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Motor practice effects and sensorimotor integration in adults who stutter: Evidence from visuomotor tracking performance

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ABSTRACT

Purpose: The purpose of this study was to utilize a visuomotor tracking task, with both the jaw and hand, to add to the literature regarding non-speech motor practice and sensorimotor integration (outside of auditory-motor integration domain) in adults who do (PWS) and do not (PWNS) stutter.
Method: Participants were 15 PWS (14 males, mean age = 27.0) and 15 PWNS (14 males, mean age = 27.2). Participants tracked both predictable and unpredictable moving targets separately with their jaw and their dominant hand, and accuracy was assessed by calculating phase and amplitude difference between the participant and the target. Motor practice effect was examined by comparing group performance over consecutive tracking trials of predictable conditions as well as within the first trial of same conditions.
Results: Results showed that compared to PWNS, PWS were not significantly different in matching either the phase (timing) or the amplitude of the target in both jaw and hand tracking of predictable and unpredictable targets. Further, there were no significant between-group differences in motor practice effects for either jaw or hand tracking. Both groups showed improved tracking accuracy within and between the trials.
Conclusion: Our findings revealed no statistically significant differences in non-speech motor practice effects and integration of sensorimotor feedback between PWS and PWNS, at least in the context of the visuomotor tracking tasks employed in the study. In general, both talker groups exhibited practice effects (i.e., increased accuracy over time) within and between tracking trials during both jaw and hand tracking. Implications for these results are discussed.

Educational Objectives: The reader will be able to: (a) describe the importance of motor learning and sensory-motor integration for speech, (b) summarize past research on PWS's performance during speech and nonspeech motor tasks, and (c) describe the relation between different aspects of speech and non-speech motor control and stuttering.

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1. Introduction

Developmental stuttering is a speech disorder characterized by disruptions in the flow of speech taking the form of repetitions, prolongations, and silent blocks. While a complex interaction of environmental, motor, emotional and cognitive-linguistic variables is believed to underlie the onset and development of stuttering (for review see Bloodstein & Bernstein Ratner, 2008), the overt behaviors of stuttering may be the result of disruptions in the respiratory, phonatory and articulatory movements leading to the inability to smoothly transition between speech sounds. For some time, it has been argued that a better understanding of the aberrant motor control processes involved in stuttering would lay a foundation for study of potential contribution of other factors, such as environmental, emotional and/or linguistic, on the development of this disorder (Max, Guenther, Gracco, Ghosh, & Wallace, 2004).

Numerous attempts have been made to describe the status of both speech and non-speech motor systems in people who stutter (PWS). One observation that has been replicated across many studies is that the speech and non-speech (i.e., orofacial, finger and hand) movements of PWS are slower and longer in duration than those of people who do stutter (PWNS), as well as more variable or less stable (for review see Bloodstein & Bernstein Ratner, 2008; Kleinow & Smith, 2000; Max, 2004; Max et al., 2004; McClean, Kroll, & Loftus, 1990; Namasivayam & van Lieshout, 2008; Olander, Smith, & Zelaznik, 2010; Smith, Sadagopan, Walsh, & Weber-Fox, 2010; Smits-Bandstra, De Nil, & Rochon, 2006; Zelaznik, Smith, Franz, & Ho, 1997; Zimmermann, 1980). These between-group and across-domain differences in movement duration, amplitude and stability, especially in non-speech (orofacial, finger, and hand) movements, suggest that stuttering may result from a more general deficit in motor control that is not speech-specific. This conclusion is supported by evidence that timing control of both speech and non-speech gestures shares a common neural substrate (Bengtsson, Ehrsson, Forssberg, & Ullén, 2005; Binkofski & Buccino, 2004).

There are several theories that attempt to explain the motor deficit believed to underlie stuttering. In the Speech Motor Skill (SMS) theory proposed by van Lieshout, Hulstijn, and Peters (2004) in which speech production is viewed in the same realm as other fine motor skills, with individual abilities falling along a continuum from least to most skilled. It is hypothesized that PWS's abilities may be located toward the lower end of the presumed normal speech motor skill continuum. Following the SMS perspective, disfluencies are viewed as disruptions in the preparation and performance of complex motor actions in the face of cognitive-linguistic, environmental or emotional influences (Namasivayam & van Lieshout, 2011; Peters, Hulstijn, & van Lieshout, 2000). Disruptions in speech motor control are thought to be subtle and only become evident when high demands for movement accuracy and speed or increased task complexity are placed on the system. For example, Smith and her colleagues have repeatedly demonstrated that PWS's speech motor variability (as measured by a "spatiotemporal index" or degree to which the pattern of movement is consistent on repeated productions of the same utterance) is strongly affected by the length and phonological complexity of the produced utterance (Kleinow & Smith, 2000; Smith, Sadagopan, Walsh, & Weber-Fox, 2010).

Despite evidence that PWS may exhibit less proficient motor performance (see evidence provided above), it is not clear if there are distinct processes within the motor system that are deficient. Both feedback and feedforward modes of control are required for skilled motor control, and it has been speculated that inefficiencies in the speech motor control of PWS could be attributed to a lack of ability to utilize and/or learn feedforward models, the overreliance of feedback or the lack of ability to integrate feedback with ongoing feedforward commands (Cai, Beal, Ghosh, Guenther, & Perkell, 2014; Cai et al., 2012; Civier, Tasko, & Guenther, 2010; Loucks, Chon, & Han, 2012; Max et al., 2004; Tourville, Reilly, & Guenther, 2008). In the following sections we will discuss research regarding the motor practice and learning abilities and utilization of sensory feedback in PWS. We will then present a case for why visuomotor tracking tasks are a good method of investigating motor practice effects and sensorimotor integration.

1.1. Motor practice effects, motor learning and stuttering

Motor learning is process that results in a long-term memory for the execution of motor skills. It is essential for the efficient and effortless execution of complex sequential movements (e.g., speaking, walking, typing, and playing musical instruments) as well as for calibrating the smoothness and accuracy of simple movements (Abbruzzese, Pelosin, & Marchese, 2008). Acquisition of motor skills is typically manifested by increased accuracy and speed of performance. It is thought that such increases in speed and accuracy of performance result from repeated exposure to a specific skill, often without conscious recollection of the prior learning episode or the rules underlying the task (Cohen & Squire, 1980).

Research has shown that motor movements, including those for speech production, require a certain degree of practice to become adult-like (Green, Moore, Higashikawa, & Steeve, 2000; Green & Nip, 2010). Proficiency in performance of those movements will likely depend on motor learning that is the result of motor practice. Within one prominent theory of motor control, the Schema Theory (Schmidt & Lee, 2005), the process of movement acquisition is viewed as an interaction between an individual's innate capacities and the type of movement to be learned. According to the SMS model previously described (Namasivayam & van Lieshout, 2011; van Lieshout et al., 2004) PWS may have a limited ability to benefit from motor practice and achieve lower levels of movement proficiency than PWNS after the same amount of practice.

Empirical evidence indicating less robust motor learning abilities in PWS comes from studies of sequence learning in various domains: finger tapping, syllable sequencing, and nonsense word learning. In an early study, Webster (1986) examined PWS and PWNS's abilities to learn four-element finger tapping sequences and found that, compared to PWNS, PWS