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# Stability and composition of functional synergies for speech movements in children with developmental speech disorders

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**Abstract**

The aim of this study was to investigate the consistency and composition of functional synergies for speech movements in children with developmental speech disorders. Kinematic data were collected on the reiterated productions of syllables spa (/spaː/) and paas (/paːs/) by 10 6- to 9-year-olds with developmental speech disorders (five with speech sound disorder [SSD] and five with subtype childhood apraxia of speech [CAS]) and six normally speaking children using electro-magnetic midsagittal articulography (EMMA).

Results showed a higher variability of tongue tip movement trajectories and a larger contribution of the lower lip relative to the jaw in oral closures for the five children with CAS compared to normally developing controls, indicating that functional synergies for speech movements in children with CAS may be both delayed and less stable. Furthermore, the SSD group showed a composition of tongue tip movements that is different from both CAS and controls. These results suggest that the differences in speech motor characteristics between SSD and subtype CAS are qualitative rather than quantitative. At the same time, the results suggest that both SSD and subtype CAS increase movement amplitude as an adaptive strategy to increase articulatory stability.

Although in direct comparison no exclusive characteristics were found to differentiate subtype CAS from the group of children with SSD and from normally developing children, these preliminary results are promising for quantifying the role of speech motor processes in childhood speech sound disorders.

**Learning outcomes:** The reader will be able to: (1) describe the development of speech motor control and explain the role of functional synergies/coordinative structures; (2) explain the measurement of the stability and composition of speech movements; (3) identify the difficulties in studying disordered speech motor development; (4) describe the differences in speech motor characteristics between SSD and subtype CAS; (5) describe the potential role of motor control strategies in developmental speech disorders.


*Keywords:* Speech motor control; Speech motor development; Developmental speech disorders; Childhood apraxia of speech; Functional synergies; Coordinative structures; Speech movement patterns

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## 1. Introduction

The diagnosis of childhood apraxia of speech (CAS) constitutes one of the main challenges in the field of pediatric speech pathology. Despite the substantial disagreement about the diagnostic differentiation between CAS and other developmental speech sound disorders (SSD), most authors do agree that the core impairments for each disorder should be localized at a different level of speech production. Whereas SSD in general is thought to involve primarily phonological processes, the subtype CAS is usually seen as a speech motor disorder with a core deficit in planning and/or programming the spatiotemporal parameters of movement sequences (ASHA, 2007; Hall, Jordan, & Robin, 2007; Maassen, Nijland, & Terband, 2010; Shriberg, 2010). The distinction between phonological and speech motor production processes thus is a central issue in the diagnostic differentiation between CAS and other developmental speech disorders.

Isolating motor processing levels from phonological (and other higher cognitive) levels proves rather complicated in general, but especially in the developmental stage. Both in normal as in disordered development, cognitive modules are rather the outcome of development than the starting point. The progression to the adult system is a gradual and continuous process comprising interactions between emerging modules (Karmiloff-Smith, 2006; Karmiloff-Smith, Scerif, & Ansari, 2003; Karmiloff-Smith & Thomas, 2003). A specific underlying impairment in speech motor planning and/or programming may interfere with the development on other levels of processing, such as phonological and linguistic processing levels or motor execution (Maassen, 2002; Maassen et al., 2010). As a result, the symptoms of CAS do not directly reflect a deficit on one particular stage or level of sensory-motor processing and the differential diagnosis of CAS requires detailed information on the developmental history of the child, combined with performance indicators on specific speech motor tasks and fine-grained acoustic and/or kinematic measurements (Maassen et al., 2010; Terband & Maassen, 2010).

### *1.1. Normal speech motor development*

One approach to the study of speech motor development is to focus on the consistency and stability of movement patterns (Smith, 2006; Smith, Johnson, McGillem, & Goffman, 2000). At the lowest level of speech motor control, the development of speech motor coordination entails the development of functional synergies of muscle activations (or coordinative structures). In this way, the degrees of freedom are reduced, which makes the control task simpler. As a result, the dynamic coordination among orofacial structures becomes more consistent as the speech motor system matures (Bernstein, 1967; Kelso, Tuller, Vatikiotis-Bateson, & Fowler, 1984; Thelen, 1991; Thelen, Kelso, & Fogel, 1987). Measuring coordination and movement variability in speech production thus provides a way of assessing the progression of speech motor development.

Movement variability can be expressed by a variety of variability measures for kinematic movement parameters such as amplitude, duration and peak velocity. These measures, however, index the movement trajectories for a given speech task (e.g., bilabial closure) at specific, single points in time, reducing the amount of information that is potentially available in the entire trajectory. These variables may also be less robust in dealing with more extreme variations (outliers) and are not consistent in direct comparisons for a given speaker and task (Alfonso & Van Lieshout, 1997; Van Lieshout & Namasivayam, 2010). To examine the entire movement trajectory over time, Smith and colleagues developed the spatiotemporal variability index (STI, Smith, Goffman, Zelaznik, Ying, & McGillem, 1995; Smith et al., 2000). The STI captures the variability in movement patterns of selected motion trajectories of repeated utterances. To this end, the movement trajectories are time and amplitude normalized. A target movement template is estimated as the mean displacement amplitude value on the normalized time axis and each movement track is matched against the template along the time axis at a certain number of intervals. The STI is then calculated by summing the standard deviations across the individual tracks. A lower STI value indicates a smaller deviation from the target movement template, and thus less variability (Lucero, 2005; Smith et al., 1995, 2000).

A number of studies have investigated speech motor development utilizing the STI. Smith and Goffman (1998) compared the stability of movement trajectories in two groups of eight children (aged 4 and 7 years) with a same sized group of young adults. The STI was measured over the movement trajectories of the lower lip in 15 repetitions of the sentence *Buy Bobby a puppy.*[1] Results showed a higher STI in the lower lip movement trajectories of the 4-year-olds as

[1] More specifically ‘‘the interval from the peak velocity of the first opening movement from/b/to/aI/in *buy* to the peak velocity of the last opening movement for the/p/to/i/in *puppy*’’ (Smith & Goffman, 1998, p. 21).