



## Distinct cerebellar lobules process arousal, valence and their interaction in parallel following a temporal hierarchy



Charis Styliadis<sup>a</sup>, Andreas A. Ioannides<sup>b</sup>, Panagiotis D. Bamidis<sup>a</sup>, Christos Papadelis<sup>c,\*</sup>

<sup>a</sup> Medical School, Faculty of Health Sciences, Aristotle University of Thessaloniki, P.O. Box 376, 54124 Thessaloniki, Greece

<sup>b</sup> Laboratory for Human Brain Dynamics, AAI Scientific Cultural Services Ltd., Office 501, Galaxias Building Block A, 33 Arch. Makarios III Avenue, 1065 Nicosia, Cyprus

<sup>c</sup> Division of Newborn Medicine, Department of Medicine, Boston Children's Hospital, Harvard Medical School, 9 Hope Av., 02453 Waltham, USA

### ARTICLE INFO

#### Article history:

Accepted 3 February 2015

Available online 7 February 2015

#### Keywords:

Cerebellum

Arousal

Valence

Emotions

Magnetoencephalography

### ABSTRACT

The cerebellum participates in emotion-related neural circuits formed by different cortical and subcortical areas, which sub-serve arousal and valence. Recent neuroimaging studies have shown a functional specificity of cerebellar lobules in the processing of emotional stimuli. However, little is known about the temporal component of this process. The goal of the current study is to assess the spatiotemporal profile of neural responses within the cerebellum during the processing of arousal and valence. We hypothesized that the excitation and timing of distinct cerebellar lobules is influenced by the emotional content of the stimuli. By using magnetoencephalography, we recorded magnetic fields from twelve healthy human individuals while passively viewing affective pictures rated along arousal and valence. By using a beamformer, we localized gamma-band activity in the cerebellum across time and we related the foci of activity to the anatomical organization of the cerebellum. Successive cerebellar activations were observed within distinct lobules starting ~160 ms after the stimuli onset. Arousal was processed within both vermal (VI and VIIIa) and hemispheric (left Crus II) lobules. Valence (left VI) and its interaction (left V and left Crus I) with arousal were processed only within hemispheric lobules. Arousal processing was identified first at early latencies (160 ms) and was long-lived (until 980 ms). In contrast, the processing of valence and its interaction to arousal was short lived at later stages (420–530 ms and 570–640 ms respectively). Our findings provide for the first time evidence that distinct cerebellar lobules process arousal, valence, and their interaction in a parallel yet temporally hierarchical manner determined by the emotional content of the stimuli.

© 2015 Elsevier Inc. All rights reserved.

### Introduction

Neurobiological and cognitive models conceptualize emotions respectively in terms of either discrete categories or underlying dimensions (Russell, 2009). Discrete-category theories propose the presence of distinct universal emotions that have discriminable signatures (Ekman and Cordaro, 2011; Ekman, 1992; Panksepp, 2005, 2007, 2011) in cortical and subcortical regions (Murphy et al., 2003; Phan et al., 2002) and specific temporal activity profiles (Esslen et al., 2004;

Hot and Sequeira, 2013). Dimensional theories conceptualize emotions as a representation of at least two independent dimensions, (i.e., arousal and valence) that span the affective space as orthogonal entities (Russell, 1980). Arousal and valence are each processed by distinct neural circuits of cortical and subcortical regions regardless of the sensory modality (Anderson et al., 2003; Dolcos et al., 2004; Lewis et al., 2007; Royet et al., 2000). These distinct brain regions may become active in emotion-specific time sequences, which depend on both arousal and valence (Olofsson et al., 2008). Both emotional theories support an anatomical segregation and specialization of cortical and subcortical structures either for distinct emotions (e.g., Adolphs, 2002; Davidson and Irwin, 1999; Wicker et al., 2003) or different dimensions of emotions (Anders et al., 2004; Anderson et al., 2003; Dolcos et al., 2004).

The cerebellum is a recent addition to our view of the emotion-related distributed circuitry. Its anatomical integration with circuits associated with emotional processing was initially observed by convergent and multimodal data (Blatt et al., 2013). Though a clear anatomical substrate for cerebello-limbic connection is still absent in humans (Strick et al., 2009), animal studies have shown that vermis (anatomical substrate of the limbic cerebellum, Schmahmann, 2000) has reciprocal

*Abbreviations:* PFC, prefrontal cortex; MFT, magnetic field tomography; SAM, synthetic aperture magnetometry; IAPS, International Affective Picture System; PHA, pleasant with high arousal; PLA, pleasant with low arousal; UHA, unpleasant with high arousal; ULA, unpleasant with low arousal; AC, apparent contrast; ICA, independent component analysis; TFA, time–frequency analysis.

\* Corresponding author at: Newborn Medicine Division, Boston Children's Hospital, Harvard Medical School, 9 Hope Av., 02453 Waltham, USA. Fax: +1 781 216 1172.

E-mail addresses: [cstyliadis@auth.gr](mailto:cstyliadis@auth.gr) (C. Styliadis), [aioannides@aaiscs.com](mailto:aioannides@aaiscs.com)

(A.A. Ioannides), [bamidis@med.auth.gr](mailto:bamidis@med.auth.gr) (P.D. Bamidis), [christos.papadelis@childrens.harvard.edu](mailto:christos.papadelis@childrens.harvard.edu) (C. Papadelis).

connections with the amygdala and the hypothalamus (Schmahmann, 2000; Strick et al., 2009), which both integrate limbic-related activity (Armony, 2012; Beauregard et al., 2001). Anatomical connections from the cingulate cortex to the cerebellum (Schmahmann and Pandya, 1997; Vilensky and van Hoesen, 1981) also favor a cerebellar contribution to emotional processing. Viral tracing techniques in non-human primates have provided evidence that both cerebellar lobules Crus I and Crus II send and receive projections from the prefrontal cortex (PFC) (Kelly and Strick, 2003), which in turn is implicated in high-order processing, important for the integration of cognition and emotion (Gray et al., 2002). Clinical studies on patients with cerebellar lesions have complemented these lines of research. They proposed key roles for the vermis in the processing of primitive emotions and for the cerebellar hemispheric lobules (VI and VII) in the modulation of higher cognitive functions (Schmahmann and Sherman, 1998; Schmahmann, 1991). It was suggested that the higher cognitive functions may include experience of higher order emotions such as happiness (Turner et al., 2007).

These key insights from animal and clinical studies provided the neuroanatomical foundation for later neuroimaging findings of emotion-related activity in specific cerebellar lobules across a variety of experimental designs and stimuli (E et al., 2014; Stoodley and Schmahmann, 2009). Right VI was found to be related to positive emotions, while left VI, right IV/V and bilateral Crus I to negative emotions (E et al., 2014). Additionally, neural activity in the vermis has been associated with high arousal (Colibazzi et al., 2010) and to each of the five primary emotions (Baumann and Mattingley, 2012), while hemispheric VI activity with unpleasantness (Colibazzi et al., 2010) and aversive stimuli (Moulton et al., 2011). The findings by Moulton et al. (2011) suggested a degree of neural specialization within the cerebellum for aversive stimuli, while those by Baumann and Mattingley (2012) highlighted an anatomical segregation and specialization for different emotional categories within the cerebellum.

The recurring observation that different cerebellar lobules are active due to specific emotional content, i.e., for the processing of arousal (Colibazzi et al., 2010; Posner et al., 2009) and valence (Colibazzi et al., 2010) indicates a possible functional segregation and specialization within the cerebellum in the processing of emotional dimensions. This can be anatomically underpinned by the cerebellum's connections with the cortical and subcortical areas of the limbic system that play pivotal roles in the processing of arousal and valence. The amygdala's sub-divisions (i.e., laterobasal and centromedial) have been found to be functionally connected to vermal and hemispheric cerebellar lobules (Roy et al., 2009). These sub-divisions play specific roles in the processing of valence and its interaction to arousal (Ball et al., 2009; Styliadis et al., 2014). Crus I has been proposed to be functionally connected with the medial PFC (Krienen and Buckner, 2009), a region involved in higher-order regulation or evaluative aspects of emotions, such as valence (Etkin et al., 2011). Additionally, Crus II–ventromedial PFC coupling has been suggested to relate to cognitive function whereas vermal–posterior cingulate cortex coupling to emotional processing in geriatric depression (Alalade et al., 2011).

Despite the converging evidence favoring a possible functional segregation and specialization of cerebellar lobules in the processing of emotional dimensions, the temporal component of this process is still unknown. Neuroimaging studies that provided the functional specificity evidence have used functional Magnetic Resonance Imaging (fMRI) and Positron Emission Tomography (PET), techniques with limited temporal resolution ranging from a couple of seconds (for fMRI) to minutes (for PET). Studying the time course of emotions is important due to the different aspects of emotional responses that develop across time (Davidson, 1998). Responses to affective stimuli unfold differentially in time due to arousal and valence with a general agreement for a late arousal effect (200–1000 ms) and a rather varied and less consistent latency range for valence (usually 100–300 ms) (Codispoti et al., 2007; Olofsson et al., 2008). The significance of the temporal component of

emotions can be amplified with respect to the cerebellum's plausible involvement in this process, since the cerebellum is an organ that provides exquisite timing as testified in studies dealing with fine control of movements (Keele and Ivry, 1990; Thach et al., 1992). The operations of the cerebellum are likely to involve timing control at the millisecond level to effectively coordinate neural circuits spread over wide brain areas in the cortex and subcortical areas. It will be thus insightful to disentangle the so far unknown temporal interplay of arousal and valence within the cerebellum by using neuroimaging techniques that offer high temporal resolution.

Although magnetoencephalography (MEG) could serve as an attractive neuroimaging tool for studying the spatiotemporal dynamics of cerebellar neural activity in a fine time scale, it has not been extensively used for this purpose. Traditionally, cerebellar activity was considered not to contribute sufficiently to the MEG signal so as to be properly measured. Undoubtedly, cerebellar activations have been previously reported in numerous MEG studies but these findings were frequently received with skepticism. The first studies to consider that MEG signals can be recorded from the cerebellum and that from such signals cerebellar activations can be reliably identified were from the low temperature laboratory in Helsinki (Jousmäki et al., 1996; Tesche and Karhu, 1997, 2000). The next major attempt was made by Hashimoto and colleagues (Hashimoto et al., 2003) who identified cerebellar responses after the electrical stimulation of the median nerve. A whole-head array with good coverage over the cerebellum was used to record a very large number of trials (~10,000) and the data were analyzed by a beamformer. Cerebellar activity has also been identified even in single trials by using magnetic field tomography (MFT) (Ioannides et al., 1990) in a variety of experimental settings ranging from eye movements, median nerve stimulation, to face affect recognition in control and schizophrenic individuals (Ioannides and Fenwick, 2005). All these studies have provided support to claims that cerebellum activity can be identified and localized with MEG (even when a relatively small number of trials are available) provided the protocol and analysis methods are appropriate. However, the accumulated evidence although mounting must still be viewed as indirect because there is as yet no confirmatory direct evidence with recordings from the cerebellum.

The aim of the present study is to reveal the spatiotemporal profile of cerebellar responses during the processing of emotional stimuli. We hypothesized that different levels of arousal and valence will excite distinct cerebellar lobules in a sequence determined by the emotional content of the stimuli (i.e., the arousal and valence content of the affective experience). By using MEG, we recorded magnetic fields elicited from healthy adult individuals passively viewing affective pictures rated along arousal and valence. We focused our analysis on the gamma-band activity since it is considered to be of particular importance for emotions (Keil et al., 2001; Luo et al., 2007, 2009, 2010; Müller et al., 1999; Oya et al., 2002). A beamformer technique called Synthetic Aperture Magnetometry (SAM) (Robinson and Vrba, 1998) was used to localize the gamma-band cerebellar responses to the emotional stimuli across time. The foci of activity were finally related to the anatomical organization of cerebellum by using the cerebellar probabilistic maps (Diedrichsen et al., 2009).

## Materials and methods

### Participants

Our subject pool comprised twelve healthy volunteers (7 males, mean age  $30.8 \pm 5.3$ , range 23 to 40 years, 5 females mean age  $27.8 \pm 5.3$ , range 21 to 35 years) of normal or corrected-to-normal visual acuity. Participants were informed of the stimuli type and modality and gave their written informed consent in compliance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) and the standards established by the host institution's ethics committee.

Download English Version:

<https://daneshyari.com/en/article/6025557>

Download Persian Version:

<https://daneshyari.com/article/6025557>

[Daneshyari.com](https://daneshyari.com)