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# Slip of the tongue: Implications for evolution and language development

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ABSTRACT

A prevailing theory regarding the evolution of language implicates a gestural stage prior to the emergence of speech. In support of a transition of human language from a gestural to a vocal system, articulation of the hands and the tongue are underpinned by overlapping left hemisphere dominant neural regions. Behavioral studies demonstrate that human adults perform sympathetic mouth actions in imitative synchrony with manual actions. Additionally, right-handedness for precision manual actions in children has been correlated with the typical development of language, while a lack of hand bias has been associated with psychopathology. It therefore stands to reason that sympathetic mouth actions during fine precision motor action of the hands may be lateralized. We employed a fine-grained behavioral coding paradigm to provide the first investigation of tongue protrusions in typically developing 4-year old children. Tongue protrusions were investigated across a range of cognitive tasks that required varying degrees of manual action: precision motor action, gross motor action and no motor actions. The rate of tongue protrusions was influenced by the motor requirements of the task and tongue protrusions were significantly right-biased for *only* precision manual motor action ($p < .001$). From an evolutionary perspective, tongue protrusions can drive new investigations regarding how an early human communication system transitioned from hand to mouth. From a developmental perspective, the present study may serve to reveal patterns of tongue protrusions during the motor development of typically developing children.



## 1. Introduction

The tongue is one of the largest muscles in the human body, controlled by the hypoglossal nerve (twelfth cranial nerve). Following brain injury, tongue protrusions can be used as a diagnostic tool to determine the anatomical level of damage (Riggs, 1984). Patients are asked to stick their tongue out straight. Damage to tongue muscles or the hypoglossal nerve can result in tongue weakness, causing the tongue to deviate toward the weak side (ipsilateral). Conversely, lesions originating from the motor cortex will cause contralateral tongue weakness. Such anatomical organization suggests contralateral hemispheric motor control of articulatory left and right tongue actions. Although the primary roles of the tongue are to aid mastication, swallowing and gustation, a secondary, but critical role of the tongue is phonetic articulation. Additionally, the tongue becomes active in nonverbal synchrony with manual motor tasks. For example, have you ever noticed that whilst performing a manual task, your tongue is pressed

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between your lips with the tip protruding from the mouth? This behavior is commonly observed in young children (Mason & Proffit, 1974) and may be noticeable in adults when pursuing high precision manual dexterity that requires focused attention, like threading a needle (Givens, 2002). However, the origin of this motor action and the basis of its functionality, has yet to be formally investigated.

To date, the literature concerning tongue protrusions concentrates on involuntary tongue protrusion, also called 'tongue thrust', 'reverse swallow' or 'immature swallow'. Tongue thrust is typically associated with psychopathology and is considered to be an orofacial muscular imbalance whereby the tongue "protrudes through the anterior incisors during swallowing, speech production, and while the tongue is at rest" (Council on children with disabilities, 2006). Tongue thrust has been documented in patients with Dystonia (Schneider et al., 2006), Down's syndrome (Limbrock, Fischer-Brandies, & Avalle, 1991), Rett syndrome (Einspieler, Kerr, & Prechtl, 2005), Tourette's syndrome (Strassnig, Hugo, & Muëller, 2004), Angelman syndrome (Williams et al., 2006) and in children with non-organic failure to thrive (Mathisen, Skuse, Wolke, & Reilly, 1989). Tongue thrust has also been reported in 67–95% of typically developing children aged 5–8 years. For most children, the behaviour extinguishes by the age of six as typical swallowing motor action matures (Mason & Proffit, 1974). However, involuntary tongue thrust relating to reflexive swallowing actions may fundamentally differ in function and neural origin from the tongue protrusions produced by typically developing individuals during tasks of high concentration.

Theories regarding the evolutionary and developmental basis of tongue protrusions during tasks of concentration range from: motor overflow during attentional processes (e.g. Waber, Mann, & Merola, 1985) to the physical rejection of the bottle or breast by infants to indicate satiation (e.g. Morris, 1978). While the former has not been formally investigated, in the latter scenario, it has been hypothesized that the tongue protrusion action is retained throughout development as a symbol of rejection, implying: 'back off' or 'leave me in peace' (e.g. Ingram, 1990). Anecdotal evidence of such an interpretation can be found in Western culture where tongue protrusions have become a popular symbol utilized by celebrities to ward off unwanted public attention. However, if a protruded tongue results from an involuntary, innate behavior to indicate satiation, one should find evidence of this symbolic defiance gesture across cultures. While there is a paucity of empirical data to consider, contrary to the above hypothesis, in Tibet, the protrusion of the tongue is considered to be a greeting (Tsering, 2008).

A more compelling theory regarding the origin of non-verbal mouth actions (not specific to tongue protrusions) is rooted in the evolution and development of language processes. A gestural origins theory supports the premise that human speech evolved from a communication system based on hand gestures (Armstrong, Stokoe, & Wilcox, 1995), underpinned by the properties of a 'mirror' neuron system (Rizzolatti & Arbib, 1998). This system serves both the production and perception of actions, potentially making a critical contribution to the emergence and development of motor skills for willed communication (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996).

Behavioral evidence from chimpanzee and human studies supports such a synergy. For example, chimpanzees generated sympathetic mouth movements significantly more often during tasks requiring fine motor manipulation compared with tasks requiring gross motor actions (Waters & Fouts, 2002). In humans, Gentilucci, Benuzzi, Gangitano, and Grimaldi (2001) demonstrated that the pronunciation of a syllable could be selectively disrupted when producing a simultaneous grasping action for target objects of a non-congruent size to that of the mouth vocalization. The finding suggests that the fine motor articulation required for grasping is processed similarly by both hand and mouth in humans, thus they tend to complement each other. In fact, so tightly are the two motor systems entwined that when either gesture or speech is disrupted the other becomes delayed (Chu & Hagoort, 2014).

Neuroimaging findings indicate close links between the brain regions related to speech production and those controlling movement of the hands and arms (Erhard et al., 1996; Rizzolatti & Arbib, 1998; Rizzolatti & Craighero, 2004). Specifically, Broca's area is activated when imitating hand movements and preparing grasps (Iacoboni, Woods, & Mazziotta, 1998) in addition to actual or internal speech (Hinke et al., 2003), supporting the notion of a common neural substrate for hand and mouth articulation. Thus, in modern humans, there exists an association between speech and gesture that "transcends the intentions of the speaker to communicate", whereby the mutual activities remain inextricably intertwined throughout life (Iverson & Thelen, 1999).

In humans, the observation of grasp alone can activate preparation of the same motor act (Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995). These findings are reminiscent of the observed and actual grasping behaviors discovered in monkeys (Rizzolatti et al., 1988), underpinned by a mirror neuron system. Broca's region in humans and the analogous neural region in the monkey brain (F5) may act as a supramodal processor for planned, structured action sequences represented by both the hands and the mouth (e.g. Petersson, Folia, & Hagoort, 2012; Pulvermüller & Fadiga, 2010). This sort of system supports perception–action coupling and may have acted as a catalyst for the emergence of syntactic processes found in modern human language (e.g. Forrester, Leavens, Quaresmini, & Vallortigara, 2011; Forrester, Quaresmini, Leavens, Spiezio, & Vallortigara, 2012; Tabiowo & Forrester, 2013). Such a processor also may have given rise to human population-level right-handedness (Annett, 2002), supported by the left hemisphere's dominance for guiding sequences of structured motor actions (e.g. Forrester, Quaresmini, Leavens, Mareschal, & Thomas, 2013).

Modern humans demonstrate population-level right-handedness for both object manipulation and gesture (Marchant, McGrew, & Eibl-Eibesfeldt, 1995). Recent studies of child handedness indicate that right-handedness is correlated with typical language development (Kastner-Koller, Deimann, & Bruckner, 2007) and that