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2 Slip of the tongue:

3 Implications for evolution and language development

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25

26   **Abstract**

27   A prevailing theory regarding the evolution of language implicates a gestural stage

28   prior to the emergence of speech. In support of a transition of human language from a

29   gestural to a vocal system, articulation of the hands and the tongue are underpinned

30   by overlapping regions dominant within the left hemisphere. Behavioral studies

31   demonstrate that human adults perform sympathetic mouth actions in imitative

32   synchrony with manual actions. Additionally, right-handedness for precision manual

33   actions in children has been correlated with the typical development of language,

34   while a lack of hand bias has been associated with psychopathology. It therefore

35   stands to reason that sympathetic mouth actions during fine precision motor action of

36   the hands may be lateralized. We employed a fine-grained behavioral coding

37   paradigm to provide the first investigation of tongue protrusions in typically

38   developing 4-year old children during cognitive tasks that required varying degrees of

39   manual action: precision motor action, gross motor action and no motor actions. The

40   rate of tongue protrusions was influenced by the motor requirements of the task and

41   tongue protrusions were significantly right-biased for *only* precision manual motor

42   action (p < .001). From an evolutionary perspective, tongue protrusions can drive new

43   investigations of how an early human communication system transitioned from hand

44   to mouth. From a developmental perspective, the present study may serve to reveal

45   patterns of tongue protrusions during the motor development of typically developing

46   children. Further research may contribute to our understanding of cerebral

47   lateralization of cognitive function.

48

49   **Keywords**: tongue, language, cerebral lateralization, typically developing children

50

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

76 documented in patients with Dystonia (Schneider, Aggarwa, Dupont, Tisch,

77 Limousin, Quinn & Bhatia, 2006), Down's syndrome (Limbrock, Fischer-Brandies &

78 Avalle, 1991), Rett syndrome (Einspieler, Kerr & Prechtl, 2008), Tourette's syndrome

79 (Strassing, Hugo & Muëller, 2004), Angelman syndrome (Williams et al., 2006) and

80 in children with non-organic failure to thrive (Mathisen, Skuse, Wolke & Reilly,

81 1989). However, tongue thrust has also been reported in 67-95% of typically

82 developing children aged 5-8 years. It is thought that for most children, it will

83 extinguish by the age of six, as a typical swallowing motor action is developed

84 (Mason & Proffit, 1974). In contrast, involuntary tongue thrust relating to reflexive

85 swallowing actions may differ in function and neural origin from the tongue

86 protrusions produced by typically developing individuals during tasks of high

87 concentration.

88

89 Theories regarding the evolutionary and developmental basis of tongue protrusions

90 during tasks of concentration range from: motor overflow during attentional processes

91 (e.g. Waber, Mann & Merola, 1985), to the physical rejection of the bottle or breast to

92 by infants to indicate satiation (e.g. Morris, 1978). While the former has not been

93 formally investigated, in the latter scenario, it has been hypothesized that the tongue

94 protrusion action is retained throughout development as a symbol of rejection,

95 implying: 'back off' or `leave me in peace` (e.g. Ingram, 1990). Anecdotal evidence

96 of such an interpretation can be found in Western culture where tongue protrusions

97 have become a popular symbol utilized by celebrities to ward off unwanted public

98 attention. However, if a protruded tongue results from an involuntary, innate behavior

99 to indicate satiation, one should find evidence of this symbolic defiance gesture across

100 cultures. While there is a paucity of empirical data to consider, contrary to the above

101   hypothesis, in Tibet, the protrusion of the tongue is considered to be a greeting

102   (Tsering, 2007).

103

104   A more compelling theory regarding the origins of nonverbal mouth actions (not

105   specific to protrusions) is rooted in the evolution and development of language

106   processes. It has been hypothesized that human speech evolved from a

107   communication system based on hand gestures (Armstrong, Stokoe & Wilcox, 1995),

108   supported by the properties of a 'mirror' neuron system (Rizzolatti & Arbib, 1998).

109   This system serves both the production and perception of actions, potentially making

110   a critical contribution to the emergence and development of motor skills for willed

111   communication (Gallese, Fadiga, Fogassi & Rizzolatti, 1996).

112

113   Behavioral evidence from chimpanzee and human studies supports such a synergy.

114   For example, chimpanzees generated sympathetic mouth movements significantly

115   more often during tasks requiring fine motor manipulation compared with tasks

116   requiring gross motor actions (Waters & Fouts, 2002). In humans, Gentilucci,

117   Benuzzi, Gangitano & Grimaldi (2001) demonstrated that the pronunciation of a

118   syllable could be selectively disrupted when producing a simultaneous grasping action

119   with the hand aimed at target objects of a non-congruent size of the mouth

120   vocalization. The finding suggests that the fine motor articulation required for

121   grasping is processed similarly by both hand and mouth in humans, thus they tend to

122   complement each other. In fact, so tightly are the two motor systems entwined that

123   when either gesture or speech is disrupted the other becomes delayed (Chu &

124   Hagoort, 2014).

125

126   Neuroimaging findings indicate close links between brain regions related to speech

127   production and those controlling movement of the hands and arms (Erhard, Kato,

128   Strupp, Andersen, Adriany, Strick & Ugurbil, 1996; Rizzolatti & Arbib, 1998;

129   Rizzolatti & Craighero, 2004). Specifically, Broca's area is activated when imitating

130   hand movements and preparing grasps (Iacoboni, Woods & Mazziotta, 1998) in

131   addition to actual or internal speech (Hinke, Hu, Stillman, Kim, Merkle, Salmi &

132   Ugurbil, 2003), supporting the notion of a common neural substrate for hand and

133   mouth articulation. Thus, in modern humans, there exists an association between

134   speech and gesture that transcends the speaker to communicate, whereby vocalization

135   and the synchronous arm movements appear intertwined in the mutual cognitive

136   activity of language and remain linked throughout the lifespan (Iverson & Thelen,

137   1999).

138

139   In humans, the observation of grasp alone can activate preparation of the same motor

140   act (Fadiga, Fogassi, Pavesi & Rizzolatti, 1995). These findings are reminiscent of the

141   observed and actual grasping behaviors discovered in monkey (Rizzolatti, Camarda,

142   Fogassi, Gentilucci, Luppino & Matelli, 1988), underpinned by a mirror neuron

143   system. Broca's region in humans and the analogous neural region in the monkey

144   brain (F5) may act as a supramodal processor for planned, structured action sequences

145   represented by both the hands and the mouth (e.g. Petersson & Hagoort, 2012;

146   Pulvermu☐ller & Fadiga, 2010). This sort of system would support perception-action

147   coupling and may have catalyzed the emergence of syntactic processes found in

148   modern human language (e.g. Forrester, Leavens, Quaresmini & Vallortigara, 2011;

149   Forrester, Quaresmini, Leavens, Spiezio & Vallortigara, 2012; Tabiowo & Forrester,

150   2013). Such a processor, dominant within the left hemisphere may have also given

151   rise to human population-level right-handedness (Annett, 2002), for efficiency in

152   carrying out sequences of structured motor actions (e.g. Forrester, Quaresmini,

153   Leavens, Mareschal & Thomas, 2013).

154

155   Modern humans demonstrate population-level right-handedness for both object

156   manipulation and gesture (Marchant, McGrew & Eibl-Eibesfeldt, 1995). Recent

157   studies of child handedness indicate that right-handedness is correlated with typical

158   language development (Kastner-Koller & Keimann, 2007) and that consistent hand

159   dominance in early infancy (6-14 months) is associated with subsequent advanced

160   language skills (18-24 months) (Nelson, Campbell & Michel, 2014). Moreover, a lack

161   of hand dominance (e.g. mixed-handed, ambi-preference) may indicate disruption to

162   the cerebral lateralization of language function (e.g. Crow, Crow, Done & Leask,

163   1998; Delcato, 1966; Orton, 1937; Rodriguez, Kaakinen, Moilanen, Taanila,

164   McGough, Loo & Järvelin, 2010; Yeo, Gangestad & Thoma, 2007; Yeo, Gangestad,

165   Thoma, Shaw & Repa, 1997). Thus, strength of handedness has been proposed to be a

166   useful behavioral marker of children at risk for dysfunction of subsequent language

167   processes long before language develops (e.g. Forrester, Pegler, Thomas &

168   Mareschal, 2014). Although it has never been systematically investigated, one may

169   hypothesize that tongue protrusions produced during manual actions may comprise a

170   lateralized component, consistent with a left hemisphere dominant neural generator.

171

172   The present study sought to investigate the frequency and laterality of tongue

173   protrusions in order to provide the first empirical dataset reflecting tongue protrusions

174   in typically developing four year-old children. Tongue protrusions were assessed

175   during six tasks of high concentration requiring either: fine motor object

176 manipulation, gross motor object manipulation or no object manipulation. Based on

177 the limited existing evidence we hypothesized increasing frequency of tongue

178 protrusions during tasks requiring prehension and additionally considered a left

179 hemisphere (right side) bias in the direction of protrusion. Findings are discussed in

180 light of both developmental and evolutionary theories.

181

182 **2. Material and Methods**

183

184 *2.1. Participants*

185 Fourteen typically developing male (n = 8) and female (n = 6) children (age range:

186 53-56 months; mean age = 54.21 months) were randomly sampled from a previously

187 recorded cohort of 150 children during their participation in a neuropsychological

188 battery of cognitive tasks (see Rodriguez & Waldenström, 2008). Rationale for the

189 age range was predicated by a previous report of tongue thrust identified in 67-95% of

190 typically developing children aged 5-8 years, but tending to extinguish by the age of

191 six (Mason & Proffit, 1974). Importantly, participants were considered to have

192 reached an age by which any concerns with delayed language development would

193 have been identified. Children participating in this study were reported to have no

194 symptoms of language dysfunction. All children were right-handed as deemed by

195 maternal and self-reports. All children came from two-parent homes with an average

196 disposable monthly income of 25000 Swedish Crowns, which corresponds to Swedish

197 national average representing 5th-8th income deciles (Swedish Statistical Central

198 Bureau).

199

200   All behavior was digitally recorded in the home of the individual participants with the

201   participant's mother close by. The procedures for this study involving human

202   participants were in accordance with ethical standards of the responsible committee

203   on human experimentation (institutional and national) and with the spirit of the

204   Helsinki Declaration of 1975, as revised in 2000.

205

206   *2.2. Data Collection*

207   Tongue protrusion behaviors were observed during a subset of the neuropsychological

208   test battery of assessed tasks (Small World, Board Game, Lock and Key, Knock and

209   Tap, Picture Block, Story Recall). This set of challenging tasks were part of a battery

210   of tests conducted to assess cognitive, behavioral, and emotional development (see

211   Rodriguez & Waldenström, 2008). The Small World and Board Game tasks were

212   performed with the child's mother and were designed to assess the mother-child

213   relationship during free-play (Small World) and structured-play (Board Game). All

214   other tasks were performed with a female experimenter. All tasks were conducted on

215   a table surface in the home of the child. All tasks except one (Story Recall) required

216   an element of object manipulation (fine motor or gross motor action) as defined by the

217   instructions. For the purposes of the present study, we were interested in the duration

218   of the task for each individual, the motor requirement of the task and the frequency

219   and laterality of spontaneous tongue protrusions produced by the child. The tasks

220   were as follows:

221

222   *Fine Motor Action*

223

9

224   *Small World:* subjects were provided with a small amount of small world play toys

225   such as miniature dolls, porcelain tea set, and furniture packed into a miniature

226   suitcase. Subjects were observed during independent play and/or interaction with the

227   mother for five minutes. All objects were small and some objects had small moving

228   parts, requiring fine coordinated manipulation.

229

230   *Board Game:* A challenging board game was presented to both child and mother.

231   Turn taking was required and a roll of the die determined a destination based on a

232   combination of a color and a picture. If the picture was present in the column of the

233   given color, a small playing chip was placed on this space on their own board. The

234   object of the game was to complete a full row or column before the other player and

235   thus varied in time across participants. The collection of cards and the movement of

236   playing chips across the spaces of the board required fine motor coordination.

237

238   *Lock and Key*: Subjects were provided with a 4 locked metal padlocks, ranging in

239   shape and size, and a set of five keys on a single ring. Each key opened one lock. The

240   process for opening a lock was demonstrated by the experimenter. The child was

241   given five minutes to open all the locks. This task required fine motor coordination to

242   manipulate both keys and locks.

243

244   *Gross Motor Action*

245

246   *Knock and Tap*: This task was taken from the NEPSY neuropsychological test battery

247   (Kemp, Kirk & Korkman, 2001; Korkman, Kirk & Kemp, 2000) to tap attention and

248   effortful control in four-year-olds. The experimenter engaged the child in the manual

249   motor sequence task. The experimenter sat opposite the child with hands laid flat on

250   the table. The child was asked to mirror the position. The child indicated which hand

251   s/he used most often. The experimenter explained that whenever she knocked (closed

252   fist) on the table, the child was to tap (opened palm down, e.g. slap) on the table. In

253   contrast, whenever the experimenter tapped (opened palm down) on the table the

254   child was to knock. Several practice trials were given to make sure that the child

255   understood the task instructions. Fifteen test trials followed. This task required gross

256   motor movements, and did not require any object manipulation. This task required

257   inhibition of the prepotent action, i.e. imitation of the experimenter's hand movement

258   and was not timed.

259

260   *Picture Block*: The experimenter presented the child a small, 2D square picture of a

261   bear with a ball. The experimenter and child talked about the distinctive features of

262   the picture. The child was then presented with nine approximately 2 inch square

263   blocks. Each block portrayed a small segment, i.e. $1/9^{th}$ of the 2D picture on the top

264   surface.   The cubes were presented in mixed order, but all correct picture segments

265   were always facing up and the child's task was to place the nine blocks to copy the

266   2D picture. Five minutes were allotted to this task. This task required the spatial

267   rotation of blocks into position in accordance with the defined picture.

268

269   *No Motor Action*

270

271   *Story Recall:* The experimenter read the Narrative Memory story from NEPSY (47,

272   48) suitable for four-year-olds. The story comprised of a complex plot involving

273   several characters and events. Children were asked to listen to the story and then were

274 asked to recall information under free and cued-recall conditions. This task did not

275 require any fine or gross manual motor actions and was not timed.

276

277 *2.3. Data Coding*

278 Videos were viewed on Windows Movie Media Player providing a viewing resolution

279 of 30 frames per second. Tongue protrusions were coded based on the following

280 criteria. A tongue protrusion was defined as any visible protrusion of the tongue from

281 or within the mouth. Although the duration of protrusions was not calculated, the start

282 of a protrusion was identified by a visible distortion of the cheek or lip, or by the

283 visible appearance of the tongue through the lips. Only the starting point of the

284 protrusion was considered. While some children performed tongue sweeps, beginning

285 with a protrusion and sweeping to the left or right, there were too few of these events

286 to be considered for further analysis. Viewing video footage of 30 frames per second

287 allowed for fine resolution coding of these events. Under these criteria, tongue

288 protrusions could be internal or external. However, internal protrusions required clear

289 visual distortion of the cheek or lips for identification. Tongue protrusions were

290 identified for lateral position i.e. directed the tip towards the left or the right of the

291 individual. When a lateral position was unclear (e.g. central), a protrusion was only

292 considered for tests of frequency and rate, but not for tests of laterality. It is possible

293 that central protrusions were lateralized, but not to an identifiable extent by the coder.

294 Any instance where one side of the mouth was otherwise engaged was not considered

295 for the final coded data. For example, if the subject was chewing something on the

296 left side of their mouth (e.g. their sleeve, a toy) and protruded their tongue to the right,

297 this was excluded from the coded data set. Tongue protrusions occurred as events

298 rather than bouts (e.g. quick successive repetitions of the same action) and were

299   analyzed accordingly. All subject footage was observed for as long as it took to reach

300   the end of all tasks, which was on average 50 minutes (+/- 10 minutes).

301

302   *2.4. Data Analysis*

303   Analyses of variance and appropriate post-hoc tests were used to assess frequencies,

304   rates and lateral biases of group-level tongue protrusions. Laterality Index scores (LI)

305   were calculated using the formula $[LI = (R-L)/(R+L)]$, with R and L being the

306   frequency counts for right and left navigational path frequency counts. LI values vary

307   on a continuum between -1.0 and +1.0, where the sign indicates the direction of

308   tongue protrusion preference. When R=L, then LI is zero, i.e. no lateral bias. Positive

309   values reflect a right protrusion while negative values reflect a left preference. The

310   absolute value depicts the strength of protrusions. In order to assess differences in the

311   frequencies of tongue protrusions across tasks, rates were calculated. Rates were

312   equal to the frequency of tongue protrusions for a given task for a specific individual

313   divided by the duration in minutes to complete the task. All statistical tests were two-

314   tailed (alpha < .05).

315

316   **3. Results**

317   Raw frequencies of tongue protrusions for each individual by task are presented in

318   Table 1. Tongue protrusions frequencies are divided into left, right and central

319   directions. For ANOVA tests, where sphericity was not assumed, Greenhouse-Geisser

320   correction was used. Non-parametric Wilcoxon signed-rank tests were used for all

321   post-hoc analyses.

322

323   - Insert Table 1 -

324

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

349   requirement (fine motor, gross motor and no motor) [$F_{(2, 26)} = 6.67$, $p = 0.005$] (see

350   Figure 1).

351

352   - Insert Figure 1 –

353

354   Post-hoc analyses revealed that tongue protrusion rates for tasks requiring gross

355   motor actions ($M = 1.55$, SE $\pm$ 0.23) elicited a significantly greater rate of tongue

356   protrusions than tasks requiring fine motor action ($M = 0.78$, SE $\pm$ 0.08) ($Z = -3.42$;

357    $p = .001$), or no motor action ($M = 0.77$, SE $\pm$ 0.17), ($Z = -2.27$; $p = .023$).

358

359   *3.2. Lateralized Tongue Protrusions*

360   Frequency of left and right tongue protrusions revealed that participants demonstrated

361   a significant bias for right tongue protrusions (frequencies: $M = 10.79$, SE $\pm$ 1.82)

362   versus left tongue protrusions (frequencies: $M = 5.57$, SE $\pm$ 0.78) collapsed across all

363   tasks ($Z = -2.76$; $p = .006$). (see Figure 2).

364

365   - Insert Figure 2 –

366

367   Further analyses of lateral tongue protrusion biases were conducted employing LI

368   scores. LI scores ensure equal weighting of participant contribution to the analysis

369   (see Table 4).

370

371   - Insert Table 4-

372

373　A 1-way ANOVA of laterality index scores of tongue protrusions was calculated by

374　motor condition (fine motor, gross motor and no motor), resulting in a significant

375　difference for mean LI scores across motor conditions [F (2, 26) = 12.36, p < 0.001]

376　(see Figure 3).

377

378　- Insert Figure 3 –

379

380　Post-hoc analyses by motor condition showed that fine motor condition (*M* = 0.63, SE

381　± 0.11) elicited significantly more right-biased tongue protrusions compared with the

382　gross motor condition (*M* = -0.08, SE ± 0.15) (Z = -2.91; p = .003) and the no motor

383　condition (*M* = -0.22, SE ± 0.17) (Z = -2.80; p = .005). Additionally, mean LI scores

384　by task were as follows: Small World = .46, Board Game = .71, Lock and Key = .52,

385　Knock and Tap = .30, Picture Block = -.28, Story Recall, -.22.

386

387　**4. Discussion**

388

389　*4.1. Rates of Tongue Protrusions*

390　The findings from this investigation demonstrated that tongue protrusions commonly

391　occur in typically developing 4-year old children. Although the literature is sparse, the

392　result is consistent with an earlier report of the incidence of tongue thrust in typically

393　developing children aged 5-8 years (Mason & Proffit, 1974). In the present study,

394　fourteen participants exhibited tongue protrusions while engaging in a range of

395　cognitive tasks requiring fine motor action, gross motor action, or no motor action.

396　There were significantly more visible external tongue protrusions overall, where the

397　tongue breached the lips, compared with internal tongue protrusions, where the

398 tongue created a bulge in the cheek or lips but was not externally visible. However,

399 this result could be due to the fact that internal tongue protrusions may not always be

400 visually detectable and our findings represent a subset of all tongue protrusions.

401

402 Tasks of fine and gross manual motor action elicited tongue protrusions. This finding

403 supports the theory that hand and mouth actions sympathize with one another as a

404 result of a single system of communication that is independent of modality (McNeill,

405 1992). The motor coupling is believed to occur due to shared neural resources for

406 hand actions (Iacoboni, Woods & Mazziotta, 1998) and actual or internal speech

407 (Hinke, Hu, Stillman, Kim, Merkle, Salmi & Ugurbil, 2003) and is further supported

408 by behavioral evidence demonstrating selective disruption of speech syllables when

409 the hands are required to perform non-congruent articulations (Gentilucci et al.,

410 2001). However, tongue protrusions were also reported during the Story Recall task

411 that had no manual motor requirement. This additional finding supports the position

412 that the hands need not be active to elicit tongue protrusions. It is possible that tongue

413 protrusions will be elicited if a task involves active language processing as required

414 by the Story Recall task.

415

416 The rates of tongue protrusions differed significantly across tasks. Rates were

417 calculated to account for the varying task durations and time to completion per

418 participant. While all tasks elicited tongue protrusions in most children, gross motor

419 tasks elicited significantly more tongue protrusions than fine motor and no motor

420 tasks. This finding is in not inconsistent with our hypothesis, predicting more frequent

421 tongue protrusions in tasks of requiring prehension. However, this finding is in

422 contrast to non-human primate research reporting that chimpanzees generated

423   sympathetic mouth actions at a significantly higher frequency during tasks of fine

424   motor manipulation compared with tasks requiring gross motor manual actions

425   (Waters & Fouts, 2002). However, Waters & Fouts (2002) considered mouth actions

426   that were not specific to tongue protrusions. It is possible that the gross motor tasks in

427   the present study required a greater rate of grasping-type hand actions in comparison

428   to the fine motor tasks. Additionally, we consider that the gross motor tasks were both

429   tasks of significant difficulty. The Knock and Tap and Picture Block tasks were both

430   effortful tasks, requiring inhibition of prepotent responses and spatial manipulations,

431   respectively. Future studies may consider how grasping rate and task difficulty

432   influences tongue protrusions in typically developing children.

433

434   The tasks included in the gross motor condition included the Knock and Tap task and

435   the Picture Block task. The Picture Block task did not elicit significantly greater

436   tongue protrusion rate than other tasks (aside from the Board Game task). The Knock

437   and Tap task, however, did elicit significantly more tongue protrusions than all fine

438   motor and no motor tasks. It is possible that the opening and closing of the hand

439   required by the fifteen trials was sufficient to elicit complementary and sympathetic

440   tongue protrusions. Alternatively, we consider the structure of the Knock and Tap

441   task. This task possessed structured rules, rapid turn-taking and hand gesturing

442   performed with only the dominant right hand. Participants were asked to respond with

443   the opposite hand position as the experimenter. The task measures effortful control

444   and the ability to inhibit behavioral impulsivity of the prepotent response (i.e.

445   imitation of the experimenter's hand position) and may have also required an element

446   of symbolic representation. This process may involve internal speech rehearsal of the

447   task rules to actively control hand movements. One interpretation of the finding is that

448   the Knock and Tap task required foundational components of the communication

449   system, engaging both symbolic hand gestures and the internal rehearsal of the verbal

450   instructions. The task elements may even resemble proto language processes both in

451   turn-taking sequences and symbolic representation of manual gestures. While

452   structured sequences are known to be a distinctive component of language (e.g.

453   Hauser, Chomsky & Fitch, 2002), it has been suggested that they also appear in

454   nonlinguistic domains such as object manipulation and gesture (for a review see,

455   Tettamanti, 2003). The rule-based motor activity required by the Knock and Tap task

456   may be likened to sequences of behavioral units, possessing the properties of an

457   action-based proto-syntax prior to the emergence of speech (Corballis, 2009). One

458   hypothesis is that sympathetic tongue protrusions increased with tasks demand for

459   rule-based structured sequences of action and the comprehension and production of

460   symbolic hand gestures (e.g. Gentilucci et al., 2001). Based on evolutionary theory,

461   goal directed sequences of actions are foundational components of human

462   communication driven by left hemisphere dominant processes that can manifest as

463   lateralized motor action (MacNeilage Rogers & Vallortigara, 2009).

464

465   *4.2. Laterality of Tongue Protrusions*

466   A significant group-level right side bias was revealed for the frequency of tongue

467   protrusions. The motor-level analyses demonstrated that fine motor tasks revealed

468   right-biased tongue protrusions. Laterality was next explored using laterality index

469   (LI) scores across fine motor, gross motor and no motor task groups. Unlike tests of

470   frequency, LI scores ensured equal weighting of each task to the analysis. The fine

471   motor action condition revealed significantly right-lateralized tongue protrusions

472   compared with the gross action condition and the no motor action condition.

473   Additionally, all three tasks revealed mean LI scores consistent with a strong right

474   bias (e.g. Oldfield, 1971).

475

476   We considered that all fine motor tasks required precision grasp and was likely to be

477   conducted by the dominant right hand and left hemisphere. The Small World task

478   included a variety of small dollhouse toys and dolls with manipulable limbs. The

479   Board Game task required moving a token across a board and the manipulation of

480   small flat discs that required precision grasp to collect. The Key and Lock task

481   required bimanual coordinated action (e.g. McGrew & Marchant, 1997) to open pad

482   locks. One hand (non-dominant) held a lock in a power grip while the other hand

483   (dominant) used a precision grasp to manipulate a key. One interpretation of this

484   finding is that fine motor tasks precipitate use of the dominant hand because it is more

485   dexterous in for operations involving sequences of fine manipulation. Studies of

486   cerebral lateralization implicate the left hemisphere and the right hand dominant for

487   such processes in the majority of the population (e.g. MacNeilage et al. 2009). We

488   propose that the dominant hand elicited lateralized sympathetic tongue action driven

489   by the support of common left hemisphere dominant neural system for the motor

490   structures that underpin communication processes (McNeill, 1992).

491

492   Gross motor tasks did not reveal a lateral tongue protrusion bias. Although the Knock

493   and Tap task did not require precision grip, it did demonstrated a weak right biased LI

494   score, possibly due to the fact that it required the use of the dominant hand. The

495   Picture Block task conversely, demonstrated a weak left biased LI score. A potential

496   reason this task did not reveal a lateral bias may have been because it did not require a

497   dominant hand. Blocks were easily slid across the surface of the table and did not

498   require turning, as the correct pictures were already oriented face-up for the

499   participant. Studies of primate manual laterality have found that gross motor actions

500   (e.g. reaching) can often fail to exhibit a significant hand preference as actions lack

501   the precision motor skill required for grasping (for a review see: Hopkins, 2006).

502

503   The present study offers the first investigation of tongue protrusions during cognitive

504   tasks requiring varying degrees of motor precision. We report on spontaneous tongue

505   protrusions in a population of typically developing children and suggest that tongue

506   protrusions are commonly exhibited by typically developing right-handed children.

507   Tongue protrusions were detected both internally and externally to the mouth

508   suggesting that this behavior may not cease in adulthood, but conscious awareness of

509   one's physical actions may cause tongue actions to become less detectable in order to

510   conform with social norms. Our findings support an intrinsic connection between

511   actions of the mouth and hands that is consistent with behavioral studies indicating

512   that vocalizations are accompanied by spontaneous and synchronous rhythmic hand

513   movements, visible from early infancy (e.g. Masataka, 2001). Our findings suggest

514   that hand and tongue actions possess a reciprocal relationship such that when

515   structured sequences of hand actions are performed they are accompanied by

516   spontaneous and synchronous tongue action. The detection of lateralized tongue

517   protrusions is consistent with a left hemisphere dominant unified communication

518   system involving both the hands and the mouth (McNeill 1992) and additionally is

519   consistent with a gestural origin of language position (Armstrong, Stokoes & Wilcox,

520   1995; Corballis, 2002). To further explore the evolution of speech and gesture, future

521   research may consider whether tongue protrusions increases in rate, strength of

522   laterality and temporal synchrony during manual motor tasks that possess

21

523   foundational structured components of communication (e.g. hierarchical sequences of

524   actions). Due to the overlapping neural resources underpinning hand and mouth motor

525   capabilities, the derivation of motor action patterns provides a novel method to draw

526   inference about the evolution of different cognitive abilities.

527

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757

758 <u>Figure Legends</u>

759

760 <u>Figure 1.</u>

761

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

763

764 <u>Figure 2.</u>

765

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

767

768 <u>Figure 3.</u>

769

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

771

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
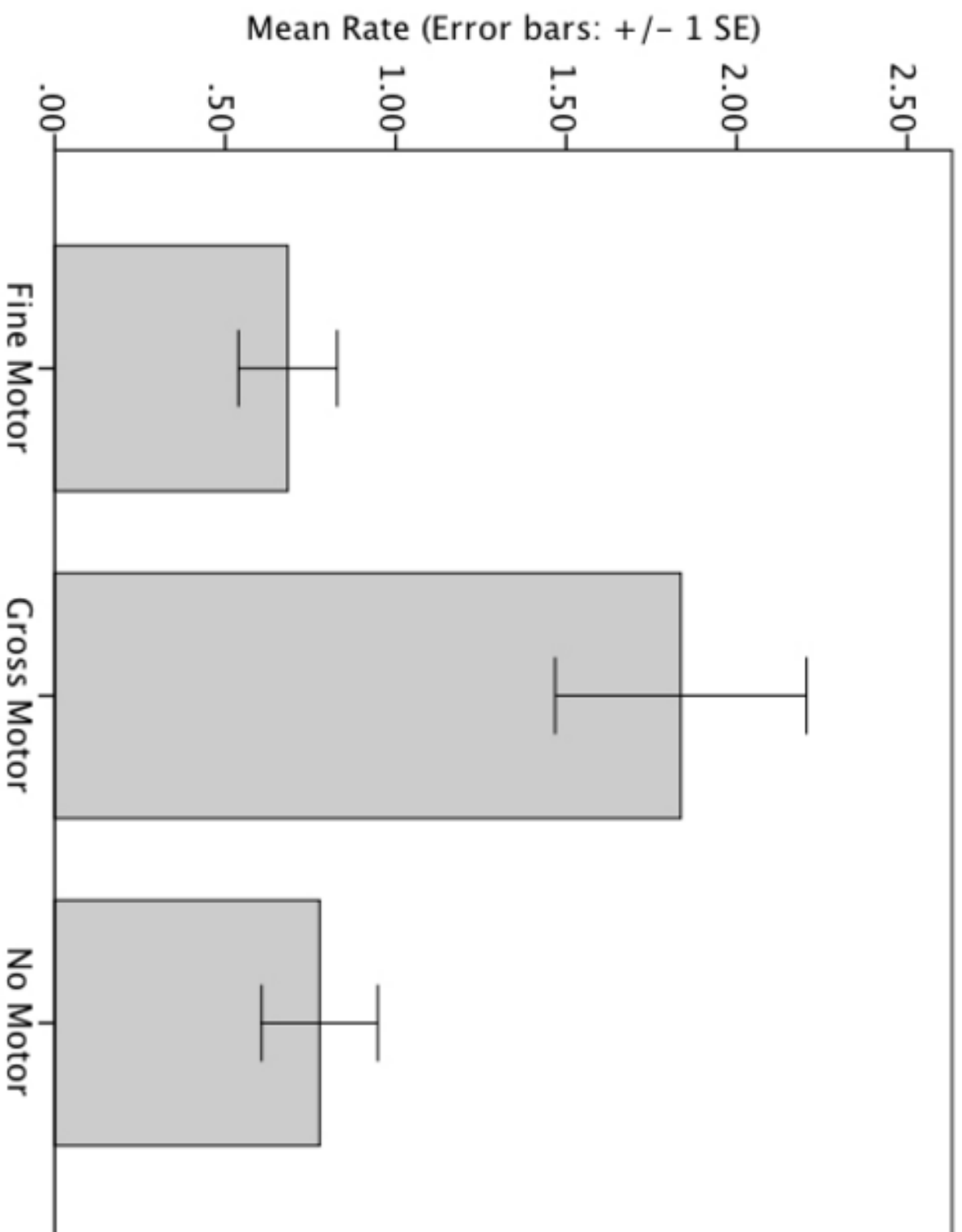
Mean Frequency (Error bars: +/− 1 SE)
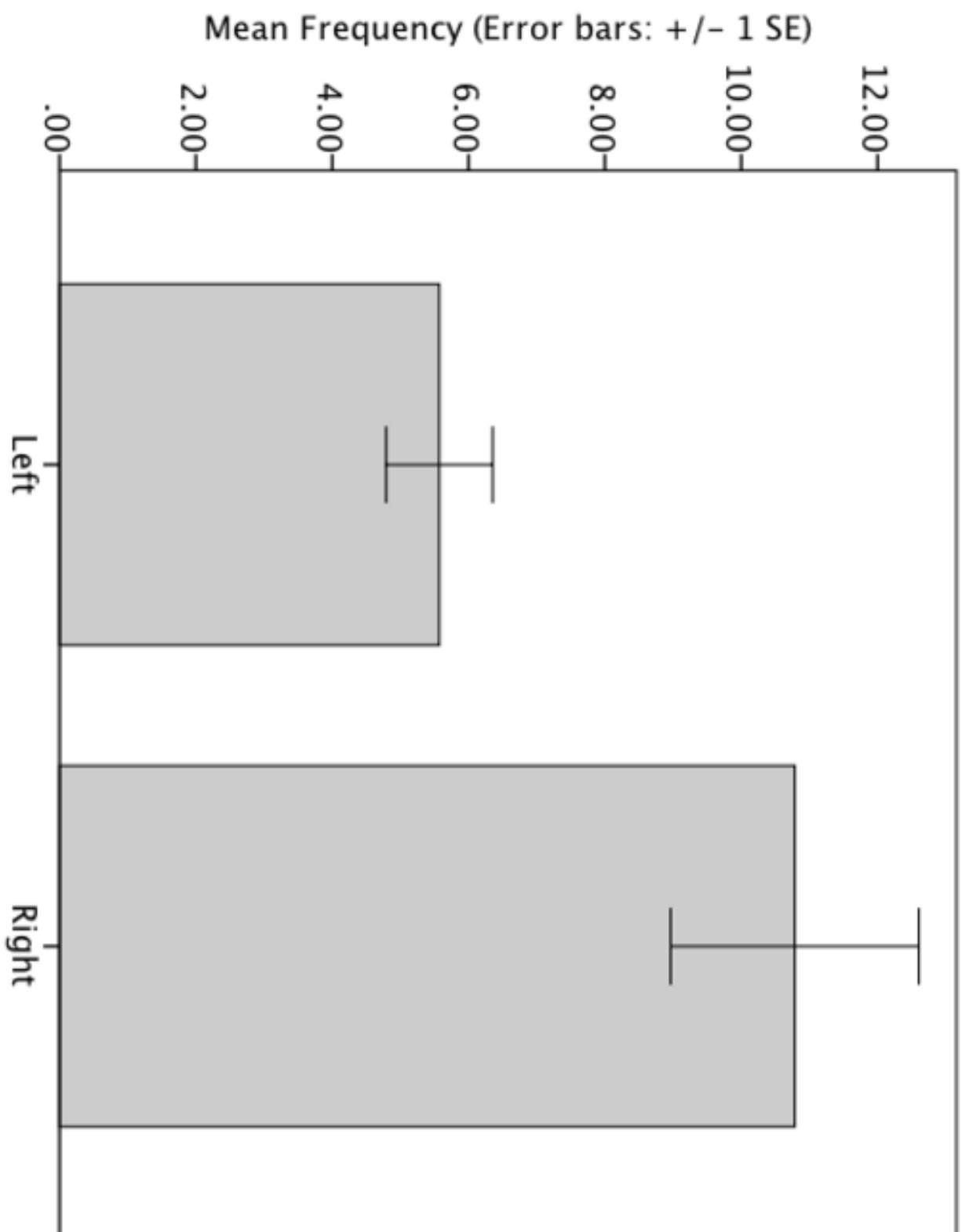
Mean Laterality Index Scores (Error bars: +/− 1 SE)
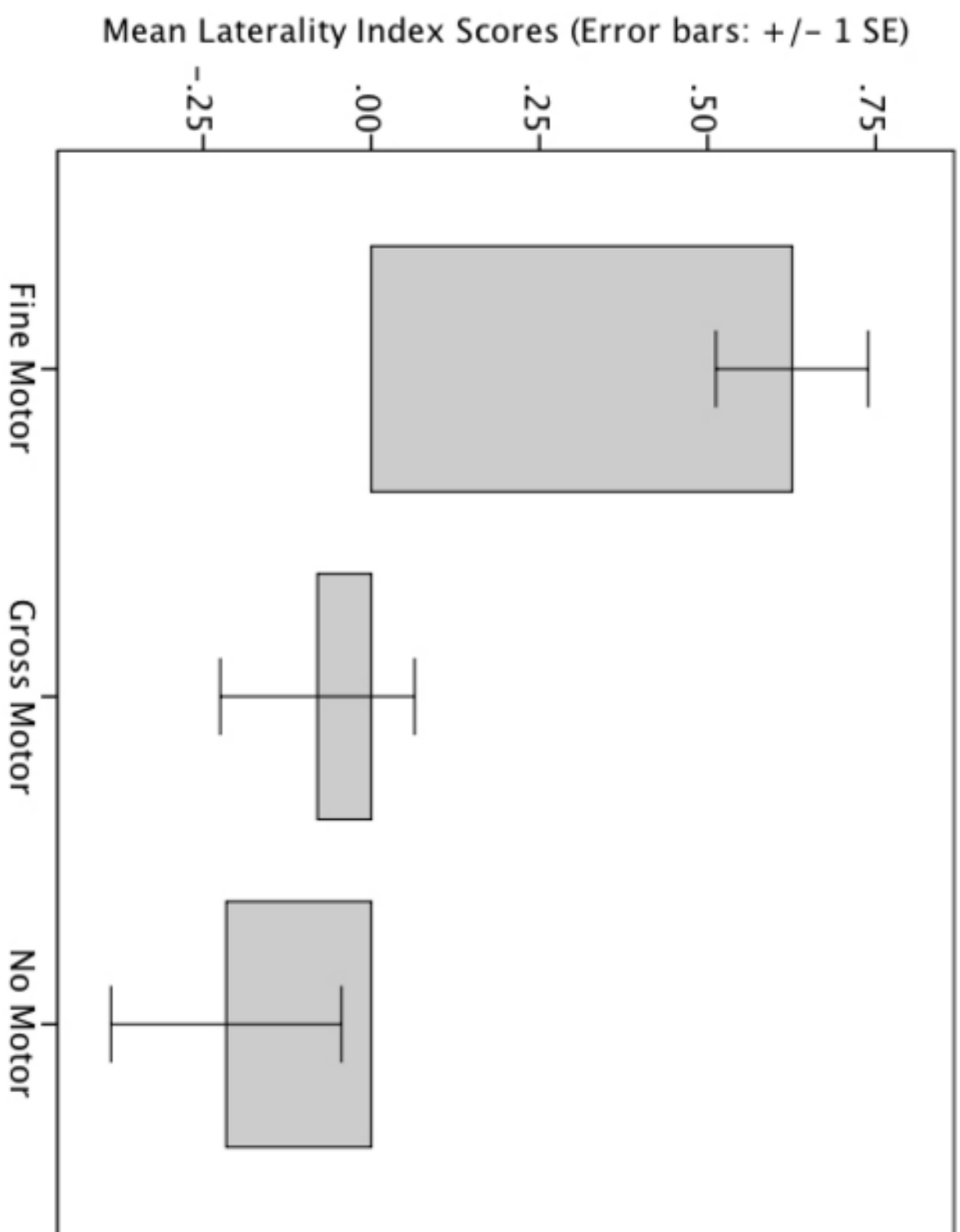
Table 1

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

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)
						Fine Motor						**Gross Motor**					**No Motor**	
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

P	Fine Motor			Gross Motor		No Motor
	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

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