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CONSENSUSPAPER: CEREBELLUM AND EMOTIONS
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The cerebellum, language and emotion: the role of emotional prosody

Stefanie Keulen^{1,2}, **Jo Verhoeven**³, **Frank Van Overwalle**⁴, **Peter Mariën**^{1,5}

¹ Department of Clinical and Experimental Neurolinguistics, CLIEN, Vrije Universiteit Brussel, Brussels, Belgium

² Center for Language and Cognition Groningen, Rijksuniversiteit Groningen, Groningen, The Netherlands

³ Department of Language and Communication Science, City University, London, UK

⁴ Faculty of Psychology and Educational Sciences, Vrije Universiteit Brussel, Brussels, Belgium.

⁵ Department of Neurology and Memory Clinic, ZNA Middelheim General Hospital, Antwerp, Belgium

During the past decades, the traditional view of the cerebellum as a mediator of motor function has been thoroughly revised and it has been recognized that the cerebellum subserves a wide range of neurocognitive, linguistic, affective and social functions (De Smet et al., 2013; Schmahmann, 2004; Beaton and Mariën, 2010; Van Overwalle et al., 2014).

A crucial aspect of speech is the role of prosody, i.e. the melody and rhythm of speech which supports the meaning of linguistic units (e.g. words, phrases or sentences). Prosody results from the complex interplay of several acoustic variables such as pitch, loudness and rhythm (Sidtis and Van Lancker Sidtis, 2003) which are typically affected after cerebellar pathology. In his hallmark 1917-paper Gordon Holmes described impaired speech following cerebellar damage as typically slow, monotonous, staccato, scanned, indistinct, remarkably irregular, jerky, explosive, slurred, and laboured resulting in what was later called ataxic dysarthria and dysprosodia.

In the past, two main types of prosody have generally been distinguished: linguistic (or propositional) and emotional (or affective) prosody. Linguistic prosody supports the distinction between different sentence types by means of intonation (e.g.

interrogative and declarative sentences), but also between word categories by means of word stress (e.g. /'ædrəs/ (noun) versus /ə'drəs/ (verb)). Emotional prosody modulates content in such a way that it conveys information about the emotional state of the speaker. In early models, the expression and comprehension of emotional prosody were typically situated in the homologous, non-dominant areas for expression and comprehension of language, i.e. the inferior frontal gyrus and the posterior temporal gyrus of the non-dominant hemisphere (see also: Wildgruber et al., 2006; Ross, 1981; Sidtis and Van Lancker Sidtis, 2003). However, recent studies have shown that both types of prosody require bilateral cerebral and even subcortical involvement to some degree (e.g. Le Jeune et al., 2008; Chancelliere and Kertesz, 1990; Van Lancker and Sidtis, 1992; Kotz et al., 2003; Mitchell et al., 2003). The different prosodic modalities have been associated with different neural correlates. Wildgruber et al. (2006), Dapretto et al. (1999) (perception tasks) and Mayer et al. (2002) (production tasks) found that linguistic prosody is selectively associated with activity in the language dominant inferior frontal and superior temporal gyrus (STG). Dogil et al. (2002) (same experiment as Mayer et al., 2002), found increased BOLD-response in the language dominant STG (when modulating-rendering pitch accents: 'focus'), and in the posterior part of the non-dominant STG extending into the middle temporal gyrus (when modulating-tone boundary-rendering boundary tones: 'modus'). ~~Emotional prosody perception~~ The perception of emotional prosody was variably associated with non-dominant inferior frontal gyrus activity (Dapretto et al., 1999), bilateral orbito-frontal activity (Wildgruber et al., 2006) and activation in the anterior part of the non-dominant STG ('affect'-mode in Dogil et al., 2002). Dogil et al. (2002) concluded that '... exclusively neocortical areas [are] critically involved in prosody generation' (p. 78). Nonetheless, studies have shown that subcortical lesions encompassing the putamen and globus pallidus induce mood disorders with deficits in emotional prosodic production (Van Lancker Sidtis et al., 2006). It has been argued that ~~the source for dysprosody may lie in deficits of timing~~ is caused by a timing deficit (Sidtis and Van Lancker Sidtis, 2003), with timing being a fundamental role of the cerebellum in motor execution processing.

Recent functional neuroimaging studies have confirmed a possible role ~~for of~~ the cerebellum in the processing of emotional prosody. In an fMRI study of emotional prosody ~~comprehension~~ recognition, in which participants listened to numbers pronounced with prosodic manipulation ~~inferring-suggesting~~ neutral versus simple

(happy, sad, angry) and complex (guilt, proud, bored) emotions, Alba-Ferrara et al. (2011) found significantly increased metabolic activation in the *right* cerebellum ($Z=3.29$) (in the presence of several left and right-hemisphere – mostly frontal, including (para)limbic – activations). This activation was ~~still-also~~ present when comparing complex ~~with-and~~ simple emotions ($Z=3.62$), even when controlled for pitch ($Z=3.66$). Strelnikov et al. (2006) studied the perception of speech prosody in read sentences with PET and apart from activity in the right dorsolateral prefrontal cortex (PFC), they also observed activity in the right posterior lobe of the cerebellum. The area mediating functional overlap between the differentially affected domains (prosody, syntax and emotion) was the right posterior PFC. Right cerebellar activity was primarily related to speech timing perception. According to Pichon and Kell (2013) the cerebellar vermis modulates fundamental frequency in emotional speech production, as increased BOLD response was ~~evoked-triggered~~ in the cerebellum, thalamus, globus pallidus, substantia nigra and superior temporal sulcus in especially the right hemisphere. Krienen et al. (2009) argued the existence of segregated fronto-cerebellar circuits: one originating in the medial PFC, which is connected to Crus I of the limbic cerebellum (Stoodley and Schmahmann, 2009; Adamaszek et al., 2013; Alalade et al., 2011). Lesion studies and studies in degenerative cerebellar disorders have provided additional evidence for ~~the~~ involvement of the cerebellum in (disrupted) emotional prosody. Sokolovsky et al. (2010) described impaired verbal emotion attribution in patients with spinocerebellar ataxia whereas Adamaszek et al. (2013) reported difficulties in prosody naming and prosody matching in a group of 15 patients with discrete ischemic cerebellar lesions. They ~~equally-also~~ found a correlation between volume of the lesion and the ~~amount number~~ of errors in emotional and complex tasks.

Although ~~a-the~~ role ~~for-of~~ the cerebellum in emotional speech processing has not been thoroughly investigated, the currently available evidence of cerebellar involvement in the processing of emotional prosody as a marker of prosody timing is growing. Future research will further ~~unveil-reveal~~ the multifaceted role of the cerebellocerebral circuitry in the linguistic production and perception of ‘emotions and affect’.

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