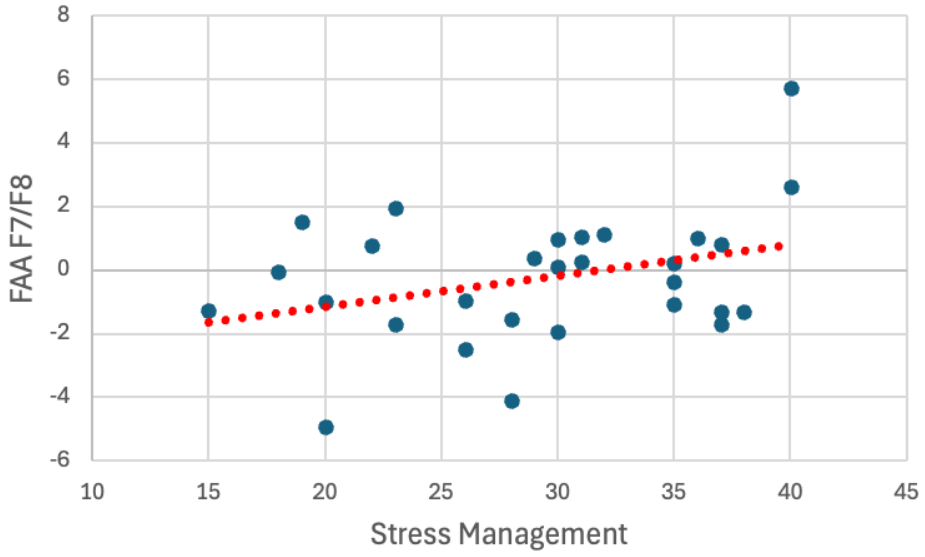
between EEG resting-state measures and EQi:YV; and **Appendix E.** Correlations between EEG resting-state measures and AQC).

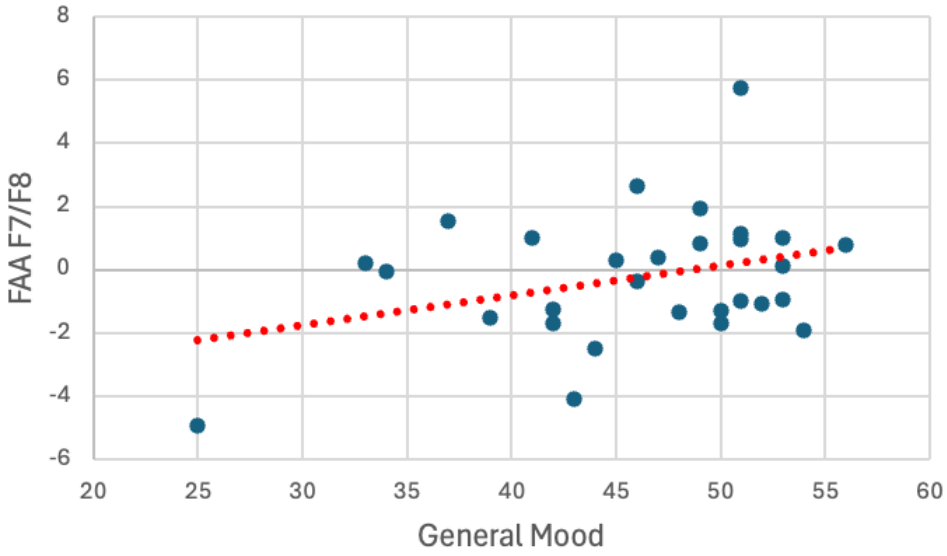
Fig. 9. Correlations between TBR and Stress Management.





Fig. 10. Correlations between FAA (F7/F8), Stress Management and General Mood.

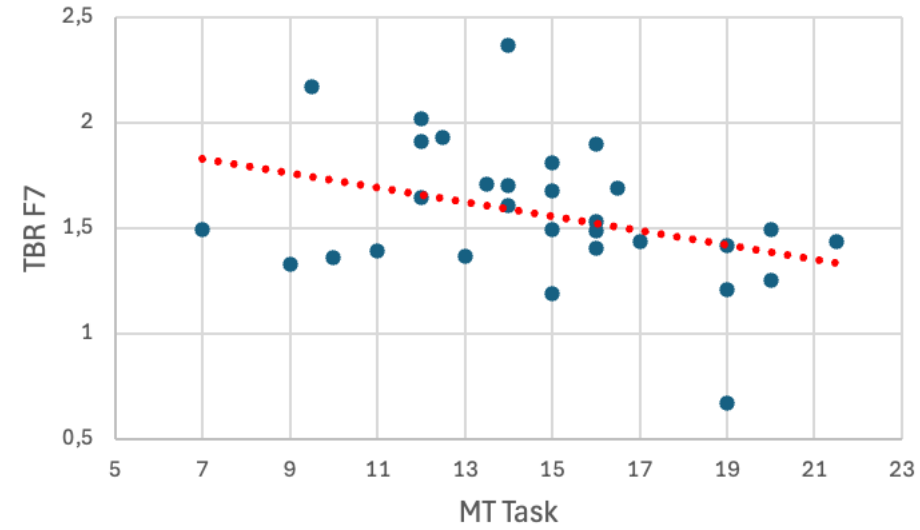


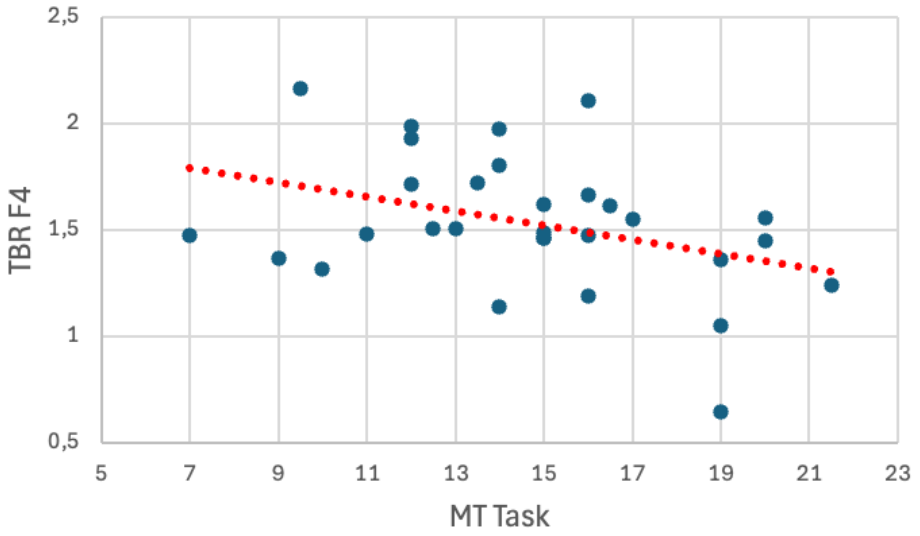


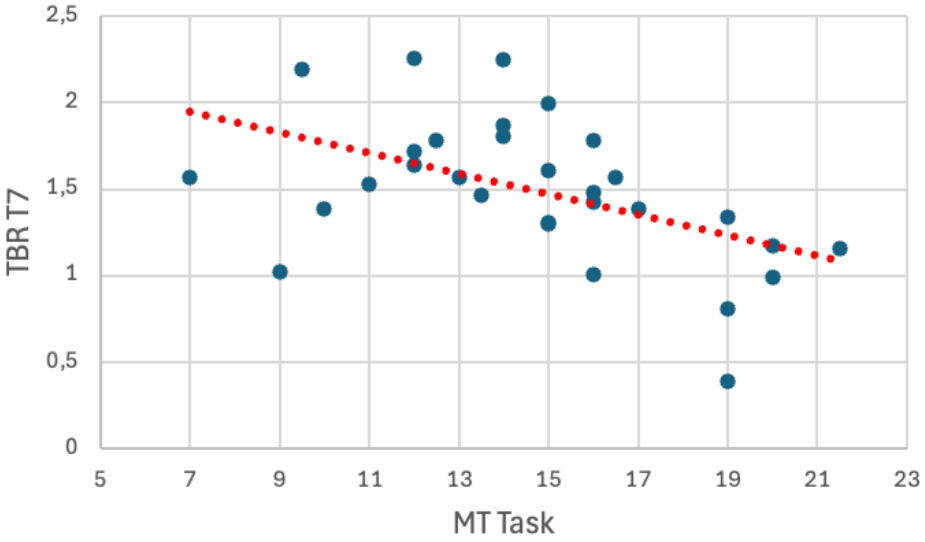
Regarding cognitive tasks, the results showed negative correlations between the MT task and the TBR measured in F7 (r = -0.365, p = 0.047), F4 (r = -0.372, p = 0.043), T7 (-0.497, p = 0.005), and CP5 (r = -0.386, p = 0.035), indicating that better text comprehension is associated with lower TBR values

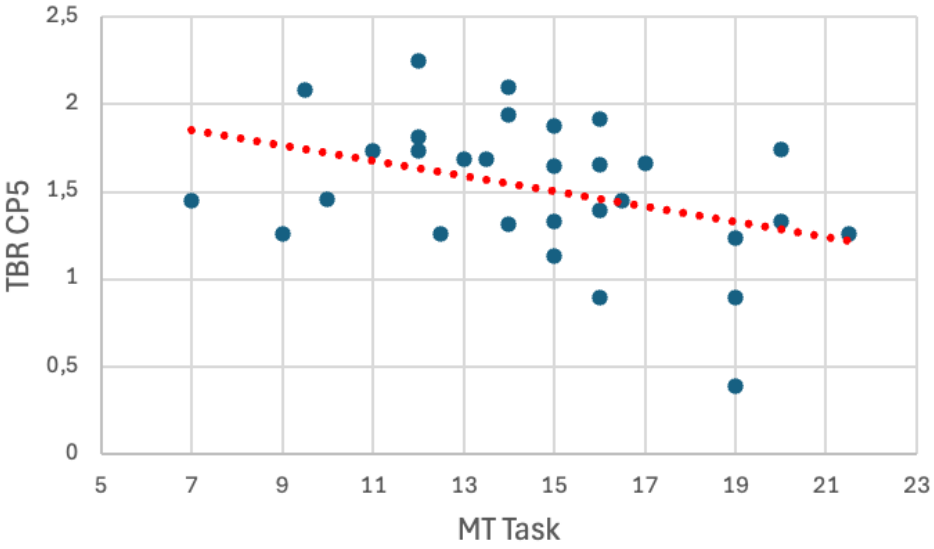
(see **Fig. 11.** Correlations between TBR and the MT task). The other correlations were not significant (see **Appendix F.** Correlations between resting-state EEG measures (FAA and TBR) and cognitive tasks).

Fig. 11. Correlations between TBR and the MT task









Correlations between ERP and FAA: We first obtained FAA for electrode pairs F3/F4, Fp1/Fp2, AF3/AF4, and F7/F8 for the 15 participants who had also completed the emotional word categorization task (mean of epochs entered for the eyes open condition = 57.20, eyes closed = 53.33; standard error for the eyes open condition = 1.46, eyes closed = 2.50; total mean = 110.533; standard error = 3.62). The number of epochs entered for analyses did not differ between the eyes-open and eyes-closed conditions (t = 1.333, p = 0.193). Additionally, we subtracted the mean ERPs between

550 and 650 ms for neutral words from ERPs between 550 and 650 ms for emotional words for electrodes Fp1 and F3 (**Δ** Fp1, **Δ** F3; see **Table 3** – Mean and standard error for **Δ** Fp1, **Δ** F3, and FAA).

Table 3. Mean and standard error of mean (SEM) for Fp1, F3 and FAA (F3/F4; Fp1/Fp2; AF3/AF4; F7/F8).

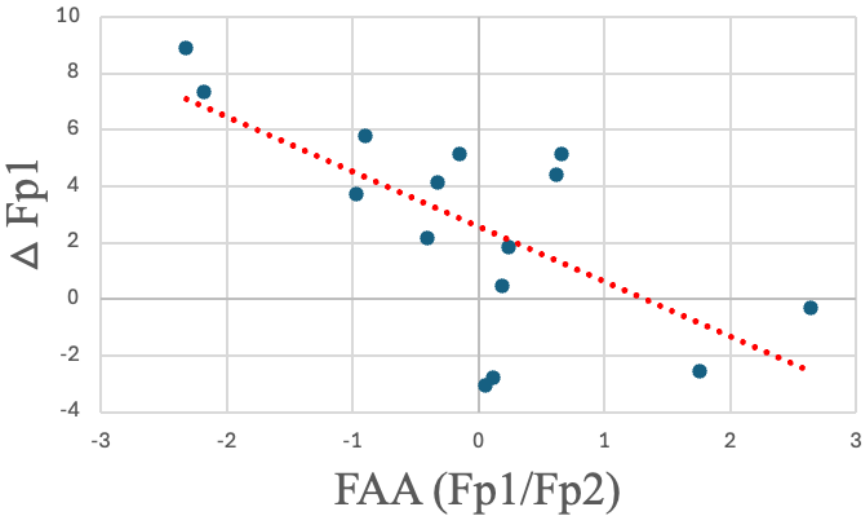
	Mean	SEM
Δ Fp1	2.697	0.958
Δ F3	2.682	0.959
FAA F3/F4	0.692	0.448
FAA Fp1/Fp2	-0.065	0.331
FAA AF3/AF4	0.387	0.355
FAA F7/F8	-0.106	0.412

We then used the Pearson correlation coefficient to calculate the correlations between the differences in ERPs between emotional and neutral words for the electrodes Fp1, F3, and FAA measured in frontal electrode pairs (see **Table 4** – Pearson's correlations for **Δ** Fp1, **Δ** F3, and FAA). Correlation analysis showed a negative correlation between **Δ** Fp1 and FAA for frontal electrode pairs Fp1/Fp2 ($r = -0.673$; $p = 0.006$; see **Fig.12** – Correlation between **Δ** Fp1 and FAA Fp1/Fp2), indicating that a greater difference in ERP activity between emotional and neutral words (**Δ** Fp1) was associated with a more negative FAA (Fp1/Fp2). The other correlations were not significant.

Table 4. Pearson's correlations for **Δ** Fp1 (550 -650 ms), **Δ** F3 (550 – 650 ms), and FAA (F3/F4; Fp1/Fp2; AF3/AF4; F7/F8)

		Δ Fp1	**Δ** F3
FAA F3/F4	Pearson's r	0.161	-0.219
	p-value	0.566	0.434
FAA Fp1/Fp2	Pearson's r	-0.673 *	-0.098
	p-value	0.006	0.727
FAA AF3/AF4	Pearson's r	-0.247	0.153
	p-value	0.375	0.586
FAA F7/F8	Pearson's r	-0.300	0.118
	p-value	0.277	0.675

Fig.12. Correlation between **Δ** Fp1 (550 -650 ms) and FAA (Fp1/Fp2)



3.7. Discussions

3.7.1. Correlations between resting-state EEG and behavioral measures

This study explored possible associations between spontaneous activity measured during resting-state EEG and some self-reported emotional and cognitive performance measures. Results showed weak positive associations of FAA with two subscales of the EQi:YV questionnaire (Stress Management, General Mood). TBR was negatively associated with the Stress Management subscale of the EQi:YV and reading comprehension measured by the MT task of reading comprehension.

The observed results are partially consistent with the scientific literature indicating FAA as a measure of affective experience (e.g., Perone & Vaughan, 2024). A more positive FAA was weakly associated with better affective indexes, i.e., higher scores on the Stress Management and General Mood scales of the EQi:YV. The findings on the relationships between TBR and self-reported emotional traits of the EQi:YV (Stress Management subscale) are also consistent with the literature, indicating that lower TBR might be related to better affective traits (e.g., Putman et al., 2010; Tortella-Feliu et al., 2014). Furthermore, this work has shown how TBR could be an informative measure concerning children's reading comprehension skills. In this regard, we observed that lower TBRs correspond to better performances in the MT reading comprehension task. Previously, only theta rhythm has been found to be associated with related aspects of reading comprehension, with results that were not always consistent (Lum et al., 2020). However, it is important to underline that the studies used experimental tasks that differed from each other and from the one used in the present work. This limitation prevents us from making direct and reliable comparisons between our results and those of other studies. Furthermore, as highlighted by Lum and collaborators (2020), studies similar to our on primary school children are almost absent, which provides a direction for future research. Nonetheless, we can state that our results are consistent with the general literature on TBR, which reports that a lower TBR is related to better executive function abilities (e.g., Perone et al., 2018; Clarke et al., 2019).

Our work has some limitations. First, to prioritize the sensitivity of the analysis, no corrections for multiple comparisons were applied in the correlations, thus limiting the risk of false negatives. Furthermore, we could not clearly identify the relationships between the FAA and self-reported affective characteristics. This may be due to several factors. Self-reported measures suffer from biases that can affect the results, such as social desirability or the different interpretations participants may give to the questions (Paulhus, 1984; Barrett, 2004). We tried to limit these issues by using control scales such as the EQi: YV's Positive Impression and Incoherence index scales and by providing adequate instructions and care to the children who participated in this study. However, our data may also reflect a lack of or poor relationship between resting FAA and self-reported emotional characteristics for the age range we investigated. Indeed, understanding of the dynamics of FAA changes across the lifespan is limited, and most studies have examined age ranges other than the one reported in our work. Further studies would be needed to understand how FAA changes across the lifespan at different developmental points. Furthermore, research on changes in the FAA before and after programs or interventions on both short and longer timescales would be needed to understand the conditions that impact the processes that the FAA reflects (Hill et al., 2020; Anaya et al., 2021). Understanding whether changes on shorter timescales predict changes on longer timescales could advance our understanding of how brain dynamics at critical moments interact with those over-development (Perone et al., 2021). Anderson and Perone (2018) observed the poor standardization of resting-state EEG measurements across studies. This aspect is linked to the numerous methodological differences present in resting-state EEG studies. The introduction of standardized protocols not only in the clinical setting but also for resting-state EEG research should, in fact, be a priority effort. The lack of standardized protocols and measures limits the possibilities of generalizing study results. Further investigations on these issues are essential to deepening our knowledge of the relationship between spontaneous activity in the resting state and behavioral characteristics and performance in laboratory studies and everyday life. Indeed, no theory specifically links resting-state brain activity,

task-related brain activity, and task performance (Anderson & Perone, 2018). It has been proposed that resting-state EEG represents a basic brain organization that supports or coordinates features experienced during more specific tasks, such as cognitive and affective ones (e.g., Bonnard et al., 2016; Lum et al., 2020). Although we have reported that the scientific literature has highlighted associations between resting-state activity and real-world behaviors, the question of what exactly links resting-state activity and such outcomes remains open.

3.7.2. Correlation between LPP and FAA

As a conclusion of this exploratory study, we wanted to investigate possible relationships between ERPs and resting-state EEG. Following the recommendations of Hajcak et al. (2010), we probed the relationship between the LPP measured during an emotional word categorization task and the FAA measured at rest in a group of children. In particular, we observed a statistically significant negative correlation between the significant difference in the LPP between emotional words and neutral words (**Δ**Fp1; 550-650 ms) and the FAA (Fp1/Fp2). A more positive LPP for emotional stimuli than neutral ones may indicate a higher emotional reactivity and a lower capacity for attentional suppression (Desatnik et al., 2017; McLean et al., 2020). Furthermore, a more negative FAA has been associated with worse affective abilities and experiences (Perone & Vaughan, 2024). Consistent with our findings, McLean et al. (2020) found that a greater difference in LPP amplitude between emotional and neutral images recorded anteriorly and within 700 ms was associated with greater depressive symptoms (McLean et al., 2020). These results are relevant for studying individual differences in emotional processing and affective development (Dennis & Hajcak, 2009; Dickey et al., 2021).

Conclusion

The results of this work represent a first attempt to address the gap in the scientific literature regarding the neurophysiology of emotions in relation to linguistic processes during development, particularly in primary school children. By recording event-related potentials (ERPs) during an emotional word categorization task, we observed a more positive modulation of the Late Positive Potential (LPP) for emotional words compared to neutral words. This finding suggests that emotional words engage greater attentional resources than neutral words in primary school children.

Interestingly, this LPP modulation was associated with resting-state frontal alpha asymmetry (FAA), a neural index that has been variably linked to individual affective characteristics. This result provides novel evidence that LPP modulations may reflect individual affective differences. Emotional words, indeed, serve an organizing function in thought and action, supporting concept formation and offering a valuable window into the structure of affective experience.

Furthermore, we identified a potential link between spontaneous neural activity during resting state and both self-reported emotional traits and cognitive performance in primary school children. Although the mechanisms linking resting-state activity to emotional traits and laboratory or real-life cognitive performance remain unclear, this finding reinforces the connection between electrophysiological and behavioral measures.

In particular, the theta/beta ratio was related to stress management, a self-reported emotional dimension, and key cognitive skills in development, such as reading comprehension. Finally, although to a lesser extent than the theta/beta ratio, frontal alpha asymmetry was consistently associated with emotional traits, including general mood and stress management.

This work has highlighted some relevant directions for future research. First, it is essential to develop standardized materials for a more reliable study of the electrophysiological correlates of emotional

word processing in primary school children. Indeed, there are no validated emotional word databases in children, which may also explain the lack of studies on emotional word processing in this age group. Second, future studies should differentiate words between emotional and neutral categories and between emotional categories (e.g., positive and negative words). Although we have shown that ERP modulations for emotional versus neutral words can be informative concerning individual affective characteristics, modulations of different categories of emotional words may be more specifically associated with individual dimensions and traits measured in children. Finally, future studies should investigate the relationship between spontaneous EEG activity and both emotional and cognitive individual characteristics of primary school children measured in different contexts. Although we have shown some relationships between resting activity and emotional and cognitive attributes in children consistent with previous studies, the scientific literature lacks a solid theory that explains such relationships. Furthermore, studying the short- and long-term changes of spontaneous activity during development and in relation to critical characteristics and life events during the individual maturation process is essential. Future studies that take into account these considerations could add decisive evidence for the identification of reliable markers of vulnerability to psychopathology based on neurophysiological indices.

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Appendix A. Correlations between questionnaires and cognitive tasks.

Variable		1	2	3	4	5	6	7	8	9	10	11	12	13
Intrapersonal (1)	r	—												
	p	—												
Interpersonal (2)	r	0.119	—											
	p	0.539	—											
Stress Management (3)	r	0.420	-0.036	—										
	p	0.023	0.855	—										
Adaptability (4)	r	0.225	0.260	-0.116	—									
	p	0.241	0.173	0.548	—									
General Mood (5)	r	0.392	0.017	0.381	0.239	—								
	p	0.035	0.932	0.041	0.211	—								
EQ (6)	r	0.747	0.449	0.655	0.511	0.464	—							
	p	< .001	0.015	< .001	0.005	0.011	—							
Difficulty Identifying Feelings (7)	r	-0.553	-0.101	-0.266	-0.163	-0.597	-0.456	—						
	p	0.002	0.609	0.171	0.406	< .001	0.015	—						
Difficulty Describing Feelings (8)	r	-0.659	-0.003	-0.190	-0.183	-0.306	-0.433	0.576	—					
	p	< .001	0.987	0.332	0.351	0.113	0.021	0.001	—					
Alexithymia (9)	r	-0.595	0.001	-0.136	-0.277	-0.530	-0.416	0.815	0.786	—				
	p	< .001	0.995	0.492	0.154	0.004	0.028	< .001	< .001	—				
Externally-oriented Thinking (10)	r	0.181	0.145	0.281	-0.176	-0.064	0.196	-0.135	-0.174	0.257	—			
	p	0.356	0.461	0.147	0.371	0.745	0.318	0.485	0.367	0.178	—			
MT task (11)	r	0.091	0.177	-0.107	0.247	0.233	0.133	-0.112	-0.308	-0.241	0.0004	—		
	p	0.637	0.357	0.581	0.196	0.224	0.492	0.564	0.104	0.208	0.998	—		
CPM (12)	r	-0.247	0.040	-0.292	0.083	0.213	-0.210	-0.156	-0.269	-0.344	-0.275	0.200	—	
	p	0.196	0.836	0.124	0.670	0.267	0.274	0.418	0.158	0.068	0.150	0.289	—	
Working Memory (13)	rho	-0.290	0.015	0.048	0.172	0.137	-0.013	-0.096	0.028	0.009	0.154	0.485	0.240	—
	p	0.142	0.940	0.813	0.392	0.497	0.948	0.634	0.892	0.965	0.445	0.010	0.228	—
OMRT (14)	r	0.048	0.070	-0.275	0.090	-0.063	-0.068	0.076	0.100	0.179	0.253	0.157	-0.046	-0.009
	p	0.811	0.727	0.165	0.656	0.753	0.735	0.701	0.611	0.361	0.193	0.424	0.818	0.963

Appendix B. Mean, Standard Error and Standard Deviation of FAA and TBR.

TBR	Frontal	Central	Parietal
Mean	1,671	1,698	1,479
Std. Error of Mean	0.062	0.073	0.073

	F3/F4	Fp1/Fp2	AF3/AF4	F7/F8	Fp1	Fpz	Fp2	AF3	AF4	F7	F3	Fz
Mean	0.005	−0.266	−0.272	0.187	1.691	1.740	1.617	1.634	1.557	1.572	1.619	1.859
Std. Error of Mean	0.278	0.257	0.274	0.299	0.059	0.061	0.066	0.059	0.063	0.060	0.068	0.072
Std. Deviation	1.521	1.409	1.499	1.636	0.322	0.335	0.360	0.325	0.344	0.329	0.372	0.392

	F4	F8	FC5	FC1	FC2	FC6	T7	C3	Cz	C4	T8	CP5
Mean	1.535	1.549	1.499	1.856	1.777	1.435	1.492	1.590	1.964	1.540	1.360	1.519
Std. Error of Mean	0.058	0.057	0.066	0.072	0.079	0.063	0.077	0.084	0.075	0.077	0.070	0.073
Std. Deviation	0.320	0.314	0.361	0.395	0.433	0.344	0.421	0.459	0.411	0.422	0.384	0.399

	CP1	CP2	CP6	P7	P3	Pz	P4	P8	POz	O1	Oz	O2
Mean	1.659	1.617	1.472	1.396	1.413	1.583	1.442	1.359	1.467	1.290	1.369	1.296
Std. Error of Mean	0.076	0.071	0.081	0.089	0.074	0.070	0.081	0.083	0.074	0.086	0.087	0.083
Std. Deviation	0.418	0.390	0.442	0.489	0.403	0.383	0.444	0.456	0.406	0.472	0.478	0.454

Appendix C. Correlations between TBR (grouped by frontal, central, and parietal electrodes) and emotional questionnaires and cognitive performance.

		TBR Frontal	TBR Central	TBR Parietal
intrapersonal	r	−0.104	0.115	0.130
	p	0.590	0.553	0.502
interpersonal	r	0.044	-6.616×10	−0.001
	p	0.820	0.997	0.996
Stress Management	r	−0.020	−0.128	−0.140
	p	0.917	0.507	0.470
Adaptability	r	−0.088	0.010	0.058
	p	0.652	0.959	0.764
General Mood	r	−0.168	−0.129	−0.127
	p	0.382	0.506	0.510
EQ	r	−0.073	−0.022	−0.003
	p	0.706	0.908	0.986
Difficulty Identifying Feelings	r	0.094	0.059	0.065
	p	0.629	0.760	0.736
Difficulty Describing Feelings	r	−0.001	−0.199	−0.125
	p	0.996	0.300	0.519
Alexithymia	r	−0.078	−0.193	−0.151
	p	0.686	0.315	0.433
Externally-oriented Thinking	r	−0.233	−0.287	−0.287
	p	0.178	0.131	0.131
MT Task	r	−0.308	−0.105	−0.312
	p	0.097	0.580	0.093
CPM	r	0.181	0.106	0.132
	p	0.338	0.577	0.487
Working Memory	rho	−0.118	−0.231	−0.323
	p	0.556	0.247	0.100
OMRT	r	−0.088	0.020	0.052
	p	0.657	0.919	0.792

Appendix D. Correlations between EEG resting-state measures (FAA and TBR) and EQi:YV.

Variable		F3/F4	Fp1/Fp2	AF3/AF4	F7/F8	Fp1	Fpz	Fp2	AF3	AF4	F7	F3	Fz
Intrapersonal	r	-0.127	-0.091	-0.181	0.003	0.080	0.100	0.156	0.116	0.086	0.164	-0.104	-0.167
	p	0.511	0.637	0.349	0.987	0.681	0.607	0.419	0.549	0.658	0.397	0.593	0.387
Interpersonal	r	-0.026	-0.142	0.070	0.113	0.088	0.139	0.175	0.034	0.083	-0.017	0.057	-0.009
	p	0.892	0.461	0.718	0.560	0.650	0.473	0.365	0.862	0.670	0.932	0.770	0.962
Stress Management	r	0.260	0.260	-0.018	0.333	-0.124	-0.095	-0.047	-0.111	-0.028	-0.037	-0.105	-0.248
	p	0.174	0.173	0.925	0.078	0.523	0.622	0.807	0.566	0.885	0.847	0.587	0.195
Adaptability	r	-0.297	-0.167	0.007	0.034	-0.141	-0.116	-0.004	0.042	0.084	-0.143	-0.015	-0.139
	p	0.118	0.388	0.972	0.861	0.467	0.551	0.982	0.828	0.666	0.460	0.937	0.471
General Mood	r	-0.061	0.180	-0.209	0.333	0.107	0.151	0.206	-0.042	0.175	0.026	-0.098	-0.235
	p	0.754	0.349	0.276	0.077	0.580	0.434	0.284	0.827	0.364	0.892	0.611	0.220
EQ	r	-0.035	-0.005	-0.253	0.234	-0.066	-0.017	0.088	0.011	0.078	-0.021	-0.086	-0.261
	p	0.857	0.981	0.185	0.222	0.732	0.931	0.650	0.954	0.688	0.916	0.656	0.172

Variable		F4	F8	FC5	FC1	FC2	FC6	T7	C3	Cz	C4	T8	CP5
Intrapersonal	r	0.005	-0.007	0.130	-0.138	0.036	0.015	0.210	0.148	0.095	0.130	-0.159	0.117
	p	0.980	0.972	0.501	0.475	0.851	0.938	0.274	0.444	0.624	0.502	0.410	0.545
Interpersonal	r	-0.029	-0.032	-0.061	0.079	-0.093	-0.179	-0.038	-0.030	0.089	-0.003	-0.153	-0.119
	p	0.883	0.868	0.754	0.685	0.632	0.354	0.846	0.876	0.647	0.987	0.429	0.537
Stress Management	r	0.007	-0.231	0.0003	-0.152	-0.092	0.025	-0.043	-0.158	-0.318	-0.113	-0.200	-0.043
	p	0.972	0.229	0.998	0.431	0.634	0.899	0.825	0.414	0.093	0.560	0.298	0.824
Adaptability	r	-0.147	0.032	0.089	-0.056	-0.187	-0.199	-0.057	0.086	-0.043	0.025	-0.039	-0.103
	p	0.448	0.871	0.647	0.774	0.332	0.302	0.767	0.657	0.824	0.899	0.839	0.595
General Mood	r	0.036	-0.048	0.010	-0.310	-0.165	0.198	-0.107	-0.062	-0.192	0.081	-0.211	-0.007
	p	0.854	0.805	0.958	0.102	0.393	0.302	0.580	0.748	0.320	0.677	0.273	0.971
EQ	r	-0.063	-0.127	0.067	-0.135	-0.142	-0.118	0.022	-0.004	-0.128	-0.003	-0.236	-0.058
	p	0.746	0.511	0.729	0.485	0.463	0.543	0.908	0.982	0.509	0.988	0.217	0.764

Variable		CP1	CP2	CP6	P7	P3	Pz	P4	P8	POz	O1	Oz	O2
Intrapersonal	r	0.098	0.083	0.046	0.267	0.145	0.178	0.125	0.120	0.152	0.147	0.129	0.068
	p	0.613	0.669	0.813	0.162	0.453	0.355	0.517	0.535	0.432	0.448	0.505	0.725
Interpersonal	r	0.044	0.044	-0.146	-0.014	0.113	0.089	0.041	-0.142	0.033	-0.105	-0.229	-0.165
	p	0.819	0.820	0.451	0.941	0.559	0.645	0.834	0.463	0.864	0.589	0.231	0.393
Stress Management	r	-0.412	-0.376	-0.077	-0.003	-0.040	-0.272	-0.103	-0.046	-0.217	-0.156	-0.165	-0.195
	p	0.026	0.044	0.693	0.988	0.837	0.154	0.595	0.813	0.257	0.420	0.393	0.311
Adaptability	r	0.004	-0.037	-0.058	0.004	0.036	0.064	-0.025	-0.186	-0.011	-0.126	-0.061	-0.224
	p	0.985	0.849	0.766	0.982	0.854	0.743	0.896	0.333	0.954	0.514	0.752	0.243
General Mood	r	-0.162	-0.190	0.072	0.042	0.032	-0.055	0.025	0.048	-0.064	-0.044	-0.109	-0.065
	p	0.400	0.323	0.710	0.830	0.870	0.776	0.896	0.806	0.740	0.822	0.573	0.737
EQ	r	-0.174	-0.176	-0.094	0.099	0.084	-0.027	-0.006	-0.099	-0.055	-0.113	-0.139	-0.224
	p	0.368	0.361	0.628	0.609	0.663	0.891	0.977	0.608	0.777	0.558	0.474	0.242

Appendix E. Correlations between EEG resting-state measures (FAA and TBR) and AQC.

Variable		F3/F4	Fp1/Fp2	AF3/AF4	F7/F8	Fp1	Fpz	Fp2	AF3	AF4	F7	F3	Fz
Difficulty Identifyng Feelings	r	0.126	−0.038	−0.005	0.020	−0.009	−0.077	−0.104	0.126	0.011	0.041	0.147	0.198
	p	0.514	0.843	0.978	0.919	0.963	0.691	0.592	0.516	0.956	0.832	0.447	0.304
Difficulty Describing Feelings	r	0.122	0.225	−0.038	0.008	−0.102	−0.077	−0.137	−0.146	−0.123	−0.080	0.105	−0.046
	p	0.529	0.241	0.845	0.968	0.597	0.691	0.478	0.449	0.525	0.679	0.586	0.814
Alexithymia	r	0.202	0.196	−0.040	0.097	−0.072	−0.125	−0.166	−0.104	−0.153	−0.025	−0.040	−0.007
	p	0.292	0.308	0.836	0.615	0.711	0.517	0.390	0.593	0.429	0.899	0.837	0.970
Externally-oriented Thinking	r	0.115	0.204	−0.030	0.201	−0.028	−0.106	−0.081	−0.227	−0.230	0.010	0.089	−0.256
	p	0.553	0.287	0.879	0.295	0.884	0.585	0.677	0.235	0.230	0.960	0.667	0.179

Variable		F4	F8	FC5	FC1	FC2	FC6	T7	C3	Cz	C4	T8	CP5
Difficulty Identifyng Feelings	r	0.056	0.074	−0.041	0.271	0.174	−0.084	0.054	0.075	0.141	0.007	0.284	0.005
	p	0.774	0.703	0.834	0.154	0.368	0.664	0.782	0.699	0.467	0.973	0.135	0.980
Difficulty Describing Feelings	r	−0.132	−0.129	−0.269	0.084	−0.082	−0.284	−0.210	−0.149	−0.148	−0.185	−0.029	−0.191
	p	0.496	0.504	0.158	0.664	0.674	0.135	0.274	0.442	0.445	0.337	0.883	0.320
Alexithymia	r	−0.143	−0.103	−0.182	0.067	0.006	−0.223	−0.072	−0.147	−0.108	−0.183	0.057	−0.148
	p	0.459	0.596	0.344	0.731	0.974	0.246	0.709	0.446	0.576	0.341	0.771	0.444
Externally-oriented Thinking	r	−0.250	−0.169	−0.013	−0.296	−0.111	−0.075	0.047	−0.281	−0.275	−0.212	−0.173	−0.110
	p	0.191	0.380	0.948	0.120	0.568	0.700	0.810	0.139	0.149	0.270	0.369	0.569

Variable		CP1	CP2	CP6	P7	P3	Pz	P4	P8	POz	O1	Oz	O2
Difficulty Identifyng Feelings	r	0.122	0.107	0.035	−0.042	−0.025	0.035	−0.042	0.024	0.055	0.041	0.189	0.021
	p	0.529	0.581	0.856	0.828	0.898	0.858	0.827	0.903	0.776	0.835	0.325	0.912
Difficulty Describing Feelings	r	−0.110	−0.141	−0.146	−0.252	−0.075	−0.092	−0.204	−0.123	−0.164	−0.250	−0.275	−0.234
	p	0.571	0.466	0.451	0.188	0.698	0.636	0.288	0.527	0.396	0.192	0.148	0.221
Alexithymia	r	−0.156	−0.115	−0.186	−0.248	−0.130	−0.187	−0.242	−0.134	−0.207	−0.234	−0.162	−0.245
	p	0.419	0.552	0.334	0.194	0.502	0.332	0.205	0.487	0.280	0.221	0.402	0.201
Externally-oriented Thinking	r	0.040	−0.248	−0.314	−0.192	−0.194	0.137	−0.255	−0.198	0.126	−0.282	−0.273	−0.301
	p	0.879	0.194	0.097	0.318	0.313	0.760	0.181	0.302	0.786	0.139	0.151	0.113

Appendix F. Correlations between EEG resting-state measures (FAA and TBR) and cognitive tasks.

Variable		F3/F4	Fp1/Fp2	AF3/AF4	F7/F8	Fp1	Fpz	Fp2	AF3	AF4	F7	F3	Fz
MT task	r	0.002	−0.302	−0.207	−0.113	−0.279	−0.240	−0.262	−0.239	−0.200	−0.365	−0.301	−0.210
	p	0.990	0.104	0.272	0.553	0.135	0.201	0.162	0.204	0.289	0.047	0.106	0.266
CPM	r	0.110	−0.098	−0.016	−0.042	0.121	0.087	0.213	0.106	0.273	0.001	0.142	0.135
	p	0.564	0.605	0.934	0.825	0.525	0.649	0.258	0.578	0.144	0.995	0.455	0.477
Working Memory	rho	0.338	−0.036	−0.033	−0.060	−0.110	−0.038	−0.071	−0.127	0.043	−0.020	−0.196	−0.037
	p	0.085	0.859	0.871	0.765	0.583	0.852	0.726	0.528	0.833	0.922	0.326	0.854
OMRT	r	−0.301	−0.127	0.194	0.150	−0.043	−0.205	−0.121	−0.086	−0.135	0.082	−0.105	−0.105
	p	0.119	0.518	0.496	0.447	0.828	0.295	0.541	0.663	0.492	0.680	0.595	0.596

Variable		F4	F8	FC5	FC1	FC2	FC6	T7	C3	Cz	C4	T8	CP5
MT task	r	−0.372	−0.253	−0.318	−0.225	−0.267	−0.227	−0.497	−0.122	0.022	−0.187	−0.098	−0.386
	p	0.043	0.177	0.087	0.231	0.154	0.228	0.005	0.522	0.909	0.322	0.606	0.035
CPM	r	0.245	0.091	0.130	0.083	0.093	0.252	0.056	0.020	0.161	0.123	0.289	0.199
	p	0.191	0.633	0.493	0.664	0.625	0.179	0.768	0.918	0.397	0.517	0.121	0.291
Working Memory	rho	−0.101	−0.111	−0.075	−0.049	−0.079	−0.106	−0.282	−0.251	−0.102	−0.280	0.018	−0.278
	p	0.615	0.582	0.710	0.809	0.696	0.597	0.155	0.207	0.612	0.158	0.930	0.160
OMRT	r	−0.029	0.131	0.027	−0.039	0.092	0.058	0.059	−0.002	−0.002	0.061	0.128	−0.052
	p	0.885	0.506	0.892	0.843	0.643	0.770	0.765	0.990	0.993	0.757	0.516	0.791

Variable		CP1	CP2	CP6	P7	P3	Pz	P4	P8	POz	O1	Oz	O2
MT task	r	−0.066	−0.239	−0.279	−0.233	−0.350	−0.266	−0.296	−0.264	−0.132	−0.334	−0.177	−0.321
	p	0.731	0.203	0.135	0.215	0.058	0.155	0.112	0.159	0.487	0.071	0.350	0.083
CPM	r	0.108	0.130	0.214	0.210	0.121	0.080	0.178	0.070	0.089	0.127	0.120	0.131
	p	0.570	0.494	0.256	0.266	0.523	0.675	0.347	0.713	0.639	0.503	0.526	0.492
Working Memory	rho	−0.327	−0.267	−0.205	−0.260	−0.324	−0.302	−0.251	−0.186	−0.269	−0.332	−0.311	−0.239
	p	0.096	0.178	0.305	0.190	0.099	0.132	0.207	0.354	0.175	0.090	0.115	0.230
OMRT	r	0.002	−0.003	−0.038	−0.020	0.032	0.119	0.009	−0.045	0.025	−0.007	0.053	−0.126
	p	0.991	0.990	0.849	0.920	0.870	0.548	0.963	0.820	0.899	0.972	0.788	0.522