Syntax and the motor system: ERD of the mu wave during natural language syntactic processing

Mirien Urteaga Aldalur, Itziar Laka
University of the Basque Country

We discuss two EEG/ERD experiments where sentence processing produced Event- Related Desynchronization (ERD) of the mu wave. Supporting evidence for the Motor Theory of Language (Pulvermüller & Fadiga, 2010) has been found for phonology (Pulvermüller *et al.*, 2006; D'Ausilio *et al*., 2009; Mesgarani *et al*., 2014) and semantics, (Pulvermüller, 2005; González *et al.*, 2006; Raposo *et al*., 2009; Kemmerer & Gonzalez-Castillo 2010), but evidence from syntax is scarce. Processing movement-related stimuli causes ERD of mu waves (Pfurtscheller, Stancák Jr & Neuper, 1996; Graimann *et al*., 2002; Pineda, 2005); and the more complex the stimuli, the greater the ERD (Stipacek *et al*., 2003). Our experiments investigate whether syntactic processing can cause such ERD and modulations.

Following Alemanno *et al*. (2012), we first investigated ERD of the mu waves in Spanish sentence processing. Four conditions were tested: (a) hand-related vs. abstract verb; (b) declarative vs. negative sentence. Materials: 160 two-word sentences, 40 per condition. Participants: 19 native speakers (9 female; mean age =22±3.23; all right handed). A 32 channel BrainVison cap recorded the EEG data. The ERD analysis (Pfurtscheller & Aranibar 1977) compared the 900ms previous to the stimuli to the 1500ms when stimulus was on screen. Similar to Alemano *et al*. (2012), all experimental conditions caused ERD of the mu band. Negative sentences showed greater desynchronisation than declaratives ($p<0.05$) over the inferior frontal gyrus (electrodes FC1, F7 and FC5) ca. 400ms post-stimuli. Unlike Alemano *et al*. (2012), no significant ERD correlation with the type of verb was found. Experiment 2 analysed ERD modulations in three increasingly complex sentence types: intransitives, transitives and ditransitives. Materials: 164 two-word Basque sentences, 54 clauses per condition. Participants: 26 native speakers (13 female; mean age =20±2.3; all right handed). A 64 channel BrainVison cap recorded the EEG data. All conditions showed a clear ERD of mu waves from ca. 400ms post-stimulus. Intransitives showed greater ERD ($p<0.05$) at 1000ms in the motor area (C3, C1, C5, Cz), premotor area (FC3, FC1, FC5) and inferior frontal gyrus (F5, F7).

These findings reveal that syntax generates similar ERD to motor processing in the mu band. Greater ERD correlates with greater syntactic complexity as shown by negative sentences when compared to declaratives. However, this correlation does not appear to hold for thematic complexity, since intransitives generated a greater ERD than both types of transitives in experiment 2.

The different temporal locations of ERD differences found in Exp.1 and 2 (400ms in the former, 1000ms in the latter), suggest different causes, potentially associated with the presence versus absence of an agent in the sentence. Mu and Han (2010) found comparable results in a judgment experiment, where self-referential traits, inherent of intransitivity, and other-referential traits caused

different ERD modulations.

In sum, our results show clear ERD in the mu band during syntactic processing in two typologically unrelated languages, providing evidence for the coinvolvement of natural language syntax and the motor system. These findings also suggest that different dimensions of syntactic complexity can cause ERD of the mu wave, parallel to what is found in motor processing regarding the ERD in the mu band.

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