How does deep brain stimulation affect regulation in speech motor control?
Doris Mücke*, Anne Hermes*, Timo B. Roettger*, Johannes Becker*, Michael Barbe*
*FL-Phonetik, University of Cologne,  Départment of Neurology, University Hospital Cologne
doris.muecke@uni-koeln.de

Chronic deep brain stimulation (DBS) of the nucleus ventralis intermedius (VIM) is an effective treatment for patients with medication resistant Essential Tremor (ET). However, these patients report that stimulation has a deleterious effect on their speech, severely impacting their quality of life and social functioning. Previous acoustic studies on VIM-DBS in patients with multiple sclerosis (Pützer et al. 2007) and essential tremor (Mücke et al. 2014) report an increase of voicing across the entire syllable cycle, as well as friction during the consonantal constriction in stops, indicating both a reduced degree of glottal abduction and an imprecise oral articulation. The present study investigates gestural coordination patterns in the speech motor system by using Electromagnetic Articulography to capture stimulation-induced effects in terms of intragestural and intergestural variability. We analyse onset coordination patterns in syllables with low and high complexity, such as /i/ and /kli/, within the coupling hypothesis of syllable structure (Browman & Goldstein 2000; Nam et al. 2009). We aim to quantify the effects of DBS on speech regulation mechanisms of oral gestures. We further aim to understand how much variation is tolerated in a phonological system before the system gets instable and patterns of syllable organisation break down.

Method: We recorded 12 ET patients with DBS in stimulation-ON and stimulation-OFF condition and 12 healthy control speakers (all native speakers of Standard German). The patients had been bilateral implanted with a DBS system in the VIM. The articulatory data was recorded with a 3D AG501 with sensors placed on upper and lower lip, tongue tip and tongue dorsum. In a first step, we recorded fast syllable repetition tasks of CV syllables, such as /papapa/, /tatata/ and /kakaka/, in order to push the speech motor system to its limits (2160 tokens). In a second step, we recorded target words with low and high complexity (CV vs. CCV) at a normal speech rate, such as <Lima> /lima/ (capital of Peru) and <Klima> /klima/ (climate’). These target words were embedded in carrier sentences such as “Er hat wieder ___ gesagt” (‘He said ___ again’), with the nuclear pitch accent on the target word (900 tokens). We labelled gestural landmarks of consonantal and vocalic gestures, i.e. onset, peak velocity and maximum target by identifying zero-crossings in the respective velocity and acceleration traces. For intragestural coordination, we computed variables used in a mass-spring model (Saltzman & Munhall 1989) such as stiffness, displacement, peak velocity, and the duration of acceleration and deceleration phases. For intergestural coordination in target words varying in complexity (low versus high), we calculated the temporal intervals between the onsets of consonantal and vocalic gestures, i.e. CV lag and CC lag. In CV syllables, it is assumed that C and V are coupled in-phase, leading to a simultaneous initiation of the consonantal and vocalic gesture (resulting in a CV lag which is zero). In CCV syllables, where a more complex competitive coupling structure is assumed, both Cs are coupled in-phase with V and at the same time in anti-phase with each other, leading to a sequential activation of the consonantal gestures (measured in CC lag).

Results: First, we report on the results for intragestural coordination in the fast syllable repetition task. Figure 1 shows the lower lip trajectory for the production of ten syllable cycles of /papapa/ of one ET patient with stimulation-OFF (Fig. 1: grey line) and stimulation-ON (Fig. 1: black line). Low values indicate that the lips are closed for the consonant /p/ and high values that the lips are open during the vowel /a/. There is a high variability comparing each syllable cycle in the patient’s production, especially in stimulation-ON condition. We ran linear mixed models using R with the predictors of DBS (ON vs. OFF), place of articulation (labial, alveolar, velar) and syllable (position within the breathing cycle). The random effects component included random intercepts for subject as well as by-subject random slopes for the effect of DBS. There is a significant effect of DBS on the duration of the acceleration phase (p=0.0035) with stimulation-ON revealing an increase of 12 ms when
compared to stimulation-OFF. For the peak velocity parameter, there was a significant effect of DBS (p=0.001) with stimulation-ON, revealing a lower peak velocity with a decrease of 26 mm/ms compared to stimulation-OFF. There was also a significant effect of DBS on the stiffness parameter (p=0.008), i.e. stiffness considerably decreases from stimulation-OFF (17.8) to stimulation-ON (16). Results on the intergestural coordination, testing syllables with low, CV, and high complexity, CCV, reveal timing deficits only in the production of syllables with high complexity, such as /kli/, and none in syllables with low complexity, such as /li/. Fig. 2 exemplifies the coordination pattern in /li/ (left) versus /kli/ (right) for one ET patient with stimulation-ON. The figure shows the averaged trajectories including repetitions for consonant and vowel production; the trajectories in the top portion of the figure display the tongue tip closure, and the trajectories in the lower part of the figure show the movement of the tongue dorsum. In /li/, the consonantal and the vocalic gestures show a synchronous pattern of temporal activation, i.e. initiated at the same time (the CV lag is zero). This pattern reflects the expected underlying coupling structure: in CV syllables, C and V are coupled in-phase. However, /kli/ fails to show the expected timing pattern. Due to a competitive coupling structure, there should be an activation delay between the two consonants. This is not the case, since the CC lags are zero, i.e. the consonants are activated at the same time and not sequentially. This indicates that ET patients show timing deficits in realizing complex coordination structures (Fig. 3). In order to compensate for these deficits, the gestural activation interval for /l/ is considerably stretched (see Fig. 2: /l/ in /kli/).

**Conclusion:** The results reveal stimulation-induced effects on the regulation in speech motor control in ET patients. Under stimulation, we found a detrimental decrease in peak velocities, stiffness and acceleration phase of oral constriction gestures leading to imprecise articulation in the production of stop consonants: movements are slower, longer and less stiff. Furthermore, we found timing deficits in the phonetic realization of competing coupling relations for complex onsets in the ET patients, shown in Fig. 3. While for syllables with high complexity, such as /kli/, a delay would have been expected between the activation of both initial consonantal gestures (Fig. 3a), in the speech of ET patients both C gestures are activated at the same time (Fig. 3b). The competitive coupling coordination, a pattern that has to be learned, is reduced to simple in-phase relations (Fig. 3c) and breaks down.

**References**