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Research report

Right-shift for non-speech motor processing in adults who stutter

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ABSTRACT

Introduction: In adults who do not stutter (AWNS), the control of hand movement timing is assumed to be lateralized to the left dorsolateral premotor cortex (PMd). In adults who stutter (AWS), the network of speech motor control is abnormally shifted to the right hemisphere. Motor impairments in AWS are not restricted to speech, but extend to non-speech orofacial and finger movements. We here investigated the lateralization of finger movement timing control in AWS.
Methods: We explored PMd function in 14 right-handed AWS and 15 age matched AWNS. In separate sessions, they received subthreshold repetitive transcranial magnetic stimulation (rTMS) for 20 min at 1 Hz over the left or right PMd, respectively. Pre- and post-stimulation participants were instructed to synchronize their index finger taps of either hand with an isochronous sequence of clicks presented binaurally via earphones. Synchronization accuracy was measured to quantify the effect of the PMd stimulation.
Results: In AWNS inhibition of left PMd affected synchronization accuracy of the left hand. Conversely, in AWS TMS over the right PMd increased the asynchrony of the left hand.
Conclusions: The present data indicate an altered functional connectivity in AWS in which the right PMd seems to be important for the control of timed non-speech movements. Moreover, the laterality-shift suggests a compensatory role of the right PMd to successfully perform paced finger tapping.

1. Introduction

Fluent speech requires the well timed selection, initiation, execution and monitoring of motor sequences. The relevant cortical and subcortical neural systems appear to be malfunctioning in developmental stuttering (Brown et al., 2005; Fox et al., 1996; Ludlow and Loucks, 2003). Stuttering is characterized by an impairment of speech rhythm or fluency (Bloodstein and Ratner, 2008). Speech disruptions typically include blocks, repetitions, or prolongations of speech

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segments (WHO, 2007b), and may be accompanied by movements of face and limb muscles and by negative emotions such as fear or embarrassment. About 5% of the population stutters at some point during childhood (Mansson, 2000). Although spontaneous recovery rate is high, stuttering without obvious neurological origin persists after puberty in about 1% of adults (Andrews and Harris, 1964; Bloodstein and Ratner, 2008; Craig et al., 2002). Exploring the underlying neural mechanisms of this disorder provides insights into mechanisms of dysfluent speech production and into models of speech planning and production in general. These insights into the physiology of stuttering may ultimately serve to improve treatments enhancing speech fluency.

Temporal patterns in speech occur on multiple timescales (i.e., subsegmental, segmental and suprasegmental, Levelt, 1989). In adults who stutter (AWS), acoustic-temporal and spatio-temporal characteristics are affected in stuttered and fluent speech on all these timescales (Jancke, 1994; Kleinow and Smith, 2000; Max and Gracco, 2005; Prins and Hubbard, 1992). Most consistent are the observations of increased variability of duration and relative timing of acoustic and kinematic features. Additionally, stuttering has been associated with altered auditory feedback control mechanisms (Max et al., 2004; Tourville et al., 2008). Altogether, these facts underline a deficit of speech motor timing and the impact of the timing of auditory information during speaking in AWS.

Alterations of timing abilities in AWS exceed the domain of speech and affect the motor control of non-speech movements as well. For example, AWS performed poorly in reproducing varying rhythmic patterns (Hunsley, 1937) or unpredictable digit sequences (Webster, 1986). Additionally, AWS exhibit prolonged initiation and execution times in finger movement sequencing tasks (Smits-Bandstra et al., 2006; Webster, 1997) and increased manual reaction times (Bishop et al., 1991; Webster and Ryan, 1991). Phase variability is greater during bimanual coordination of auditory paced movements (Zelaznik et al., 1997) and movement variability is increased during simultaneous synchronization of speech and hand movements (Hulstijn et al., 1992). However, studies on auditory paced isochronous finger movements did not find differences of timing accuracy and timing variability between AWS and controls (Hulstijn et al., 1992; Max and Yudman, 2003; Melvine et al., 1995; Zelaznik et al., 1994).

Two separate processes have been related to timing accuracy: a neural clock mechanism (Rao et al., 1997; Ivry and Spencer, 2004), and an emergent property of the kinematics of movements itself (Ivry and Spencer, 2004; Mauk and Buonomano, 2004). This dissociation between event timing and emergent timing has been corroborated by previous findings (Spencer et al., 2003; Zelaznik et al., 2005, 2002). Timing in the sub- and supra-second range involves dissociable neural networks (Gibbon et al., 1997; Lewis and Miall, 2003; Wiener et al., 2010). Sub-second timing engages cerebello-thalamo-cortical network (Pollok et al., 2005), whereas supra-second timing tasks were more prone to activate cortical structures such as supplementary motor area (SMA) and prefrontal cortex (Wiener et al., 2010). For an event timing task like self-paced finger tapping, Wing and Kristofferson (1973) indicate a dichotomy between central clock and motor execution by suggesting that a central timekeeper supplies intervals of the adequate length and drives motor commands at the end of each interval. The original Wing–Kristofferson model was concerned with the special case of self-paced finger tapping and therefore neglected the process of integrating external cues. This contrasts with finger tapping in synchrony with an acoustically presented pacer, a timed motion task that additionally involves the integration of the external event and the monitoring of the synchrony of the pacer and the tapping.

Finger tapping accuracy can be disturbed by transcranial magnetic stimulation (TMS) (Doumas et al., 2005; Levit-Binnun et al., 2007; Malcolm et al., 2008; Pollok et al., 2008), a neurophysiological technique inducing a brief electric current in the brain using a magnetic field to pass the scalp and the skull safely and painlessly. Repetitive TMS (rTMS) is capable of inducing excitability changes of neural networks outlasting the stimulation period (Hallett, 2000; Miniussi et al., 2008; Siebner and Rothwell, 2003; Siebner et al., 2009), thereby temporarily disrupting activity in local or remote cortical areas (Wagner et al., 2009; Walsh and Rushworth, 1999). Thus, rTMS disrupts brain functions for a finite time with relatively high spatial resolution.

In the present study rTMS was employed to induce a transient virtual lesion of the dorsolateral premotor cortex (PMd). Traditionally the premotor cortices (PM) were assumed to be key structures in the motor domain and thereby associated with the preparation and the organization of movements and actions (Wise, 1985). Imaging studies suggest a specific significance of the PMd for cognitive functions (Abe and Hanakawa, 2009), sensorimotor integration (Pollok et al., 2009; Schubotz et al., 2003) and rhythm perception (Bengtsson et al., 2009), as well. Recent studies provide evidence for a specific role of the left PMd for movement timing of both hands (Pollok et al., 2009, 2008). Interestingly, externally paced finger movements as well as syllable repetition seem to recruit the same cerebral network involving the left PMd (Riecker et al., 2006). However, the PMd seems to play a role during fluency enhancing mechanisms in AWS. Fluency is reliably enhanced when speech is timed to a pacer: either an external pacer such as a rhythmic beat (Wingate, 2002; Wohl, 1968), the unison speaking with another person (Adams and Ramig, 1980; Ingham and Carroll, 1977; Saltuklaroglu et al., 2009), or an internal pacer such as rhythmic arm swinging or a finger tapping (Bloodstein and Ratner, 2008). Alternative fluency enhancing techniques are delayed or frequency shifted auditory feedback (Antipova et al., 2008; Van Riper, 1970). Such fluency enhancing mechanisms involve right premotor regions as well as the cerebellum (Braun et al., 1997; Fox et al., 1996; Tourville et al., 2008; Watkins et al., 2008). Hence, the PM seem to play an important role for motor timing control as well as the implementation of fluency enhancing techniques.

Theoretical frameworks on stuttering suggest an aberrant timing of neural activity in different brain regions that are relevant for speech processing (Alm, 2004; Howell, 2004; Ludlow and Loucks, 2003). Specifically, the basal ganglia-cortical route might be impaired in providing internal cues for the exact timing of movements, while the PMd in concert with the cerebellum successfully utilizes external time cues resulting in enhanced fluency for example during metronome speaking (Alm, 2004). Interestingly, in AWS even a non-speech motor task like externally paced finger tapping mirrored an