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Manual disfluency in drawing while producing and listening to disfluent speech

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ABSTRACT

This study investigated the extent to which manual fluency was associated with speech fluency in fluent speakers engaged in dual motor tasks. Thirteen right-handed adult females repeatedly drew circles with a pen on a digitizer tablet under five conditions: (1) a baseline (without reading or listening to speech), (2) reading fluently, (3) reading disfluently, (4) listening to fluent speech, and (5) listening to disfluent speech. The primary measure of disfluency was normalized mean squared jerk (NJ) in the pen strokes. Pen stroke time (ST) and pressure (PP) were also measured. NJ of the circle movements was significantly increased in both the disfluent reading and the disfluent listening conditions ($p < 0.05$), compared to the baseline condition. In the fluent listening and reading conditions, NJ in circle drawing was unaltered compared to the baseline condition. Relative to baseline, ST increased significantly ($p < 0.05$), but to a similar extent in all experimental conditions. Significantly ($p < .05$) greater pen pressure were also found in the disfluent versus fluent conditions. Positive correlations ($r = 0.33–0.63$) were found between NJ and ST across conditions. These findings demonstrate that in dual-tasks, speech fluency can influence manual fluency. This is consistent with the corpus of data showing neural connectivity between manual and speech tasks, as well between perception and production. The mirror neuron system is implicated as a mechanism involved in forging these links.

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1. Introduction

Though manual and speech systems often function independently, human beings demonstrate strong connectivity between these motor systems, especially when communicating with each other. Conversational speech is often produced synchronously with manual gestures that highlight, clarify or contribute additional meaning to the vocal message (Alibali, Heath, & Myers, 2001; Hubbard, Wilson, Callan, & Dapretto, 2009; Jacobs & Garnham, 2007; Kendon, 2004; McNeill, 1992). Similarly manually based languages such as American Sign Language (ASL) are often produced in conjunction with expressive facial and oral movements to convey additional meaning (Corina, Bellugi, & Reilly, 1999; Ruben, 2005). Thus, humans are capable of independently deploying or harmoniously integrating manual and speech mechanisms in complex and specialized motor sequences. Not surprisingly, investigations exploring the interconnectivity of these systems, whose cortical motor representations are anatomically close to each other, remain an area of considerable interest (Corballis, 2010; Gentilucci & Dalla Volta, 2008).

One explanation for the interconnectivity between manual and speech systems arises from an evolutionary perspective. Spurred by the need to communicate over longer distances, in the absence of daylight, and to free the hands for tool use, primitive manual gestures of our predecessors evolved into the complex system of dynamic, overlapping vocal tract gestures that have characterized modern speech for the last 50,000 years (Arbib, 2005; Corballis, 2002; Gentilucci & Corballis, 2006; Lieberman, 2007; Rizzolatti & Arbib, 1998; Ruben, 2005). According to this perspective, a primary driving force behind the evolution of language is the presence of the 'mirror neuron' system, which is thought to encode actions motorically (Corballis, 2010; Rizzolatti & Arbib, 1998), thereby creating a neural link between sensory and motor processing (i.e., action perception, and production). Direct evidence of mirror neurons was originally discovered in monkeys, with neurons in the F5 motor region becoming activated when the monkey both produced and perceived a meaningful goal-directed action (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti & Arbib, 1998; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996; Rizzolatti, Fogassi, & Gallese, 2001). This region would eventually become Broca's area which, along with the premotor cortex, has been strongly implicated as an important frontal region in the human mirror system (Corballis, 2010).

In support of the evolutionary link between hand and speech systems mediated by the mirror neuron system, an increasingly large body of neuroimaging evidence has clearly demonstrated connectivity in both sensory and motor tasks. For example, motor cortical representations of hand movements have been recorded during word, phrase (Aziz-Zadeh, Wilson, Rizzolatti, & Iacoboni, 2006; Hauk & Pulvermüller, 2004), and sentence comprehension tasks (Tettamanti et al., 2005) that describe actions performed by the hand. Similarly, Floel, Ellger, Breitenstein, and Knecht (2003) found that both listening to and producing linguistic information could activate motor cortices for the hands. In addition, activation of the hand motor cortex has been found during covert reading and while anticipating speech production (Meister, Buelte, Staedtgen, Boroojerdi, & Sparing, 2009; Meister et al., 2003; Seyal, Mull, Bhullar, Ahmad, & Gage, 1999; Tokimura, Tokimura, Oliviero, Asakura, & Rothwell, 1996). A number of studies have also demonstrated interconnectivity between modalities related to function. For example, activation of the hand motor cortex has been shown to produce accelerated lexical and syntactic decisions (Glenberg & Kaschak, 2002; Pulvermüller, Hauk, Nikulin, & Ilmoniemi, 2005). Likewise, activating Broca's area facilitates or inhibits voluntary hand movements (Uozumi, Tamagawa, Hashimoto, & Tsuji, 2004).

Behavioral paradigms offer another window on the interconnectivity between speech and manual systems. Dual-task interference paradigms have demonstrated that word reading can interfere with finger tapping (i.e., alter rate of tapping or disrupt tapping) and vice versa (Hiscock, Cheesman, Inch, Chipuer, & Graff, 1989; Hiscock & Chipuer, 1986; Smith, McFarland, & Weber, 1986; Van Hoof & Van Strien, 1997). Vowel formants are altered when words are concurrently produced with hand gesture (Barbieri, Buonocore, Dalla Volta, & Gentilucci, 2009; Bernardis & Gentilucci, 2005) and lip movements during speech are decreased during a manual motor task (Dromey & Benson, 2003). Likewise, a change in the rate and type of manual gesture production occurs as fluent speakers produce speech under