Scalar and biomechanic complexity in phase shifts: Implications on phonological development and speech pathologies

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1.0 Introduction

To date, there is very little consensus among speech scientists regarding how we define and quantify articulatory complexity and the effects this concept has on the syllable. Less is understood regarding complexity’s role in phonological development and pathologies which affect speech production.

A paradigmatic shift to dynamic, non-linear models of speech in the past three decades has offered new insight into the forces which regulate syllable structure. Articulatory Phonology, elaborated by Browman and Goldstein (1986), contends that syllable structure falls out from stable relations of intergestural timing between speech gestures. It is generally accepted that onset consonants are phased globally in relation to the following vocalic target, while coda gestures are organized linearly with the preceding vocalic gesture.

It has been hypothesized that coupling in in-phase configurations is stronger than in anti-phase. It is argued that stronger coupling leads to greater stability for in-phase gestures. This assertion is based on a series of experiments initiated in the 1980’s by Kelso and colleagues (1985 and much subsequent research) in which it was noticed that in many bimanual tasks, anti-phase patterns will often converge to in-phase when cycle frequencies increase. Pouplier and Goldstein (2005) found similar results in a series of speech experiments in which subjects were asked to repeat word pairs containing both in-phase and anti-phase gestures. They found that past a critical frequency, speech errors emerge. It was hypothesized that these errors are the upshot of a universal principle governing the stability relations between onset and coda gestures.

2.0 Articulatory Complexity in [C.C.] clusters

2.1 Initial presumptions and hypotheses

Currently, the facts extracted from a case study of synchronic metathesis in the phonological development of Spanish children are being examined. In these cases the subjects systematically switched all [ɾ..] sequences to [..ɾ] upon acquiring multiple vibrant [ɾ]. In light of recent discoveries in multidisciplinary research addressing motor task coordination, I explain this process as a preference for more stable modes of frequency locking found in onset. According to this approach, nevertheless, there is no way of explaining why certain clusters such as [ɾ..] are particularly susceptible to such a process, while others seem impervious to the procedure, [ɾ.t] for example. Quite simply, not enough is known regarding the scalar and biomechanic factors which underlie articulatory stability.

My hypothesis is that the scalar and biomechanic complexity of the shift between anti-phase and in-phase gestures plays a fundamental role in the relative stability of certain anti-phase/in-phase configurations. Past studies have documented the effects of complexity on the speech dysfluencies of stuttering patients. Huinek et al (2003), for example, present data which seem to support the hypothesis that the relative complexity between coda and onset gestures in homorganic sequences may have an effect on fluid speech, evidenced by longer speech reaction times. It is thought that increased complexity across syllable boundaries involves higher demands on motor planning. There appears to be, however, a general lack of explicitness regarding how
complexity in this instance is defined and quantified.

There is robust experimental evidence to superficially corroborate the interconnection between articulatory complexity, gestural overlap and stability. Romero’s (1996) electropalatographic data measuring the overlap in homorganic sequences across syllabic boundaries, for example, reveals there is no possible overlapping of gestures in intervocalic \( [r..] \) sequences due to the phonetic postures of the individual units. Independent acoustic data measuring the lag time and formant transition slopes between the release and onset of many intervocalic consonant sequences support this claim (Gibson forthcoming). Honoroff (1995) notes that in \([r.t]\) sequences it is not uncommon for \([t]\) to be realized in the alveolar region instead of dental. If the realization of \([t]\) as alveolar in this case is interpreted as a tendency to reduce articulatory complexity between intrinsic phasing modes, then the result would be a more stable anti-phase/in-phase sequence, meaning this cluster should be more impervious to a switch to in-phase coupling.

Nevertheless, due to methodological restrictions and lack of EMG data tracking muscle coordination in the tongue between the release of \([r]\) and the activation of \([.]\), there simply is not enough information by which to formalize a far reaching, functional model of relative phase-shift complexity. Available data only treat the postures of the individual units and do not address the dynamic interaction between movements. Moreover, no prediction can be made regarding how complexity between gestures may affect the articulatory system as a whole.

In a first instance, I describe complexity in terms of the relation between effector coordination (organismic), task demands (internal dynamics), environmental constraints (task space) and kinematics (energy expended to effectuate phase shift). A model is currently being developed in order to accurately quantify the relative complexity of phase shifts in intervocalic consonant clusters.

2.2 Phonological implications of relative complexity in [C.C] clusters and the effects on phonological development

The relative complexity of the shift between anti-phase \([r]\) and in-phase \([.]\) can theoretically explain why certain clusters are more prone to a shift to in-phase coupling, while other sequences seem to be more resilient to such a procedure. However, the bigger question remains concerning why this factor (1) emerged suddenly in the phonological development of several of our subjects, and (2) systematically coincided with the acquisition of multiple vibrant \([r]\). These points raise interesting questions concerning how we currently envisage phonological development and the factors which underlie lexical codification.

There are two basic ways by which to explain the effects of articulatory complexity on the phonology. On one hand, constraints referencing the complexity values of certain clusters could hypothetically be programmed into the grammar. Most computationalist accounts of metathesis explain this as a grammatical procedure in which some high-level correspondence constraint regulates the linear organization of input segments in the output. Aside from the fundamental circularity of the argument itself and the lack of physiological data to link high-level abstractions with low-level correlates, this explanation takes for granted that the underlying representation on which further computations are based is an automatically static description, which our research (data extracted from the same subjects) does not support. I propose, on the other hand, that complexity and stability relations are a programmed component of the underlying representation of words, and that high-level lexical descriptions are plastic for a time until the complexity/stability relations between gestures are acquired.

Taking into account Browman and Goldstein’s (1986) gestural score model, I propose a model of phonological development and lexicalization based on simple Gaussian process regression which envisages phonological acquisition as a learning route between novice and expert behavior. Following Nourrit et al (2003) the first stage of cognitive encoding would involve learning individual articulatory gestures (sensorimotor). In past studies, some motor-task scientists have referred to this phase of learning as the Raleigh stage. Subsequently, speakers learn that gestures
can be organized in two ways as per their relation with the vocalic target; the transition phase. Finally, the linear organization of underlying gestures becomes fixed once the learner acquires the patterns of relative complexity and stability between gestures, which is considered to constitute ‘expert’ command of the articulatory procedures required for speech production. In previous studies treating learning in motor tasks this stage is known as the van der Pohl phase:

Gestural organization at the phonological level.

i. Individual gestures are extracted.

ii. Patterns of intergestural timing between gestures become encoded.

iii. Patterns of complexity across syllable boundaries correlate syllables.

It is hypothesized that cognitive representations are plastic until full acquisition (expert) of complexity patterns is attained. Learning along this route, theoretically, should be continuous since expert behavior constitutes a mere adaptation of the initial behavior. Notwithstanding, the metathesis cases under study in this current project suggest that discontinuities may arise due to a parametric evolution of the initial coordination dynamic.

3.0 Experimental testing

In order to corroborate the hypotheses presented above, I have designed a battery of experimental tests which involve (1) measuring articulatory complexity in intersyllabic consonant sequences, within and beyond word boundaries (2) testing the stability of sequences when cycle frequency increases, and (3) observing qualitative changes between developmental phases (novice to expert) in L2 speakers undergoing progressive training. Below I elaborate on each one of these.

3.1 Quantifying articulatory complexity in [C.C] clusters

As noted above, there is no comprehensive account with regard to measuring complexity patterns between intrinsic phasing modes. Huinck et al (2003) provide data which show that increased complexity of homorganic consonant sequences has a negative effect on the fluent speech of stuttering patients, yet their study does not explicitly address what factors may ultimately underlie this complexity. It is supposed that since the same effector is needed in order to realize both gestures of the sequence, coordination of the two gestures in time is challenged. Extending this line of reasoning, I would like to collect EMG, electropalatographic and aerodynamic data for intervocalic consonant sequences within the word and at word boundaries in order to propose a model of articulatory complexity based on the interaction of environmental, organismic and task constraints. Cine-MRI data would also be beneficial in the sense that a visual demonstration of the dynamic interaction between effector coordination and environmental constraints could be obtained.

One of the offshoots of the hypothesis I propose regarding the cognitive codification of complexity patterns in lexical forms is that there should be a qualitative difference between the complexity of phase shifts in word medial position and across word boundaries. I predict that since complexity patterns form part of the high-level representation of lexical items, the speaker may have greater leeway to reduce complexity in word-internal position, [βéɾ..es.pwés] ver después ‘to see after’, however, phase-shift complexity cannot be represented since words can combine freely and, hence, increased complexity should be anticipated.

3.2 Correlating complexity to stability

Following Pouplier and Goldstein’s (2005) study, I would like to conduct an experiment in which subjects are prompted to repeat words containing consonant sequences with varying degrees of complexity between phasing modes while incrementing cycle frequency. I predict that more complex phase shifts will lead to increased susceptibility to speech errors, similar to the
synchronic cases of metathesis, past a critical frequency, superficially corroborating my claim of an inherent correlation between complexity, overlap and stability.

3.3 Learning complexity
Following Nourrit et al (2003) I would like to track the progress of learning routes for speakers acquiring patterns of intersyllabic complexity in order to observe qualitative changes between the phases of phonological development. Ideally, it would be advantageous to observe this process in L1 speakers acquiring their first language, but due to the intrusive nature of articulatory testing and the real time involved in the route from novice to expert behavior in L1 development, such testing is untenable. In its stead, it is predicted that similar testing in L2 subjects could also render interesting insight into the different phases involved in learning complexity and stability patterns.

4.0 Final remarks
The previous outline provides a very rough sketch of my current research. Due to constraints of time and space, I have purposefully omitted critical aspects of my argumentation. I will address those topics on Friday February 3 in Paris.