

# ONSET COORDINATION IN ESSENTIAL TREMOR PATIENTS WITH DEEP BRAIN STIMULATION: AN EMA STUDY

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## ABSTRACT

The present study is the first kinematic study to investigate the speech production of ET patients with VIM-DBS. More specifically, it explores the coordination patterns of articulatory gestures in syllables with simple and complex onsets, CV and CCV, in German. It provides a preliminary analysis of gestural coordination under stimulation for the target words /lima/ and /klima/ in the framework of Articulatory Phonology. The findings reveal a timing deficit in the phonetic realization of competing coupling relations for complex onsets for the patients. The observed perturbation of gestural phase relations can be related to the coupling hypothesis of syllable structure and are taken to be a symptom for dysarthria.

**Keywords:** Deep Brain Stimulation, Essential Tremor, gestural coordination patterns, coupling hypothesis of syllable structure, dysarthria

## 1. INTRODUCTION

### 1.1. Deep brain stimulation

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, inducing a severe impact on quality of life and social functioning. And indeed, in the literature stimulation induced dysarthria is reported as being a common side effect affecting between 10% and 75% of patients [4].

Previous studies on VIM-DBS in patients with multiple sclerosis [5] and essential tremor [6] have shown a detrimental effect of stimulation on the speech when looking at the subsyllabic level. These studies report an increase of voicing across the entire syllable cycle, as well as frication during the consonantal constriction in stops, indicating both a reduced degree of glottal abduction and an imprecise oral articulation. The studies were restricted to measures in the acoustic domain. For the speech material, fast syllable repetition tasks with CV

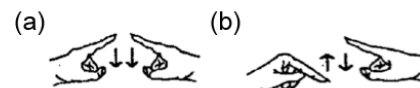
syllables such as /papapa/, /tatata/ or /kakaka/ were used.

### 1.1. Coupling hypothesis of syllable structure

In Articulatory Phonology, speech can be decomposed into gestures [7]. Temporal patterns of gestural coordination are specified in an inter-oscillator coupling network [8,9,10,11]. In this model, each gesture is associated with an oscillator (or ‘clock’). These oscillators are coupled to one another in a pairwise fashion.

Two intrinsic modes of coupling are incorporated in the model [12]: in-phase (gestures start at the same time, phase 0° of gesture’s oscillator) and anti-phase (gestures are initiated sequentially, phase 180° of gesture’s oscillator). These modes are exemplified in a non-speech task in figure 1, showing coordination during finger wagging.

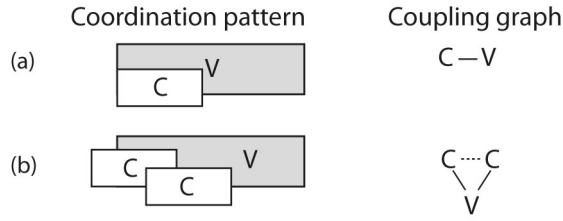
**Figure 1:** (a) In-phase and (b) anti-phase mode in inter-limb coordination (finger wagging), taken from [12].



In *simple onset coordination* (CV syllables), the consonant and the vowel are coupled in-phase. The consonant and the vowel are initiated simultaneously. Since vowels exhibit slower movements (lower stiffness) than consonants, the gestural activation interval for the vowel is longer than for the consonant. The in-phase mode, being innate, is reported to be the most stable one, a fact that has been related to the universality of CV syllables.

In *complex onset coordination* (CCV syllables), both consonants are coupled in-phase with the vowel and at the same time in anti-phase with another. These incompatible modes (in-phase between CV and anti-phase between CC) are competing with another, leading to a rightward shift of the prevocalic consonant to make room for the added one and a leftward shift of the added C. Complex onset coordination has been shown to occur in many languages such as Georgian [8], English [9], Italian [10] and German [11].

**Figure 2:** Coordination pattern and respective coupling graphs for (a) CV and (b) CCV syllables (in-phase: solid line, anti-phase: dotted line)



The present study is the first study that investigates the speech production of ET patients with VIM-DBS in the kinematic domain. More specifically, it explores the coordination patterns of articulatory gestures in syllables with simple and complex onsets, CV and CCV, in German. It provides a preliminary analysis of gestural coordination under stimulation for the target words /lima/ and /klima/.

## 2. METHOD

We recorded three essential tremor (ET) patients with deep brain stimulation (1 male and 2 female, aged between 59 and 73) and one healthy control speaker (female, 67 years), all native speakers of Standard German. The patients had been bilateral implanted with a DBS system in the VIM. The data was recorded with a 3-D electromagnetic articulograph (AG501). Sensors were placed on the midpoints of upper and lower lip, tongue tip (1cm behind the tip) and tongue dorsum (4 cm behind the tip). Three additional reference sensors were used for dynamic head movement correction. All kinematic data were recorded at 1200Hz, downsampled to 250Hz and smoothed with a 3-step floating mean.

The speech material contains target words with simple and complex onsets, e.g. /lima/ (*capital of Peru*) and /klima/ (*'climate'*) with lexical stress on the first syllable. The target word is embedded in a carrier sentence and bears a nuclear pitch accent:

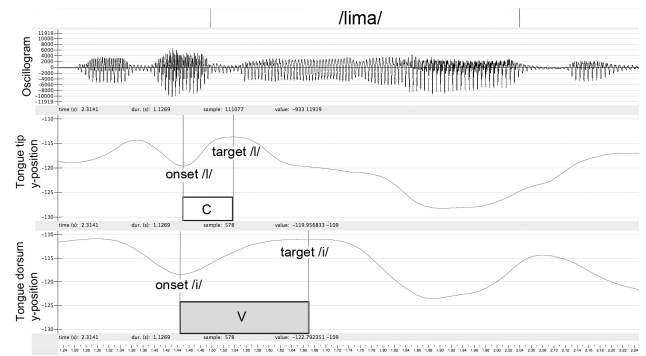
- (1) Er hat wieder \_\_\_ gesagt.  
(*'He said \_\_\_ again'*).

Each target word was presented 5 times in a pseudo-randomised order. In total, 280 tokens (14 target words x 5 repetitions x 4 speakers) were recorded. In this paper we report on the target words /lima/ and /klima/. The speakers were instructed to read the sentences at a normal speaking rate.

Kinematic data was labelled manually in the EMU speech database system [1]. We labelled

onsets and maximum targets for consonantal and vocalic gestures in word initial CV and CCV sequences by identifying zero-crossings in the respective velocity traces. A labelling scheme for the target word /lima/ is provided in figure 3. In cases where the maximum consonantal constriction was realised with a plateau, the midpoint of the plateau was chosen as the relevant landmark corresponding to the maximum target.

**Figure 3:** Labelling scheme for gestural activation intervals, i.e. onset and target for /l/ and /i/ (top to bottom: oscillogram, tongue tip and tongue dorsum y-position).



The analysis focuses on the target words /lima/ and /klima/. To capture intergestural timing relations we computed CV lags in /lima/ and CC lags in /klima/. The following kinematic measures on intergestural timing (i-ii) and intragestural duration (iii) were computed<sup>1</sup>:

- (i) *CV lag*: Temporal interval between the onset of the tongue tip closure for /l/ and the onset of the tongue dorsum rising for /i/ in /lima/.
- (ii) *CC lag*: Temporal interval between the onset of the tongue dorsum closure for /k/ and the onset of the tongue tip closure for /l/ in /klima/.
- (iii) *Gestural activation interval*: The duration of the tongue tip movement for /l/ from the onset to the maximum target.

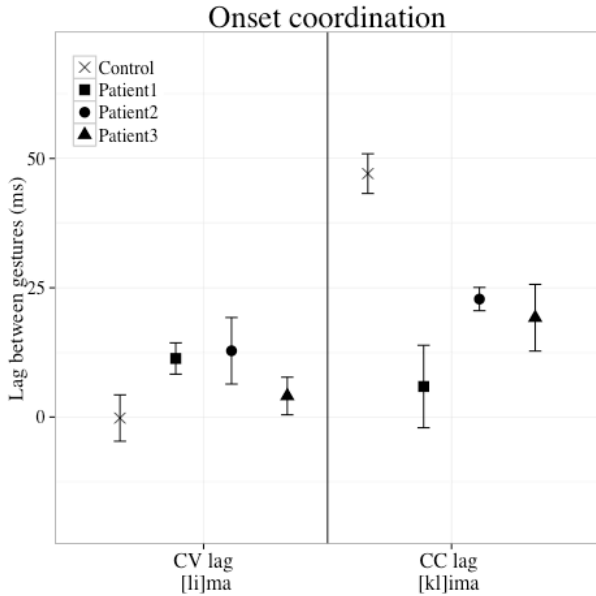
## 3. RESULTS

### 3.1. Intergestural coordination patterns

We investigated the intergestural coordination patterns for simple and complex onset coordination in /lima/ and /klima/. Figure 4 presents the results for the respective CV lags in /lima/ (figure 4, left) and CC lags in /klima/ (figure 4, right), separately for three ET patients with DBS and one healthy control speaker. The lags report the temporal interval between two landmarks, such as A minus B. Thus, a negative value implies that A occurs earlier than B, and vice versa for a positive value.

First, we describe the patterns for the healthy control speaker, and afterwards the patterns for the essential tremor patients with DBS.

**Figure 4:** Means and standard deviations for CV lags in /lima/ (left) and CC lags in /klima/ (right), separately for one healthy control speaker and three ET patients with DBS.



*Healthy control speaker:* In /lima/, as expected, the CV lags are close to zero. The onsets of the consonantal and vocalic gestures are tightly synchronised, i.e. both gestures are initiated at the same time. In /klima/, the CC lags amount to 47ms (see Table 1). The onset of the dorsal gesture for /k/ considerably precedes the tongue tip gesture for /l/. Both gestures are initiated sequentially with respect to each other.

**Table 1:** Means and standard deviations (in parentheses) for CV lags in /lima/ and CC lags in /klima/ (in ms).

	/lima/	/klima/
Control	0 (4)	47 (4)
Patient 1	11 (3)	6 (8)
Patient 2	13 (6)	23 (2)
Patient 3	4 (4)	19 (6)

*ET patients with DBS:* In /lima/, the onset of the tongue tip gesture for /l/ slightly precedes the onset of the tongue dorsum rising for /i/, but lags were rather small ( $\bar{x}$ =9ms, across patients). As for the healthy control speaker, the consonant and the vowel are initiated at the same time. Surprisingly, CC lags in /klima/ were also rather small ( $\bar{x}$ =16ms, across patients). More specifically, the lags for /k/ and /l/ activation were 31ms smaller in the patients' group

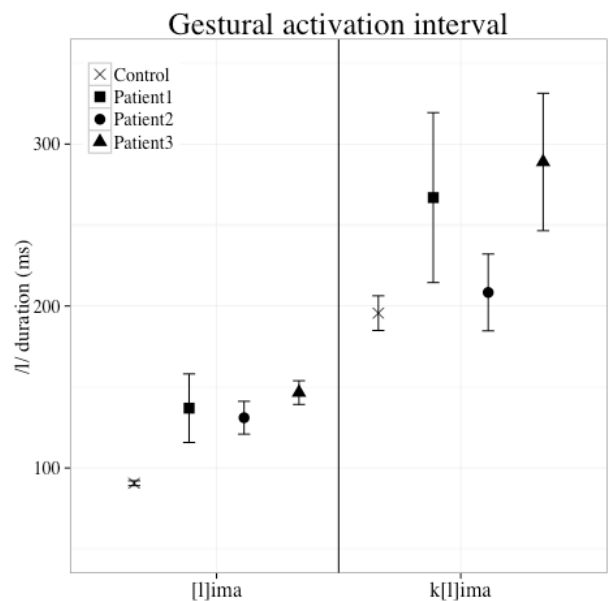
than for the healthy control speaker. In contrast to the control speaker, who produced simultaneous activation in /lima/ and sequential activation in /klima/, this difference was not found in the coordination patterns of the patients (see Table 1). For the ET patients the activation of CV and CC gestures appear to start simultaneously.

### 3.2. Intragestural coordination patterns – Duration of /l/ gesture

We measured the duration of the tongue tip gesture for /l/ in /lima/ and /l/ in /klima/, i.e. from the onset to the maximum target (gestural activation interval). Figure 5 displays the gestural activation interval for /l/ in /lima/ (figure 5, left) and /klima/ (figure 5, right), separately for all speakers. Analogously to section 3.1, we first discuss the results for the healthy control speaker, and then for the ET patients.

*Healthy control speaker:* In /lima/, the duration of the tongue tip gesture /l/ is 91ms and in /klima/, 196ms. The /l/ gesture is considerably longer in the complex onset condition than in the simple onset condition. This can be due to the fact that /kl/ in German is usually produced with a considerably high degree of overlap [3]. The variability in the duration of the /l/ closure is rather low (/lima/: sd=2ms; /klima/: sd=11ms).

**Figure 5:** Means and standard deviations for gestural activation interval of /l/ in /lima/ and /klima/, separately for one healthy control speaker and three ET patients with DBS.



*ET patients with DBS:* Across all conditions, the patients show considerably longer durations for the

/l/ closure than the healthy control speaker. The /l/ durations were on average 47ms longer in /lima/ and 59ms longer in /klima/ than in the healthy control speaker. Furthermore, the data variability was rather high in the patients' group, especially in the complex onset condition (e.g. in /klima/ for patient 1: sd=52ms and for patient 2 sd=42ms).

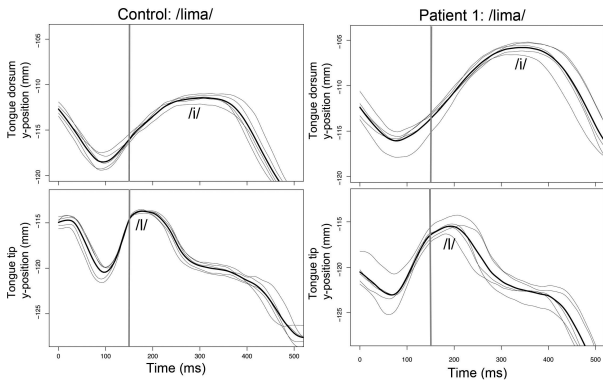
**Table 2:** Means and standard deviations (in parentheses) for duration of /l/ gesture (in ms).

	/lima/	/klima/
Control	91 (2)	196 (11)
Patient 1	137 (21)	267 (52)
Patient 2	131 (10)	208 (24)
Patient 3	147 (7)	289 (42)

#### 4. DISCUSSION

When comparing syllables with simple onsets (e.g. /lima/), we found similar coordination patterns for essential tremor patients with VIM-DBS and for the healthy control speaker. The consonantal and the vocalic gestures in /li/ (target word /lima/) show a synchronous pattern of temporal activation. This pattern reflects the underlying coupling structure: in CV syllables, consonant and vowels are coupled in-phase. This timing relation is exemplified in figure 6. It shows averaged trajectories and repetitions for /lima/ for the healthy control speaker (fig.6, left) and for one patient with DBS (fig.6, right) for the tongue dorsum rising during /i/ (fig. 6, top) and the tongue tip closure during /l/ (fig. 6, bottom). The trajectories were aligned with the acoustic onset of the word (indicated by the vertical grey line). The patients show considerably longer activation intervals for the consonantal gesture /l/ than the healthy control speaker, pointing in the direction of slower articulation rates as a symptom of dysarthria in the speech of essential tremor patients with VIM-DBS [3].

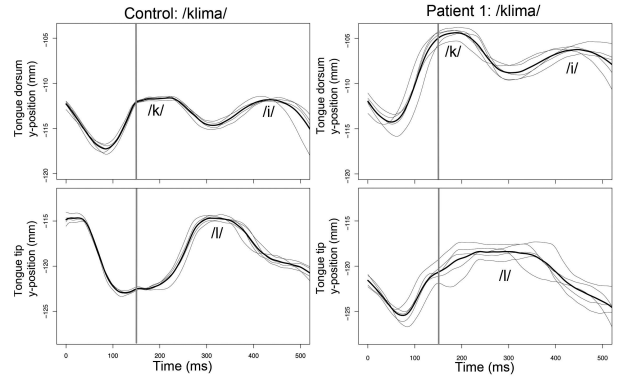
**Figure 6:** Averaged trajectories (bold solid line) and repetitions (thin solid lines) for healthy control speaker (left) and patient 1 (right) in /lima/.



However, comparing syllables with complex onsets (e.g. /klima/), the picture changes. There are strong differences in the temporal coordination patterns of the /kl/ cluster when comparing the healthy control speaker with the essential tremor patients with DBS. The healthy control speaker initiates the consonants in a *sequenced* order, reflecting competing coupling relations between the consonantal and vocalic gestures (in-phase between C and V and anti-phase between Cs). In contrast, the patients initiate the consonants *synchronously*, i.e. they activated the movements for /k/ and /l/ at the same time. We interpret the results for the patients as an indicator for timing deficits in realizing complex coordination structures. To compensate for the perturbed timing pattern, they considerably stretch the gestural activation interval for /l/. This is supported by the fact that the duration of the gestural activation interval for /l/ shows a very high degree of variability.

Figure 7 exemplifies the patterns for the healthy control speaker and one patient.

**Figure 7:** Averaged trajectories (bold solid line) and repetitions (thin solid lines) for healthy control speaker (left) and patient 1 (right) in /klima/.



These preliminary results point to the fact that the patients show timing deficits in the phonetic realization of competing coupling relations for complex onsets. Competing coupling relations have to be learned, and appear to be more susceptible to perturbation than patterns purely based on intrinsic modes (in-phase and anti-phase attractors). Furthermore, the in-phase attractor appears to be stronger than the competing anti-phase attractor in word initial clusters. Thus, this observed in-phase stability under perturbation provides further evidence for the universality of CV syllables.

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<sup>1</sup> Due to the occurrence of multiple dorsal gestures for the initial velar stop /k/ and the following high front vowel /i/, the vocalic onset in /klima/ is not detectable. In Standard German, clear /l/ is produced in all syllable positions [2].