# 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 regions dominant within the left hemisphere. 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 during 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 of 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. Further research may contribute to our understanding of cerebral lateralization of cognitive function.

**Keywords**: tongue, language, cerebral lateralization, 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 towards 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 role of the tongue is for mastication, swallowing and gustation, a secondary, but critical role of the tongue is phonetic articulation. Moreover, the tongue also becomes active in nonverbal synchrony with manual motor tasks. For example, have you ever found yourself performing a manual task and notice that your tongue is pressed 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). To date, the origin of this motor action and the basis of its functionality, have gone unexplored.

To date, the literature concerning tongue protrusions concentrates on involuntary tongue protrusion, also called ‘tongue thrust’, ‘reverse swallow’ or ‘immature swallow’. Tongue thrust has been mainly associated with psychopathology and is considered to be an orofacial muscular imbalance whereby the tongue “protrudes through the anterior incisors during swallowing, speech, and while the tongue is at rest” (Council on Children with Disabilities, 2006). Tongue thrust has been documented in patients with Dystonia (Schneider, Aggarwa, Dupont, Tisch, Limousin, Quinn & Bhatia, 2006), Down’s syndrome (Limbrock, Fischer-Brandies & Avalle, 1991), Rett syndrome (Einspieler, Kerr & Prechtl, 2008), Tourette's syndrome (Strassing, Hugo & Muëller, 2004), Angelman syndrome (Williams et al., 2006) and in children with non-organic failure to thrive (Mathisen, Skuse, Wolke & Reilly, 1989). However, tongue thrust has also been reported in 67-95% of typically developing children aged 5-8 years. It is thought that for most children, it will extinguish by the age of six, as a typical swallowing motor action is developed (Mason & Proffit, 1974). In contrast, involuntary tongue thrust relating to reflexive swallowing actions may 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 to 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, 2007).

A more compelling theory regarding the origins of nonverbal mouth actions (not specific to protrusions) is rooted in the evolution and development of language processes. It has been hypothesized that human speech evolved from a communication system based on hand gestures (Armstrong, Stokoe & Wilcox, 1995), supported 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 & Grimaldi (2001) demonstrated that the pronunciation of a syllable could be selectively disrupted when producing a simultaneous grasping action with the hand aimed at target objects of a non-congruent size 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 brain regions related to speech production and those controlling movement of the hands and arms (Erhard, Kato, Strupp, Andersen, Adriany, Strick & Ugurbil, 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, Hu, Stillman, Kim, Merkle, Salmi & Ugurbil, 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 speaker to communicate, whereby vocalization and the synchronous arm movements appear intertwined in the mutual cognitive activity of language and remain linked throughout the lifespan (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 monkey (Rizzolatti, Camarda, Fogassi, Gentilucci, Luppino & Matelli, 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 & Hagoort, 2012; Pulvermüller & Fadiga, 2010). This sort of system would support perception-action coupling and may have catalyzed 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, dominant within the left hemisphere may have also given rise to human population-level right-handedness (Annett, 2002), for efficiency in carrying out 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 & Keimann, 2007) and that consistent hand dominance in early infancy (6-14 months) is associated with subsequent advanced language skills (18-24 months) (Nelson, Campbell & Michel, 2014). Moreover, a lack of hand dominance (e.g. mixed-handed, ambi-preference) may indicate disruption to the cerebral lateralization of language function (e.g. Crow, Crow, Done & Leask, 1998; Delcato, 1966; Orton, 1937; Rodriguez, Kaakinen, Moilanen, Taanila, McGough, Loo & Järvelin, 2010; Yeo, Gangestad & Thoma, 2007; Yeo, Gangestad, Thoma, Shaw & Repa, 1997). Thus, strength of handedness has been proposed to be a useful behavioral marker of children at risk for dysfunction of subsequent language processes long before language develops (e.g. Forrester, Pegler, Thomas & Mareschal, 2014). Although it has never been systematically investigated, one may hypothesize that tongue protrusions produced during manual actions may comprise a lateralized component, consistent with a left hemisphere dominant neural generator.

The present study sought to investigate the frequency and laterality of tongue protrusions in order to provide the first empirical dataset reflecting tongue protrusions in typically developing four year-old children. Tongue protrusions were assessed during six tasks of high concentration requiring either: fine motor object manipulation, gross motor object manipulation or no object manipulation. Based on the limited existing evidence we hypothesized increasing frequency of tongue protrusions during tasks requiring prehension and additionally considered a left hemisphere (right side) bias in the direction of protrusion. Findings are discussed in light of both developmental and evolutionary theories.

## 2. Material and Methods

### *2.1. Participants*

Fourteen typically developing male (n = 8) and female (n = 6) children (age range: 53-56 months; mean age = 54.21 months) were randomly sampled from a previously recorded cohort of 150 children during their participation in a neuropsychological battery of cognitive tasks (see Rodriguez & Waldenström, 2008). Rationale for the age range was predicated by a previous report of tongue thrust identified in 67-95% of typically developing children aged 5-8 years, but tending to extinguish by the age of six (Mason & Proffit, 1974).  Importantly, participants were considered to have reached an age by which any concerns with delayed language development would have been identified. Children participating in this study were reported to have no symptoms of language dysfunction. All children were right-handed as deemed by maternal and self-reports. All children came from two-parent homes with an average disposable monthly income of 25000 Swedish Crowns, which corresponds to Swedish national average representing 5th-8th income deciles (Swedish Statistical Central Bureau).

All behavior was digitally recorded in the home of the individual participants with the participant's mother close by. The procedures for this study involving human participants were in accordance with ethical standards of the responsible committee on human experimentation (institutional and national) and with the spirit of the Helsinki Declaration of 1975, as revised in 2000.

### *2.2. Data Collection*

Tongue protrusion behaviors were observed during a subset of the neuropsychological test battery of assessed tasks (Small World, Board Game, Lock and Key, Knock and Tap, Picture Block, Story Recall). This set of challenging tasks were part of a battery of tests conducted to assess cognitive, behavioral, and emotional development (see Rodriguez & Waldenström, 2008). The Small World and Board Game tasks were performed with the child's mother and were designed to assess the mother-child relationship during free-play (Small World) and structured-play (Board Game). All other tasks were performed with a female experimenter. All tasks were conducted on a table surface in the home of the child. All tasks except one (Story Recall) required an element of object manipulation (fine motor or gross motor action) as defined by the instructions. For the purposes of the present study, we were interested in the duration of the task for each individual, the motor requirement of the task and the frequency and laterality of spontaneous tongue protrusions produced by the child. The tasks were as follows:

#### *Fine Motor Action*

*Small World:* subjects were provided with a small amount of small world play toys such as miniature dolls, porcelain tea set, and furniture packed into a miniature suitcase. Subjects were observed during independent play and/or interaction with the mother for five minutes. All objects were small and some objects had small moving parts, requiring fine coordinated manipulation.

*Board Game:* A challenging board game was presented to both child and mother. Turn taking was required and a roll of the die determined a destination based on a combination of a color and a picture. If the picture was present in the column of the given color, a small playing chip was placed on this space on their own board. The object of the game was to complete a full row or column before the other player and thus varied in time across participants. The collection of cards and the movement of playing chips across the spaces of the board required fine motor coordination.

*Lock and Key*: Subjects were provided with a 4 locked metal padlocks, ranging in shape and size, and a set of five keys on a single ring. Each key opened one lock. The process for opening a lock was demonstrated by the experimenter. The child was given five minutes to open all the locks. This task required fine motor coordination to manipulate both keys and locks.

*Gross Motor Action*

*Knock and Tap*: This task was taken from the NEPSY neuropsychological test battery (Kemp, Kirk & Korkman, 2001; Korkman, Kirk & Kemp, 2000) to tap attention and effortful control in four-year-olds. The experimenter engaged the child in the manual motor sequence task. The experimenter sat opposite the child with hands laid flat on the table. The child was asked to mirror the position. The child indicated which hand s/he used most often. The experimenter explained that whenever she knocked (closed fist) on the table, the child was to tap (opened palm down, e.g. slap) on the table. In contrast, whenever the experimenter tapped (opened palm down) on the table the child was to knock. Several practice trials were given to make sure that the child understood the task instructions. Fifteen test trials followed. This task required gross motor movements, and did not require any object manipulation. This task required inhibition of the prepotent action, i.e. imitation of the experimenter's hand movement and was not timed.

*Picture Block*: The experimenter presented the child a small, 2D square picture of a bear with a ball. The experimenter and child talked about the distinctive features of the picture. The child was then presented with nine approximately 2 inch square blocks. Each block portrayed a small segment, i.e. 1/9th of the 2D picture on the top surface. The cubes were presented in mixed order, but all correct picture segments were always facing up and the child's task was to place the nine blocks to copy the 2D picture. Five minutes were allotted to this task. This task required the spatial rotation of blocks into position in accordance with the defined picture.

*No Motor Action*

*Story Recall:* The experimenter read the Narrative Memory story from NEPSY (47, 48) suitable for four-year-olds. The story comprised of a complex plot involving several characters and events. Children were asked to listen to the story and then were asked to recall information under free and cued-recall conditions. This task did not require any fine or gross manual motor actions and was not timed.

### *2.3. Data Coding*

Videos were viewed on Windows Movie Media Player providing a viewing resolution of 30 frames per second. Tongue protrusions were coded based on the following criteria. A tongue protrusion was defined as any visible protrusion of the tongue from or within the mouth. Although the duration of protrusions was not calculated, the start of a protrusion was identified by a visible distortion of the cheek or lip, or by the visible appearance of the tongue through the lips. Only the starting point of the protrusion was considered. While some children performed tongue sweeps, beginning with a protrusion and sweeping to the left or right, there were too few of these events to be considered for further analysis. Viewing video footage of 30 frames per second allowed for fine resolution coding of these events. Under these criteria, tongue protrusions could be internal or external. However, internal protrusions required clear visual distortion of the cheek or lips for identification. Tongue protrusions were identified for lateral position i.e. directed the tip towards the left or the right of the individual. When a lateral position was unclear (e.g. central), a protrusion was only considered for tests of frequency and rate, but not for tests of laterality. It is possible that central protrusions were lateralized, but not to an identifiable extent by the coder. Any instance where one side of the mouth was otherwise engaged was not considered for the final coded data. For example, if the subject was chewing something on the left side of their mouth (e.g. their sleeve, a toy) and protruded their tongue to the right, this was excluded from the coded data set. Tongue protrusions occurred as events rather than bouts (e.g. quick successive repetitions of the same action) and were analyzed accordingly. All subject footage was observed for as long as it took to reach the end of all tasks, which was on average 50 minutes (+/- 10 minutes).

### *2.4. Data Analysis*

Analyses of variance and appropriate post-hoc tests were used to assess frequencies, rates and lateral biases of group-level tongue protrusions. Laterality Index scores (LI) were calculated using the formula [LI = (R-L)/(R+L)], with R and L being the frequency counts for right and left navigational path frequency counts. LI values vary on a continuum between -1.0 and +1.0, where the sign indicates the direction of tongue protrusion preference. When R=L, then LI is zero, i.e. no lateral bias. Positive values reflect a right protrusion while negative values reflect a left preference. The absolute value depicts the strength of protrusions. In order to assess differences in the frequencies of tongue protrusions across tasks, rates were calculated. Rates were equal to the frequency of tongue protrusions for a given task for a specific individual divided by the duration in minutes to complete the task. All statistical tests were two-tailed (alpha < .05).

## 3. Results

Raw frequencies of tongue protrusions for each individual by task are presented in Table 1. Tongue protrusions frequencies are divided into left, right and central directions. For ANOVA tests, where sphericity was not assumed, Greenhouse-Geisser correction was used. Non-parametric Wilcoxon signed-rank tests were used for all post-hoc analyses.

- Insert Table 1 -

### *3.1. General Description of Tongue Protrusions*

Across participants, the frequency of tongue protrusions ranged between 16-49, (*M* = 30; SD = 9.89). On average, the group elicited significantly more detectable external (frequencies: *M* = 16.79, SE = 1.62; proportions: *M* = 0.562, SE = 0.027) versus internal tongue protrusions (frequencies: *M* = 13.21, SE = 1.395; proportions: *M* = 0.438, SE = 0.027) collapsed across all tasks (frequencies: $t(13) = 2.417$, $P = 0.031$; proportions: $t(13) = 2.314$, $P = 0.038$). A 1-way ANOVA indicated no significant difference in the frequency of tongue protrusions across tasks: small world (*M* = 5.23, SE = 3.07); Board Game (*M* = 5.50, SE = 2.07); Lock and Key (*M* = 4.29, SE = 3.34); Knock and Tap (*M* = 4.14 SE = 3.44); Picture Block (*M* = 5.50, SE = 3.39); Story Recall (*M* = 5.29, SE = 4.75) [F(5, 65) = 5.812, p = 0.277]. However, as tasks varied in duration or time to completion (see Table 2), thus rates of tongue protrusions per minute (rate = (seconds to complete task/ # of tongue protrusions)/60)) were also calculated to equalize the weighting that each task contributed to the dataset (see Table 3).

- Insert Table 2 -

- Insert Table 3 -

A 1-way ANOVA indicated a significant difference in rates across tasks [Small World (*M* = 0.90, SE ± 0.15); Board Game (*M* = 0.76, SE ± 0.11); Lock and Key (*M* = 0.68, SE ± 0.14); Knock and Tap (*M* = 1.84 SE ± 0.37); Picture Block (*M* = 1.27, SE ± 0.25); Story Recall (*M* = 0.77, SE ± 0.17) [F(2.72, 35.41) = 4.52, p = 0.011]. Additionally, a 1-way ANOVA revealed a significant difference in task motor requirement (fine motor, gross motor and no motor) [F (2, 26) = 6.67, p = 0.005] (see Figure 1).

- Insert Figure 1 –

Post-hoc analyses revealed that tongue protrusion rates for tasks requiring gross motor actions (*M* = 1.55, SE ± 0.23) elicited a significantly greater rate of tongue protrusions than tasks requiring fine motor action (*M* = 0.78, SE ± 0.08) (Z = -3.42; p = .001), or no motor action (*M* = 0.77, SE ± 0.17), (Z = -2.27; p = .023).

### *3.2. Lateralized Tongue Protrusions*

Frequency of left and right tongue protrusions revealed that participants demonstrated a significant bias for right tongue protrusions (frequencies: *M* = 10.79, SE ± 1.82) versus left tongue protrusions (frequencies: *M* = 5.57, SE ± 0.78) collapsed across all tasks (Z = -2.76; p = .006). (see Figure 2).

- Insert Figure 2 –

Further analyses of lateral tongue protrusion biases were conducted employing LI scores. LI scores ensure equal weighting of participant contribution to the analysis (see Table 4).

- Insert Table 4-

A 1-way ANOVA of laterality index scores of tongue protrusions was calculated by motor condition (fine motor, gross motor and no motor), resulting in a significant difference for mean LI scores across motor conditions [F (2, 26) = 12.36, p < 0.001] (see Figure 3).

- Insert Figure 3 –

Post-hoc analyses by motor condition showed that fine motor condition (*M* = 0.63, SE ± 0.11) elicited significantly more right-biased tongue protrusions compared with the gross motor condition (*M* = -0.08, SE ± 0.15) (Z = -2.91; p = .003) and the no motor condition (*M* = -0.22, SE ± 0.17) (Z = -2.80; p = .005). Additionally, mean LI scores by task were as follows: Small World = .46, Board Game = .71, Lock and Key = .52, Knock and Tap = .30, Picture Block = -.28, Story Recall, -.22.

## 4. Discussion

### *4.1. Rates of Tongue Protrusions*

The findings from this investigation demonstrated that tongue protrusions commonly occur in typically developing 4-year old children. Although the literature is sparse, the result is consistent with an earlier report of the incidence of tongue thrust in typically developing children aged 5-8 years (Mason & Proffit, 1974). In the present study, fourteen participants exhibited tongue protrusions while engaging in a range of cognitive tasks requiring fine motor action, gross motor action, or no motor action. There were significantly more visible external tongue protrusions overall, where the tongue breached the lips, compared with internal tongue protrusions, where the tongue created a bulge in the cheek or lips but was not externally visible. However, this result could be due to the fact that internal tongue protrusions may not always be visually detectable and our findings represent a subset of all tongue protrusions.

Tasks of fine and gross manual motor action elicited tongue protrusions. This finding supports the theory that hand and mouth actions sympathize with one another as a result of a single system of communication that is independent of modality (McNeill, 1992). The motor coupling is believed to occur due to shared neural resources for hand actions (Iacoboni, Woods & Mazziotta, 1998) and actual or internal speech (Hinke, Hu, Stillman, Kim, Merkle, Salmi & Ugurbil, 2003) and is further supported by behavioral evidence demonstrating selective disruption of speech syllables when the hands are required to perform non-congruent articulations (Gentilucci et al., 2001). However, tongue protrusions were also reported during the Story Recall task that had no manual motor requirement. This additional finding supports the position that the hands need not be active to elicit tongue protrusions. It is possible that tongue protrusions will be elicited if a task involves active language processing as required by the Story Recall task.

The rates of tongue protrusions differed significantly across tasks. Rates were calculated to account for the varying task durations and time to completion per participant. While all tasks elicited tongue protrusions in most children, gross motor tasks elicited significantly more tongue protrusions than fine motor and no motor tasks. This finding is in not inconsistent with our hypothesis, predicting more frequent tongue protrusions in tasks of requiring prehension. However, this finding is in contrast to non-human primate research reporting that chimpanzees generated sympathetic mouth actions at a significantly higher frequency during tasks of fine motor manipulation compared with tasks requiring gross motor manual actions (Waters & Fouts, 2002). However, Waters & Fouts (2002) considered mouth actions that were not specific to tongue protrusions. It is possible that the gross motor tasks in the present study required a greater rate of grasping-type hand actions in comparison to the fine motor tasks. Additionally, we consider that the gross motor tasks were both tasks of significant difficulty. The Knock and Tap and Picture Block tasks were both effortful tasks, requiring inhibition of prepotent responses and spatial manipulations, respectively. Future studies may consider how grasping rate and task difficulty influences tongue protrusions in typically developing children.

The tasks included in the gross motor condition included the Knock and Tap task and the Picture Block task. The Picture Block task did not elicit significantly greater tongue protrusion rate than other tasks (aside from the Board Game task). The Knock and Tap task, however, did elicit significantly more tongue protrusions than all fine motor and no motor tasks. It is possible that the opening and closing of the hand required by the fifteen trials was sufficient to elicit complementary and sympathetic tongue protrusions. Alternatively, we consider the structure of the Knock and Tap task. This task possessed structured rules, rapid turn-taking and hand gesturing performed with only the dominant right hand. Participants were asked to respond with the opposite hand position as the experimenter. The task measures effortful control and the ability to inhibit behavioral impulsivity of the prepotent response (i.e. imitation of the experimenter’s hand position) and may have also required an element of symbolic representation. This process may involve internal speech rehearsal of the task rules to actively control hand movements. One interpretation of the finding is that the Knock and Tap task required foundational components of the communication system, engaging both symbolic hand gestures and the internal rehearsal of the verbal instructions. The task elements may even resemble proto language processes both in turn-taking sequences and symbolic representation of manual gestures. While structured sequences are known to be a distinctive component of language (e.g. Hauser, Chomsky & Fitch, 2002), it has been suggested that they also appear in nonlinguistic domains such as object manipulation and gesture (for a review see, Tettamanti, 2003). The rule-based motor activity required by the Knock and Tap task may be likened to sequences of behavioral units, possessing the properties of an action-based proto-syntax prior to the emergence of speech (Corballis, 2009). One hypothesis is that sympathetic tongue protrusions increased with tasks demand for rule-based structured sequences of action and the comprehension and production of symbolic hand gestures (e.g. Gentilucci et al., 2001). Based on evolutionary theory, goal directed sequences of actions are foundational components of human communication driven by left hemisphere dominant processes that can manifest as lateralized motor action (MacNeilage Rogers & Vallortigara, 2009).

### *4.2. Laterality of Tongue Protrusions*

A significant group-level right side bias was revealed for the frequency of tongue protrusions. The motor-level analyses demonstrated that fine motor tasks revealed right-biased tongue protrusions. Laterality was next explored using laterality index (LI) scores across fine motor, gross motor and no motor task groups. Unlike tests of frequency, LI scores ensured equal weighting of each task to the analysis. The fine motor action condition revealed significantly right-lateralized tongue protrusions compared with the gross action condition and the no motor action condition.

Additionally, all three tasks revealed mean LI scores consistent with a strong right bias (e.g. Oldfield, 1971).

We considered that all fine motor tasks required precision grasp and was likely to be conducted by the dominant right hand and left hemisphere. The Small World task included a variety of small dollhouse toys and dolls with manipulable limbs. The Board Game task required moving a token across a board and the manipulation of small flat discs that required precision grasp to collect. The Key and Lock task required bimanual coordinated action (e.g. McGrew & Marchant, 1997) to open pad locks. One hand (non-dominant) held a lock in a power grip while the other hand (dominant) used a precision grasp to manipulate a key. One interpretation of this finding is that fine motor tasks precipitate use of the dominant hand because it is more dexterous in for operations involving sequences of fine manipulation. Studies of cerebral lateralization implicate the left hemisphere and the right hand dominant for such processes in the majority of the population (e.g. MacNeilage et al. 2009). We propose that the dominant hand elicited lateralized sympathetic tongue action driven by the support of common left hemisphere dominant neural system for the motor structures that underpin communication processes (McNeill, 1992).

Gross motor tasks did not reveal a lateral tongue protrusion bias. Although the Knock and Tap task did not require precision grip, it did demonstrated a weak right biased LI score, possibly due to the fact that it required the use of the dominant hand. The Picture Block task conversely, demonstrated a weak left biased LI score. A potential reason this task did not reveal a lateral bias may have been because it did not require a dominant hand. Blocks were easily slid across the surface of the table and did not require turning, as the correct pictures were already oriented face-up for the participant. Studies of primate manual laterality have found that gross motor actions (e.g. reaching) can often fail to exhibit a significant hand preference as actions lack the precision motor skill required for grasping (for a review see: Hopkins, 2006).

The present study offers the first investigation of tongue protrusions during cognitive tasks requiring varying degrees of motor precision.  We report on spontaneous tongue protrusions in a population of typically developing children and suggest that tongue protrusions are commonly exhibited by typically developing right-handed children. Tongue protrusions were detected both internally and externally to the mouth suggesting that this behavior may not cease in adulthood, but conscious awareness of one's physical actions may cause tongue actions to become less detectable in order to conform with social norms. Our findings support an intrinsic connection between actions of the mouth and hands that is consistent with behavioral studies indicating that vocalizations are accompanied by spontaneous and synchronous rhythmic hand movements, visible from early infancy (e.g. Masataka, 2001). Our findings suggest that hand and tongue actions possess a reciprocal relationship such that when structured sequences of hand actions are performed they are accompanied by spontaneous and synchronous tongue action. The detection of lateralized tongue protrusions is consistent with a left hemisphere dominant unified communication system involving both the hands and the mouth (McNeill 1992) and additionally is consistent with a gestural origin of language position (Armstrong, Stokoes & Wilcox, 1995; Corballis, 2002). To further explore the evolution of speech and gesture, future research may consider whether tongue protrusions increases in rate, strength of laterality and temporal synchrony during manual motor tasks that possess foundational structured components of communication (e.g. hierarchical sequences of actions). Due to the overlapping neural resources underpinning hand and mouth motor capabilities, the derivation of motor action patterns provides a novel method to draw inference about the evolution of different cognitive abilities.

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## Figure Legends

Figure 1.

Figure 1. Mean rates of tongue protrusions across motor conditions.

Figure 2.

Figure 2. Right and left tongue protrusions collapsed across all tasks.

Figure 3.

Figure 3. Tongue protrusion mean laterality index scores across motor conditions.

## Highlights

- Tongue and hand articulations are controlled by left hemisphere biased brain regions
- Tongue protrusions in children were right lateralized for only precision manual tasks
- The rate of tongue protrusions was influenced by both motor and language syntax
- Tongue protrusions provide a new method to study language evolution and development

Figure 1

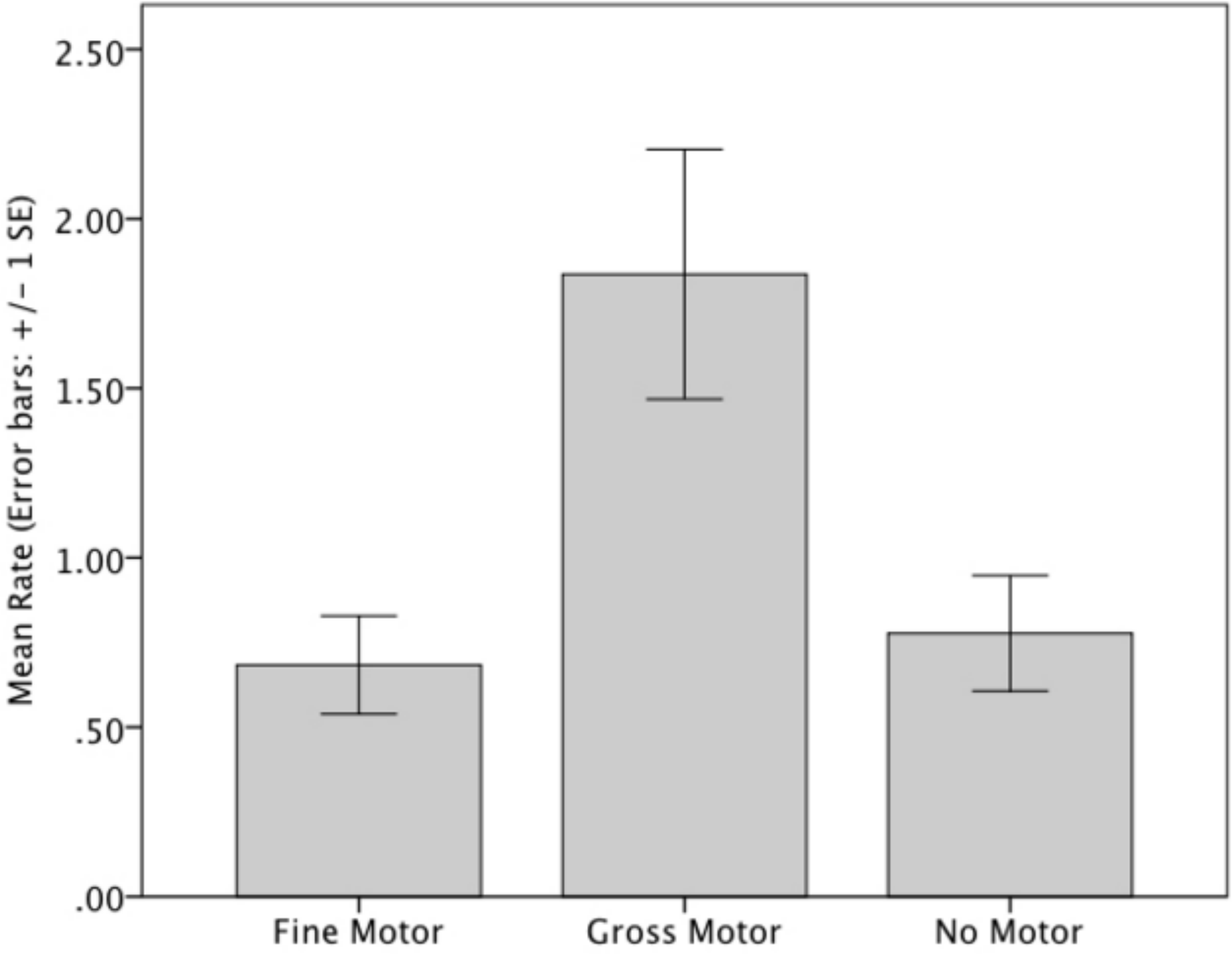
Mean Rate (Error bars: +/− 1 SE)
2.50
2.00
1.50
1.00
.50
.00
Fine Motor
Gross Motor
No Motor

Figure 2

Click here to download high resolution image

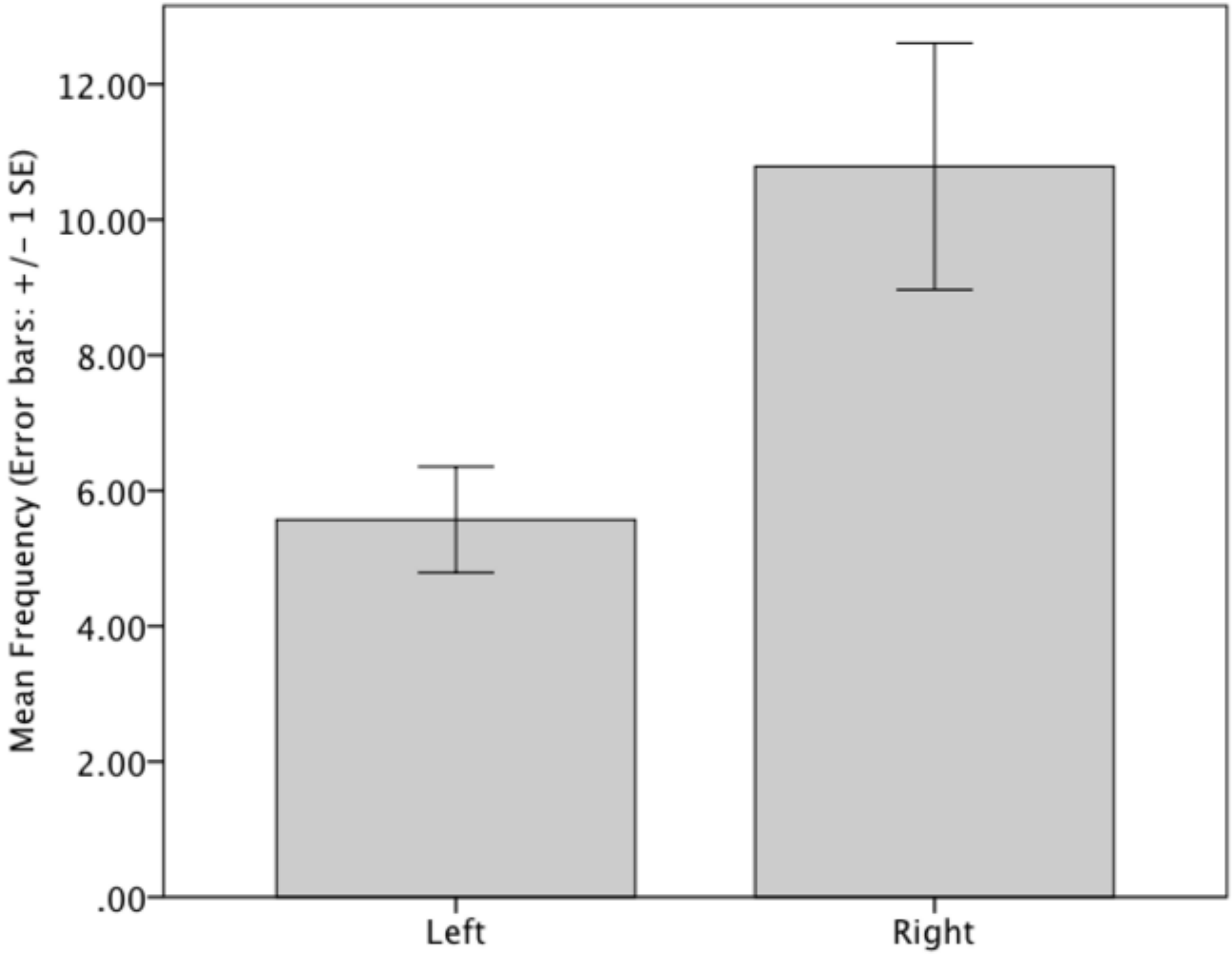

Figure 3

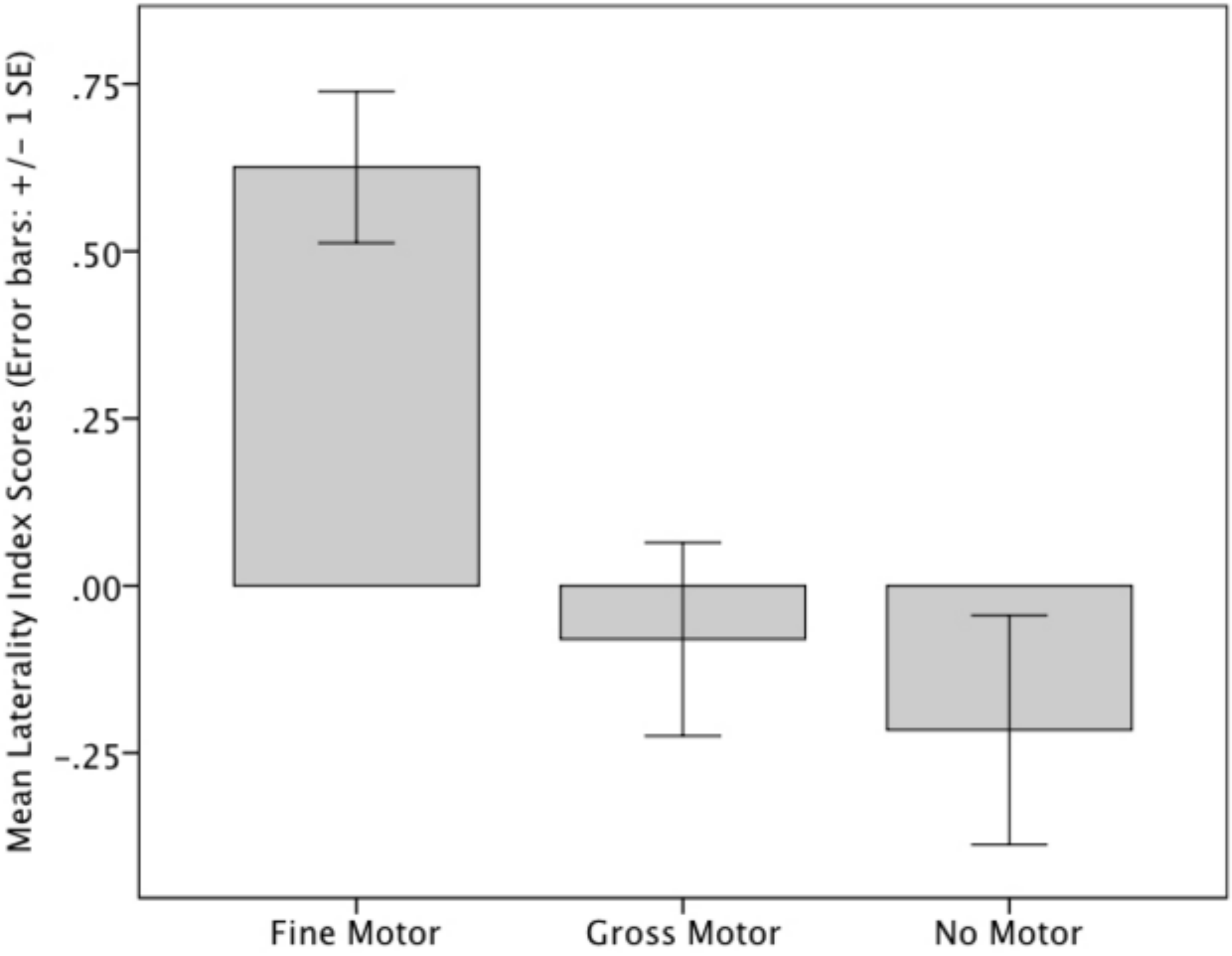
Mean Laterality Index Scores (Error bars: +/- 1 SE)
.75
.50
.25
.00
-.25
Fine Motor
Gross Motor
No Motor

**Table 1**

Table 1. Left, right and central tongue protrusion frequencies by task and motor condition.

| | Fine Motor | | | | | | | | | Gross Motor | | | | | | No Motor | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P | SW (L) | SW (R) | SW (C) | BG (L) | BG (R) | BG (C) | LK (L) | LK (R) | LK (C) | KT (L) | KT (R) | KT (C) | BL (L) | BL (R) | BL (C) | SR (L) | SR (R) | SR (C) |
| 1 | 3 | 3 | 0 | 1 | 6 | 3 | 2 | 6 | 2 | 0 | 4 | 1 | 4 | 3 | 2 | 0 | 2 | 0 |
| 2 | 0 | 0 | 2 | 0 | 1 | 4 | 0 | 3 | 1 | 0 | 0 | 0 | 5 | 2 | 3 | 0 | 0 | 0 |
| 3 | 0 | 4 | 2 | 0 | 5 | 3 | 0 | 2 | 2 | 0 | 5 | 5 | 2 | 6 | 2 | 2 | 0 | 1 |
| 4 | 0 | 1 | 2 | 0 | 1 | 4 | 0 | 3 | 2 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 5 |
| 5 | 0 | 2 | 5 | 0 | 0 | 4 | 0 | 3 | 3 | 0 | 0 | 1 | 2 | 0 | 1 | 1 | 0 | 0 |
| 6 | 1 | 2 | 2 | 0 | 2 | 4 | 0 | 1 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 5 | 2 | 8 |
| 7 | 3 | 1 | 4 | 0 | 2 | 2 | 2 | 2 | 0 | 0 | 2 | 3 | 1 | 0 | 3 | 1 | 9 | 3 |
| 8 | 0 | 1 | 3 | 2 | 0 | 2 | 0 | 0 | 4 | 0 | 0 | 3 | 3 | 0 | 1 | 1 | 0 | 5 |
| 9 | 0 | 1 | 3 | 1 | 4 | 1 | 1 | 0 | 0 | 3 | 1 | 0 | 1 | 4 | 2 | 3 | 4 | 2 |
| 10 | 1 | 4 | 4 | 1 | 5 | 2 | 0 | 4 | 7 | 1 | 2 | 8 | 5 | 0 | 4 | 0 | 0 | 1 |
| 11 | 3 | 4 | 5 | 0 | 2 | 3 | 0 | 0 | 1 | 0 | 0 | 2 | 3 | 1 | 4 | 1 | 0 | 3 |
| 12 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 1 | 2 | 3 | 0 | 4 | 2 | 0 | 0 | 0 |
| 13 | 0 | 2 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 2 | 1 | 6 |
| 14 | 2 | 1 | 2 | 0 | 4 | 2 | 1 | 4 | 2 | 0 | 3 | 4 | 2 | 0 | 0 | 3 | 2 | 1 |
| M | 0.93 | 1.86 | 2.50 | 0.36 | 2.50 | 2.64 | 0.43 | 2.07 | 1.79 | 0.36 | 1.36 | 2.43 | 2.14 | 1.57 | 1.79 | 1.36 | 1.43 | 2.50 |
| SD | 1.27 | 1.41 | 1.61 | 0.63 | 1.95 | 1.08 | 0.76 | 1.86 | 1.93 | 0.84 | 1.69 | 2.21 | 1.70 | 1.99 | 1.37 | 1.50 | 2.50 | 2.59 |

P = participant, SW = Small World, BG = Board Game, LK = Lock and Key, KT = Knock and Tap, PB = Picture Block, SR = Story Recall; (l) = left, (r) = right, (c) = central, M = mean, SD = standard deviation

**Table 2**

Table 2. Time to complete task in seconds.

| P | SW | BG | LK | KT | PB | SR |
|---|---|---|---|---|---|---|
| 1 | 380 | 540 | 410 | 97 | 335 | 354 |
| 2 | 355 | 531 | 423 | 105 | 174 | 338 |
| 3 | 319 | 699 | 383 | 125 | 356 | 330 |
| 4 | 360 | 552 | 393 | 116 | 412 | 333 |
| 5 | 359 | 422 | 240 | 73 | 224 | 365 |
| 6 | 342 | 471 | 400 | 131 | 420 | 444 |
| 7 | 401 | 565 | 376 | 151 | 250 | 442 |
| 8 | 545 | 863 | 415 | 133 | 334 | 407 |
| 9 | 334 | 344 | 421 | 86 | 406 | 460 |
| 10 | 335 | 346 | 411 | 206 | 229 | 334 |
| 11 | 336 | 180 | 423 | 123 | 209 | 391 |
| 12 | 318 | 456 | 424 | 207 | 398 | 367 |
| 13 | 331 | 472 | 391 | 124 | 224 | 400 |
| 14 | 290 | 418 | 384 | 140 | 160 | 377 |
| M | 357.50 | 489.93 | 392.43 | 129.79 | 295.07 | 381.57 |
| SD | 60.53 | 163.20 | 46.88 | 38.69 | 94.39 | 44.05 |

P = participant, SW = Small World, BG = Board Game, LK = Lock and Key, KT = Knock and Tap, PB = Picture Block, SR = Story Recall, M = mean, SD = standard deviation

**Table 3**

Table 3. The rate of tongue protrusions by motor condition and task

| | Fine Motor | | | Gross Motor | | No Motor |
|---|---|---|---|---|---|---|
| P | SW | BG | LK | KT | PB | SR |
| 1 | 0.95 | 1.11 | 1.46 | 3.09 | 1.61 | 0.34 |
| 2 | 0.34 | 0.56 | 0.57 | 0.00 | 3.45 | 0.00 |
| 3 | 1.13 | 0.69 | 0.63 | 4.80 | 1.69 | 0.55 |
| 4 | 0.50 | 0.54 | 0.76 | 1.03 | 0.15 | 0.90 |
| 5 | 1.17 | 0.57 | 1.50 | 0.82 | 0.80 | 0.16 |
| 6 | 0.88 | 0.76 | 0.30 | 0.92 | 0.00 | 2.03 |
| 7 | 1.20 | 0.42 | 0.64 | 1.99 | 0.96 | 1.76 |
| 8 | 0.44 | 0.28 | 0.58 | 1.35 | 0.72 | 0.88 |
| 9 | 0.72 | 1.05 | 0.14 | 2.79 | 1.03 | 1.17 |
| 10 | 1.61 | 1.39 | 1.61 | 3.20 | 2.36 | 0.18 |
| 11 | 2.14 | 1.67 | 0.14 | 0.98 | 2.30 | 0.61 |
| 12 | 0.00 | 0.53 | 0.00 | 1.74 | 0.90 | 0.00 |
| 13 | 0.54 | 0.25 | 0.15 | 0.00 | 1.07 | 1.35 |
| 14 | 1.03 | 0.86 | 1.09 | 3.00 | 0.75 | 0.95 |
| M | 0.90 | 0.76 | 0.68 | 1.84 | 1.27 | 0.80 |
| SD | 0.14 | 0.11 | 0.14 | 0.37 | 0.25 | 0.16 |

P=participant, SW = Small World, BG = Board Game, LK = Lock and Key, KT = Knock and Tap, PB = Picture Block, SR = Story Recall, M = mean, SD = standard deviation

Table 4. Laterality index scores by motor condition

| P | Fine Motor | Gross Motor | No Motor |
|---|---|---|---|
| 1 | 0.43 | 0.27 | 1.00 |
| 2 | 1.00 | -0.43 | 0.00 |
| 3 | 1.00 | 0.69 | -1.00 |
| 4 | 1.00 | 0.00 | 0.00 |
| 5 | 1.00 | -1.00 | -1.00 |
| 6 | 0.67 | 0.00 | -0.43 |
| 7 | 0.00 | 0.33 | 0.80 |
| 8 | -0.33 | -1.00 | -1.00 |
| 9 | 0.43 | 0.11 | 0.14 |
| 10 | 0.73 | -0.50 | 0.00 |
| 11 | 0.33 | -0.50 | -1.00 |
| 12 | 1.00 | 0.71 | 0.00 |
| 13 | 1.00 | 0.00 | -0.33 |
| 14 | 0.50 | 0.20 | -0.20 |
| M | 0.63 | -0.08 | -0.22 |
| SD | 0.42 | 0.54 | 0.64 |

P = participant, M = mean, SD = standard deviation