The cerebellum, language and emotion: the role of emotional prosody

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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. /ˈædrɛs/ (noun) versus /əˈdrɛs/ (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 accent~~s: '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’.

REFERENCES

Adamaszek, M., D'Agata, F., Kirkby, K.C., Trenner, M.U., Sehm, B., Steele, C.J., Berneiser, J., Strecker, K. (2014). Impairment of emotional facial expression and prosody discrimination due to ischemic cerebellar lesions. *Cerebellum*, 13, 3:338-45. Doi: 10.1007/s12311-013-0537-0.

Alalade, E., Denny, K., Potter, G., Steffens, D., and Wang, L. (2011) Altered Cerebellar-Cerebral Functional Connectivity in Geriatric Depression. PLoS One. Doi: 10.1371/journal.pone.0020035

Alba-Ferrara, L., Hausmann, M., Mitchell, R. L., and Weis, S. (2011). The Neural Correlates of Emotional Prosody Comprehension: Disentangling Simple from Complex Emotion. PLoS One. DOI: 10.1371/journal.pone.0028701

Beaton, A., and Mariën, P. (2010). Language, cognition and the cerebellum: grappling with an enigma. *Cortex*, 46, 811-820.

Chancelliere, A., and Kertesz, A. (1990). Lesion localization in acquired deficits of emotional expression and comprehension. *Brain and Cognition*, 13, 133-147.

Dapretto, M.; Hairiri, A., Bialik, M. and Bookheimer, S. (1999). Cortical correlates of affective vs. linguistic prosody: an fMRI study. *NeuroImage*, 9, 1054.

De Smet, H. J.. Paquier, P., Verhoeven, J., and Mariën, P. (2013). The cerebellum: its role in language and related cognitive and affective functions. *Brain Lang.*,127(3),334-42. Doi: 10.1016/j.bandl.2012.11.001.

Holmes, G. (1917). The symptoms of acute cerebellar injuries due to gunshot injuries. *Brain,* 40:461–535.

Hoshi, E., Tremblay, L., Féger, J., Carras, P.L., and Strick, P.L. (2005). The cerebellum communicates with the basal ganglia. *Nature Neuroscience*, 8(11), 1491 - 1493

Jackson, J. H. (1915). On affections of speech from diseases of the brain. *Brain*, 38, 106-174.

Kotz, S. A., Meyer, M., Alter, K., Besson, M., von Cramon, Y., and Friederici, A. D. (2003). On the lateralization of emotional prosody: An event-related functional MR investigation. *Brain Lang*., 86, 366-376.

Krienen F. M., and Buckner, R. L. (2009). Segregated Fronto-Cerebellar Circuits Revealed by Intrinsic Functional Connectivity. Cereb. *Cortex* 19(10), 2485-2497.

Le Jeune, F., Péron, J., Biseul, I., Fournier, S., Sauleau, P., Drapier, S., and Vérin, M. (2008). Subthalamic nucleus stimulation affects orbitofrontal cortex in facial emotion recognition: A pet study. *Brain: A Journal of Neurology*, 131, 1599–1608.

Mayer, J.; Wildgruber, D., Riecker, A., Dogil, G.; Ackermann, H.; Godd, W. (2002). Prosody Production and Perception: Converging Evidence from fMRI Studies, *Proceedings from ISCA 2002: International Speech Communication Association: Speech Prosody 2002*, 487-490.

Mitchell, R. L. C., Elliott, R., Barry, M., Cruttenden, A., and Woodruff, P. W. R. (2003). The neural response to emotional prosody, as revealed by functional magnetic resonance imaging. *Neuropsychologia*, 41, 1410-1421.

Pichon, S., and Kell, C. A. (2013). Affective and sensorimotor component of emotional prosody generation. *J. of Neuroscience*, 33(4), 1640-1650.

Ross, E. E. (1981). The aprosodias: functional-anatomic organization of the affective components of language in the right hemisphere. *Arch. Neurol*., 38, 561-570.

Schmahmann, J. (2004). Disorders of the Cerebellum: Ataxia, Dysmetria of Thought, and the Cerebellar Cognitive Affective Syndrome. *J Neuropsychiatry Clin Neurosci,* 16(3), 367–378.

Sidtis, J. J., and Van Lancker Sidtis, D. A (2003). Neurobehavioral Approach to Dysprosody. *Seminars in Speech and Language*, 24(2), 93-105.

Sokolovsky, N,, Cook, A., Hunt, H., Giunti, P., and Cipolotti L. (2010). A preliminary characterization of cognition and social cognition in spinocerebellar ataxia types 2, 1, and 7. *Behavioral Neurology*, 23(1–2),17–29.

Stoodley C. J., and Schmahmann, J. D. (2009). Functional topography in the human cerebellum: a meta-analysis of neuroimaging studies. *NeuroImage,* 44(2),489-501. Doi: 10.1016/j.neuroimage.2008.08.039.

Strelnikov, K., Vorobyev, V. A., Chernigovskaya T. V., and Medvedev, S. V. (2006). Prosodic clues to syntactic processing—a PET and ERP study. *Neuroimaging,* 29, 1127–1134.

Van Lancker, D., and Sidtis, J. J. (1992). The identification of affective-prosodic stimuli by left- and right-hemisphere-damaged subjects: all errors are not equal. *Journal of Speech and Hearing*, 35, 963-970.

Van Lancker Sidtis, D., Pachana, N., Cummings, J. L., and Sidtis, J. J. (2006). Dysprosodic speech following basal ganglia insult: toward a conceptual framework for the study of the cerebral representation of prosody. *Brain Lang*. 97, 2:135-153.

Vanoverwalle, F., Baetens, K., Mariën, P., and Vandekerckhove, M. (2014). Social cognition and the cerebellum: a meta-analysis of over 350 fMRI studies. *NeuroImage*; 86: 554-572.

Wildgruber, D., Ackermann, H., Kreifelts, B. and Ethofer, T. (2006). Cerebral processing of linguistic and emotional prosody: fMRI studies. Progress in Brain Research, 156, 249–268