

What are the dynamical laws of speech?

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Learning to speak involves learning to control a high-dimensional movement space spanning multiple muscles in the tongue, lips, larynx, etc. A fundamental insight about biological systems is that this coordination problem is often simplified by reducing the control of complex systems to simpler, low-dimensional problems (Bernstein 1967). If true, this raises an important question: **what are the laws that govern the low-dimensional control of speech?**

If the dynamics governing speech movements are simple – autonomous attractors with fixed parameters – then the learner’s task is relatively constrained: find the targets and the system does the rest. If the dynamics are complex – time-varying, nonlinear, context-dependent – then the learning task is considerably more demanding. The answer to “what are the dynamical laws of speech?” therefore has direct implications for how we understand the acquisition of speech and its development over the lifespan. A range of candidate theories for the nature of articulatory control exist, spanning autonomous task dynamics (Saltzman & Munhall 1989; Sorensen & Gafos 2016; Kirkham 2025a), optimal control of non-autonomous dynamics (Turk & Shattuck-Hufnagel 2020), and feedback-driven control (Guenther 2016; Parrell et al. 2019; Tilsen 2022). Yet it is challenging to adjudicate between these different paradigms, because any single observation can be realized by multiple models (see Putnam 1967).

Rather than assuming a particular model and fitting its parameters, an alternative is to define the hypothesized system by its behaviour, such as the set of trajectories it can produce (Willems 2007). This forces us to ask: **what are the simplest dynamical laws consistent with the observed behaviour?** In this talk I present a programme of work aimed at recovering the dynamical laws of speech directly from articulatory movement data. I describe two complementary approaches. The first involves sparse identification of nonlinear dynamics (SINDy) to discover governing equations from articulatory trajectories without assuming a particular dynamical form in advance (Brunton et al. 2016; Kirkham 2025b). This reveals that the control of speech must be modelled as a nonlinear system to account for substantial properties of observed kinematics (Sorensen & Gafos 2016). Second, I introduce a Bayesian state-space approach that treats gestural targets as latent variables to be inferred from observed kinematics, without making assumptions about when gestures begin or end. Crucially, this framework allows us to test whether dynamical parameters are time-invariant for brief periods (i.e. corresponding to periods of gestural stability) or continuously modulated during production. This is a distinction with significant consequences for theories of speech production, coarticulation, and motor learning.

The findings reveal that the dynamics of gestural targets are **more structured than a purely continuous controller** would predict but **less static than task dynamics often assumes**. There exist substantial periods of stability, yet the temporal variability of targets problematizes a straightforward view of gestures as autonomous systems. More broadly, the ability to recover dynamical parameters from movement data exposes new opportunities in understanding how the control of speech changes across the lifespan, from the developing motor system of a child to age-related changes in motor control. By establishing the nature of these dynamical laws in adult speakers, we lay the groundwork for asking how those laws are acquired, refined, and reorganised across speech development.

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