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Mechanisms of regulation in speech: Linguistic structure and physical control system

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ABSTRACT

Speech variation is a naturally-induced phenomenon in human speech communication which can be attributed to the inevitably multifaceted nature of interactions between various higher-order linguistic and lower-order physiological factors. Speech is dynamic, and it is assumed that there are regulation mechanisms behind these complex interactions of structural, contextual and phonetic cues leading to an overwhelming variety of gradient phenomena in the speakers' linguistic behaviour. Recent years have increasingly witnessed the extensive development of dynamical theories which attempt to capture mechanisms of regulation that underlie speech production and perception in a unified way. In this introductory paper, we touch on some basic theoretical groundings of speech dynamics, and discuss the significance of the contributions made by each paper of the special issue under the rubric of mechanisms of regulation in speech. The special issue is interdisciplinary in nature, bringing together papers from different perspectives, ranging from tutorial and critical review papers on dynamic systems to original research papers on the regulation of speech in both normal and adverse (atypical) conditions. These selected papers, taken together, make considerable advancements in illuminating how variation in production and perception can be seen as a window to linguistic structure within and across languages.
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1. Mechanisms of regulation in speech

One of the goals of linguistic phonetics is the understanding of underlying principles and mechanisms that regulate variation in speech production. A complex interplay between linguistic structure and the physical system leads to a huge amount of naturally-induced variability. Speakers generate an overwhelming variety of gradient phenomena in their linguistic behaviour. A bundle of factors playing a role in the natural process of human communication trigger and constrain variation in speech, most of them reaching deeply into human physiology, cognition and grammar. There are regulation mechanisms behind these complex interactions of structural, contextual and phonetic cues mediating between naturally-induced variability (e.g. due to prosodic marking) and the need for gestural coherence in order to preserve the phonological form of a given pattern. This is illustrated in Fig. 1. On the one hand, there is a need for prosodic marking (e.g. boundary marking) in the articulatory substance. The higher the prosodic domain, the stronger the spatial and temporal modifications on domain-initial consonants. Fougeron and Keating (1997) have shown in an EPG study of French that the linguopalatal contact for the alveolar nasal /n/ increases at strong boundaries and decreases at weak boundaries. On the other hand, there is a need for gestural coherence in order to preserve phonological form. Segments differ in terms of their degree of coarticulatory resistance (Farnetani & Recasens, 2010). Alveolar fricatives such as /s/, for example require a very precise predorsal activation. They show fewer degrees of articulatory and acoustic freedom (Bombien, Mooshammer, Hoole, & Kühnert, 2010:390) and therefore they are more resistant to prosodic changes than segments such as /n/, which have a lower degree of coarticulatory resistance. In a similar vein, Cho (2004) demonstrated that articulatory gestures for vowels in VCV context in English resisted coarticulation both at prosodic junctures and under prominence (e.g. receiving pitch accent), showing an interplay between naturally-induced variation and gestural coherence being modulated by prosodic structure.

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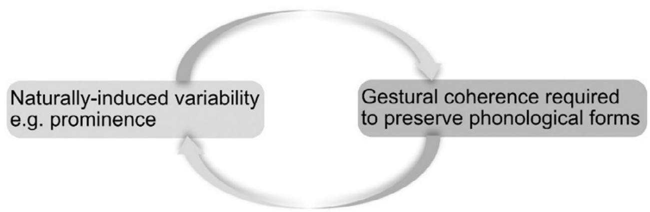

Fig. 1. Regulation mechanisms in speech.

Understanding how speech variation is regulated, however, appears to be never complete and in turn entails new questions. In his paper "*The devil is in the detail*", Nolan (1999:1) also notes that "the more detailed our knowledge of the properties of speech becomes, the more difficult it is to sustain our simplifying assumptions, our models which help us comprehend our universe".

The last few decades, however, have witnessed development of theories of speech dynamics which aim at illuminating mechanisms of regulation in speech in a unified way. In dynamic approaches, phonetic detail is seen as a direct window to linguistic structure rather than as the 'curse' of modern measuring techniques. Consequently, variability in the physical world is seen as a direct outcome of the system's behaviour, a challenge between naturally-induced pattern variability in human communication and the need for pattern stability to preserve phonological forms, mostly language-driven.

In this thematic special issue, we attempt to take a step forward toward disentangling the complexity in the mechanisms of speech regulation by bringing together different studies at different levels of description under the rubric of speech dynamics, exploring fundamentals of regulation in terms of dynamical systems, regulation of articulatory gestures and regulation of speech in adverse conditions. We assume that complexity in mechanisms of speech regulation can be best understood by allowing for a number of different perspectives (Wagner et al., 2015). In addition to a tutorial on the basics of dynamical systems, a review of dynamics in perception and production is presented. The special issue presents studies that show the need for speech systems that are flexible and adaptive to changes over time and that can respond to the complex interplay of grammatical, prosodic and physiological demands. Intonation as well as supralaryngeal articulation are presented in terms of continuous parameters that should be – in the future – integrated in a unified system. A combined focus on clinical and non-clinical speech in terms of the interaction between dynamical diseases and the requirements of a phonological system in a given language displays the complexity of speech regulation and deals with the breakdown of phonological patterns as a gradient phenomenon.

The papers in this special issue are organized into three sections: Section 1.1, Dynamic systems; Section 1.2, Regulation of articulatory gestures; Section 1.3, Regulation in adverse conditions. Each section starts with a brief overview of the research field and then deals with the individual contributions to the special issue.

1.1. Regulation in terms of dynamic systems

Dynamic systems describe the evolution of the complex behaviour of a system—that is, the language in this case. In a linguistic system, phonological information (low-dimensional) can be mapped directly onto continuous phonetic cues (high-dimensional) without the need for an interface between phonological form and phonetic substance (Browman & Goldstein, 1992; Gafos & Beňuš, 2006; Goldstein, Byrd, & Saltzman, 2006; Mücke, Grice, & Cho, 2014; Saltzman & Munhall, 1989). A dynamic system changes its behaviour in a lawful manner such that *rules of change* in terms of mathematical laws can be captured by the use of differential equations. Those dynamic approaches bridge the gap between discrete phonological description and continuous phonetic representations by modelling them in a unified system.

The differential equation of a dynamic system specifies the continuous behaviour of the system over time. While the equation is invariant, the physical output is not (Browman & Goldstein, 1989, 1992; Gafos, 2006; Gafos, Charlow, Shaw, & Hoole, 2014; Kelso, 1995; Spivey, 2007). Once a dynamic system is set into motion, it evolves towards a specific (linguistic) target (i.e. equilibrium position). This target is defined by an attractor, which defines values or regions of values in the possible phase space of the system. Attractors are often compared with a marble rolling to the bottom center of a bowl (Haken, Kelso, & Bunz, 1985; Nam, Goldstein, & Saltzman, 2010). In the rolling marble metaphor, a marble rolls into a bowl. The bowl defines all possible values of the phase space, and the attractor would be the bottom center of the bowl. Those dynamic systems always encode context-dependent variability. If the marble starts to roll next to the bottom center of the bowl, the path to the center is short. If it starts to roll from the bowl's margin, the path to the center is long. However, in both cases the marble is likely to roll towards the bottom center of the bowl, where the system eventually stabilizes and the marble comes to rest. If there is competition between multiple target attractors, the system evolves to one of the attractors as a function of the different starting conditions and attractor strengths (Tuller & Lancia, 2017).

Many skilled movements by humans have been characterized as being controlled by such a dynamical (point-attractor) system (see Goldstein et al., 2006 and the references therein). Speech production and perception can also be understood as dynamic systems using attractors that reflect linguistic structure. Let's assume that the attractor is a linguistic goal such as the lip closure during the production of an intervocalic consonant in a sequence such as /ibi/ and /aba/. The goal for the lips in /b/ is invariant (full closure of the lips), but the way the lips travel differs in the two conditions. The way is shorter in /ibi/ than in /aba/, because due to the different starting conditions the jaw is already higher in the high vowel /i/ than in the low vowel /a/. A dynamic system in speech needs to be flexible, and redundancy plays an important role (Browman & Goldstein, 1992; Fowler, Rubin, Remez, & Turvey, 1980; Goldstein & Pouplier, 2014; Hawkins, 1992; Saltzman & Kelso, 1987; Saltzman & Munhall, 1989). A great amount of context-dependent variability is generated in such a system, reflecting functional synergies of the articulators moving

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