Journal of Communication Disorders 51 (2014) 64–77

Contents lists available at ScienceDirect

Journal of Communication Disorders

Auditory feedback perturbation in children with developmental speech sound disorders

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ARTICLE INFO

Article history:
Received 19 April 2014
Received in revised form 7 June 2014
Accepted 30 June 2014
Available online 1 August 2014

Keywords:
Speech sound disorders
Childhood Apraxia of Speech
Auditory feedback control
Auditory feedback perturbation
Internal models

ABSTRACT

Background/purpose: Several studies indicate a close relation between auditory and speech motor functions in children with speech sound disorders (SSD). The aim of this study was to investigate the ability to compensate and adapt for perturbed auditory feedback in children with SSD compared to age-matched normally developing children.
Method: 17 normally developing children aged 4.1–8.7 years (mean = 5.5, SD = 1.4), and 11 children with SSD aged 3.9–7.5 years (mean = 5.1, SD = 1.0) participated in the study. Auditory feedback was perturbed by real-time shifting the first and second formant of the vowel /e/ during the production of CVC words in a five-step paradigm (practice/familiarization; start/baseline; ramp; hold; end/release).
Results: At the group level, the normally developing children were better able to compensate and adapt, adjusting their formant frequencies in the direction opposite to the perturbation, while the group of children with SSD followed (amplifying) the perturbation. However, large individual differences lie underneath. Furthermore, strong correlations were found between the amount of compensation and performance on oral motor movement non-word repetition tasks.
Conclusions: Results suggested that while most children with SSD can detect incongruencies in auditory feedback and can adapt their target representations, they are unable to compensate for perturbed auditory feedback. These findings suggest that impaired auditory–motor integration may play a key role in SSD.

Learning outcomes: The reader will be able to: (1) describe the potential role of auditory feedback control in developmental speech disorders (SSD); (2) identify the neural control subsystems involved in feedback based speech motor control; (3) describe the differences between compensation and adaptation for perturbed auditory feedback; (4) explain why auditory–motor integration may play a key role in SSD.

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http://dx.doi.org/10.1016/j.jcomdis.2014.06.009
0021-9924/

1. Introduction

1.1. Developmental speech sound disorder

Pediatric or developmental speech sound disorder (SSD) is an umbrella term that encompasses a variety of diagnostic labels, such as Speech Delay, Phonetic Articulation Disorder, Phonological Disorder with subtypes consistent or inconsistent, and pediatric Motor Speech Disorders with subtypes Childhood Apraxia of Speech and developmental dysarthria (Dodd, 2005; Lewis et al., 2006; Strand, McCauley, Weigand, Stoeckel, & Baas, 2013; Terband, Maassen, Guenther, & Brumberg, 2014). Although these categories are meant to represent core impairment at different levels of speech development and different parts of the speech production chain, speech and language processes are interactive and influence each other during development (Kent, 2004; Smith & Goffman, 2004; Strand et al., 2013; Terband & Maassen, 2010; Terband et al., 2014). Consequently, there is a large overlap in clinical symptoms which, moreover, change during successive stages of development: often starting with no or little babbling and subsequently less variegated babbling during the first year, followed by a slowed expansion of vocabulary during the second year, and the presence of many speech sound substitution errors in kindergarten (Maassen, 2002; Maassen, Nijland, & Terband, 2010; Terband & Maassen, 2010). From then on, the speech is characterized in general as unintelligible and often effortful, with a high rate of mispronunciations or apparently 'normal' slips of the tongue (ASHA, 2007; Dodd, 2005; Maassen et al., 2010; Shriberg, 2010).

Prevalence of SSD reported in the literature is around 6% (Broomfield & Dodd, 2004; Campbell et al., 2003; Law, Boyle, Harris, Harkness, & Nye, 2000; McKinnon, McLeod, & Reilly, 2007; Shriberg, Tomblin, & McSweeny, 1999) and SSD are estimated to form about 75% of all communication disorders in children (Van Borsel, 2009). The majority of these children visit speech pathologists for examination and treatment. However, little is known about the mechanisms behind SSD. More specifically: how do the phonological and sensorimotor impairments relate to the core deficit, derived or consequential deficits and adaptive strategies, and how do they express themselves in symptomatology? This knowledge could be crucial for effective diagnosis and treatment of children that suffer from SSD.

Findings from both behavioral and neurocomputational modeling studies indicate that the interaction between auditory and speech motor functions may play a critical role in SSD. Empirical data indicate that there is a close relation between production symptoms and perceptual acuity in children with speech sound disorders (SSD): poor perceptual performance is related to poor production performance (Edwards, Fox, & Rogers, 2002; Groenen, Maassen, Crul, & Thoonen, 1996; Maassen, Groenen, & Crul, 2003; Nijland, 2009; Raaymakers & Crul, 1988). Computer simulations with the DIVA model suggest that the ability for auditory self-monitoring might influence the nature of speech-motor deficits during development (Terband et al., 2014). These findings indicate that the quality of auditory feedback and the capacity to use it may be key factors in SSD.

1.2. Auditory feedback control in adults and children

The role of auditory feedback in speech production is twofold. First, it is important for acquiring sensory goals for producing speech sounds and serves as a teaching signal for the acquisition and adaptation of speech motor programs (Guenther, Hampson, & Johnson, 1998; Guenther & Perkell, 2004; Perkell, 2012; Perkell et al., 1997). Second, auditory feedback serves as a guiding signal in the online control and correction of speech movements. The coordination of the timing and magnitude of the movements in the different systems involved (i.e., the muscular structures controlling respiration, resonance, phonation, and the articulators) has been found to be largely dependent on auditory feedback (Perkell, 2012; Perkell et al., 2007, 1997). Furthermore, several studies demonstrated that perturbation of auditory feedback during speech production elicits a compensatory response in the opposite direction to maintain the intended auditory outcome (Cai, Ghosh, Guenther, & Perkell, 2010; Houde & Jordan, 2002; Villacorta, Perkell, & Guenther, 2007). In this experimental paradigm, an acoustic cue is manipulated in real time during speech production and presented to the speaker through headphones. This creates an apparent mismatch between the speech sound the speaker intended to produce and what he/she hears. Using the auditory feedback control subsystem, the speaker is able to generate a compensatory response to the acoustic shifts in order to match the intended target. However, it has been found that some speakers show production changes that follow the direction of the perturbations and not all speakers show a consistent response. Typically, around 70% of the speakers show (partial) compensation (see Cai et al., 2010 for an overview). A possible explanation is that in the speakers who do not show a response, the perturbations might be undetected by the speech motor control system (Purcell & Munhall, 2006). It has also been suggested that there is a trade-off with somatosensory feedback and that individual speakers weight the different types of feedback differently (Katseff, Houde, & Johnson, 2012; Lametti, Nasir, & Ostry, 2012; Purcell & Munhall, 2006).

Only a few studies have investigated auditory feedback in speech development. Ménard and colleagues used a lip-tube to alter F1 and F2 of vowels produced by 4-year-old French speakers (Ménard, Perrier, & Aubin, 2013; Ménard, Perrier, Aubin, Savariaux, & Thibeault, 2008). Results showed that while the children were able to reach compensation in some vowels, a consistent compensatory effect was absent. This suggests that they were able to use auditory feedback to develop a compensatory strategy, but were unable to (learn to) update and store their representations. In an auditory perturbation study involving 9–11-year-old children, spectral properties of /s/ were manipulated toward /?/ in a series of monosyllabic words (Shiller, Gracco, & Rvachew, 2010). Results showed that the children were able to compensate for the altered auditory feedback to a comparable degree as adults, albeit with a larger token-to-token variability. These findings were replicated for