Higher-order kinematic analysis of speech movement data

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We present techniques and results of a higher-order kinematic analysis of speech movement data registered by contemporary Electromagnetic Articulography (EMA). In particular, we first demonstrate the applicability of a well-established in the human movement field (but in speech rarely used) spline-smoothing approach and illustrate its superiority over traditional signal representations in EMA research. Second, using an heptic spline-smoothing approach, we reveal a so far unknown set of acceleration-based kinematic relations in data of repetitive speech. This set of empirical relations is finally shown to be the theoretical consequence of what a linguist considers to be the dynamical standard model of speech.

The kinematic analysis of movement data is one of the most often used techniques to assess and examine the phonetic and phonological structure of speech. However, kinematic analyses generally require the evaluation of quantities not directly measurable in speech, like the time derivatives of articulatory displacement (velocity, acceleration, etc.). Thus, there is need for an appropriate (numerical) estimation of these quantities. In other fields of human motion analysis, the ubiquitous but arduous task of finding derivatives of noisy displacement data had stimulated a large number of investigations which have led to several solutions (see Wood, 1982; Woltring, 1985; Medved, 2001 for exhaustive overviews). Today, in these fields, one of the most often used techniques is that of splines (Medved, 2001), with simpler methods of digital filtering and finite differences considered to be inadequate (Wood, 1982; D'Amico and Ferrigno, 1992). Yet the latter are routinely used in the domain of speech.

For the present work, we registered (by EMA) speech movement data from a task of repeated syllable production at a wide range of speech rates (/ka/ and /ta/ syllables at 1.5–9.5 syllables per second). In total, we collected data of approx. 17 500 syllables from seven native speakers of German and English. All registered movements were represented by heptic-order splines using Woltring (1986)'s generalized, cross-validatory spline smoothing and differentiation method with fixed predicted mean-squared error criterion (Wahba, 1979). We assess the applicability of this approach with regard to the analysis of kinematic parameters (which are duration, amplitude and peak velocity of a movement) and their relations. Specifically, we illustrate the superiority of the spline-smoothing approach over traditional filtering and finite difference techniques by means of higher correlation strengths of the well-known (velocity-based) kinematic relations in speech (Ostry et al., 1983; Ostry and Munhall, 1985; Munhall et al., 1985; Kelso, 1986; Vatikiotis-Bateson and Kelso, 1993). In addition, by use of the more faithful acceleration estimates from the spline representation, we present a novel, so far unknown set of acceleration-based kinematic relations. We show that these novel relations can be analytically derived from the standard model of a speech gesture (known as Task Dynamics, Saltzman and Munhall, 1989). These empirical observations and their theoretical substantiation further underpin the usefulness of a spline-smoothing approach in the domain of speech.

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