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AGE-INDUCED DIFFERENCES IN BRAIN NEURAL ACTIVATION ELICITED BY VISUAL EMOTIONAL STIMULI: A HIGH-DENSITY EEG STUDY

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Abstract—Identifying the brain sources of neural activation during processing of emotional information remains a very challenging task. In this work, we investigated the response to different emotional stimuli and the effect of age on the neuronal activation. Two negative emotion conditions, i.e., 'anger' and 'fear' faces were presented to 22 adult female participants (11 young and 11 elderly) while acquiring high-density electroencephalography (EEG) data of 256 channels. Brain source localization was utilized to study the modulations in the early N170 event-related-potential component. The results revealed alterations in the amplitude of N170 and the localization of areas with maximum neural activation. Furthermore, age-induced differences are shown in the topographic maps and the neural activation for both emotional stimuli. Overall, aging appeared to affect the limbic area and its implication to emotional processing. These findings can serve as a step toward the understanding of the way the brain functions and evolves with age which is a significant element in the design of assistive environments.

Key words: emotional stimuli, age effect, brain source localization, high-density EEG.

INTRODUCTION

Human nature is characterized by its social interaction. This interaction involves other people identities, social behavior, emotions and intentions (Fusar-poli et al., 2009). The ability to encode emotional information is critical toward recognizing potential threats and establishing adaptive behavior (Batty and Taylor, 2003). Emotion is an episodic, biologically based pattern of perception, in response to a specific stimulus (Keltner and Gross ,1999). Emotion research utilizes different types of stimuli, such as pictures (Ekman, 1992), sounds (Redondo et al., 2008) and words (Strapparava and Valitutti, 2004). Facial expressions are a nonverbal communication tool while they can contain information that is useful or even vital in everyday life (Britton et al., 2006). As Ekman said, "emotions last only a few seconds and have a distinct duration depending on their type" (Ekman, 1992). There is evidence that emotional facial stimuli, e.g. fear results in greater neural activation in certain brain areas and also greater autonomic response than affective pictures such as IAPS (Britton et al., 2006; Vuilleumier and Pourtois, 2007).

Multiple studies have been presented on emotion processing in the human brain. Emotional face perception is a complicated visual process involving a wide brain network (Gobbini and Haxby, 2007). A lot of brain regions seem to consist a so-called face-processing network, responsible for the initial perception, recognition, and further emotional processing. This face-processing network includes in general: visual areas, limbic areas, temporo-parietal areas, prefrontal areas, subcortical areas (i.e., putamen) and cerebellum (Fusar-poli et al., 2009). Brain imaging studies have shown that several regions in visual cortex exhibit greater activation to emotional than neutral faces (Ishai et al., 2004). Even the time sequence of activation seems to be different and characteristic for each emotion. Unfortunately, the structure of each emotion remains not clear. EEG studies present differences between positive and negative emotional stimuli (Costa et al., 2006) with different results about the valence effect on several latency ranges (Yuan et al., 2007; Olofsson et al., 2008). Even fMRI studies which have proposed lots of different brain areas activated during each emotion present inconsistent results (Sabatinelli and Bradley, 2005; Fusar-poli et al., 2009; Campanella et al., 2013).

The exact way in which the human brain works in response to facial expression might still be unknown. There is evidence though that human brain performs

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Abbreviations: EEG, electroencephalography; EPN, early posterior negativity; ERP, event-related-potential; LORETA, Low Resolution Electromagnetic Tomography; LPC, late positive complex; POFA, Pictures of Facial Affect; SST, Socioemotional Selectivity Theory.

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several functions such as emotion recognition and, subsequently, physiological and autonomic changes (Britton et al., 2006). Face expression and facial identity seems to be processed along two different routes. It seems that visual structural encoding precedes and expression processing follows. However, expression perception can be affected by face identity and familiarity, suggesting dependencies between these processes (Vuilleumier and Pourtois, 2007).

Complex visual analysis and the emotional enhancement start approximately 50 ms after the first discriminatory activation. According to Vuilleumier and Pourtois, this fact might reflect additional processing in other brain areas, not confined within the limbic system (Braeutigam and Swithenby, 2003; Vuilleumier and Pourtois, 2007). EEG and MEG studies have shown that face processing activates specialized neurons in inferior temporal cortex within 200 ms post-stimulus, as typically indexed by the N170 component (Campanella et al., 2006). This delayed modulation of neuronal activation due to emotional facial expressions would be in favor of the existence of a direct pathway connecting the visual cortex and the limbic region, which is a major contributor in affective processing (Amaral et al., 2003). Moreover, the activation of fronto-parietal areas mirrors the attentional engagement toward the more prominent facial stimuli (Pessoa et al., 2002).

Aging has been related to a progressive cognitive slowing, which is apparent in a variety of cognitive tasks and is related to various neurodegenerative changes, such as total brain volume decrease and alteration in white and gray matter integrity (Firbank et al., 2007). Several brain areas present age-related structural and functional impairment, i.e., prefrontal areas, whereas others such as visual areas are usually not significantly affected (Raz et al., 2010). There is evidence of delayed evoked responses of early event-related-potentials (ERPs) to faces, suggesting an overall deceleration of perception with age (Gazzaley et al., 2008; Rousselet et al., 2010; Bieniek et al., 2013). This fact, in turn, would affect higher cognitive functions such as working memory (Gazzaley et al., 2008) and attention (Vuilleumier and Pourtois, 2007). Bieniek et al. suggested that early ERPs to faces (< 200 ms) delay due to aging may have a cortical origin (Bieniek et al., 2013). It is noteworthy that Rousselet et al. reported a delay of about 1 ms/year in visual processing from the age of 20 years old onward (Rousselet et al., 2010). However, results are still inconsistent while other studies report no aging effect of early ERPs to faces (Daniel and Bentin, 2012; Wiese et al., 2012).

The negative N170 component has been the most thoroughly investigated ERP component among studies related to facial processing. Therefore, N170 has been regarded as a selective face component. It is generated by the fusiform gyrus recorded of occipito-temporal sites around 170 ms (between 140–200 ms) after stimulus onset. It is modulated by emotional and identity category and differentiates from facial to non-facial visual stimuli (Campanella et al., 2006). It was generally believed that emotional effects on N170 are not selective for any specific expression, suggesting a non-specific role of structural encoding of facial cues than with emotional significance (Campanella et al., 2002). However, current data suggest that it may also reflect an early modulation from neural systems involved in rapid emotional processing (Blau et al., 2007). Hence, N170 amplitude and latency result from a rapid brain process including detection and structural or configular info due to viewing a face (Jacques and Rossion, 2007).

Early posterior negativity (EPN) and Late Posterior Positivity (LPP) are also two ERP components commonly studied in emotional processing studies. Recent studies suggest that EPN is sensitive to task-induced changes in stimulus complexity, showing that current categorization of the stimuli could even diminish the emotion-specific modulation (Mavratzakis et al., 2016). Past research has shown that negative expressions are most often confused (Calvo and Beltrán, 2013; Recio et al., 2014) and so EPN activity could have been driven, at least partially, by the emotion recognition difficulty in the case of our study. Current data remain inconsistent, while study results vary widely. Mavratzakis et al. showed that EPN slightly increased for fearful faces compared to neutral or happy, and was pronounced for scenes with positive content (Mavratzakis et al., 2016) whereas Recio et al. presented that the EPN effects due to facial expressions were emotion-unspecific (Recio et al., 2014). Finally, concerning EPN in response to emotional facial stimuli, the time course of the component temporally coincides with N170 component (Bayer and Schacht, 2014). This fact remains a matter of controversy while recent studies suggested the involvement of at least partially dissociable neural sources (Rellecke et al., 2012) and that was another reason for excluding EPN. Also, late positive complex (LPC), seems to have also a negativity–bias effect regarding facial expressions, showing as well high task-emotional dependence of emotion effects (Bayer and Schacht, 2014). Emotion-related LPC consists a more complex and advanced processing stage, depending on the participant's state (Rellecke et al., 2012). A recent study showed that LPC presented significantly enhanced modulation only by scene, relativity to face stimuli (Thom et al., 2014). Regarding all the above, we decided to study only the face-specific N170 ERP component for our innovative study.

The temporal evolution of distinct emotions is a crucial component, and it should be taken into account in emotion research. In this study, high-density EEG recordings are utilized, and the active neuronal sources in the brain are investigated by applying the sLORETA brain source localization technique. The face-selective N170 component characteristics were used to constrain brain localization, having in mind that a neurophysiologic marker evoked by emotional stimuli will reflect differences in the intensity of responses in brain regions specifically devoted to 'anger' or 'fear' emotion conditions. The fast detection of environmental changes by the human nervous system has often been assessed in event-related potential studies. Given the discrepancies in the literature, the aim of this study is to

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