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2   *The Left Cradling Bias: An Evolutionary Facilitator of Social Cognition?*

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19   **Highlights**

20   1. LCB reflects an evolutionarily old behavioral bias for perceiving social stimuli

21   2. A pillow with a face symbol, but not a control stimulus elicited a LCB

22   3. Cradling side of an infant human doll interacted with social ability in children

23   4. An infant primate doll reversed the LCB

24   5. LCB reflects population level brain organisation and domain-specific function

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28   Declarations of interest: none

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33 **Abstract**

34 A robust left side cradling bias (LCB) in humans is argued to reflect an evolutionarily

35 old left visual field bias and right hemisphere dominance for processing social

36 stimuli. A left visual field bias for face processing, invoked via the LCB, is known to

37 reflect a human population-level right cerebral hemisphere specialization for

38 processing social stimuli. We explored the relationship between cradling side biases,

39 hand dominance and socio-communicative abilities. Four and five year old typically-

40 developing children (N = 98) participated in a battery of manual motor tasks

41 interspersed by cradling trials comprising a(n): infant human doll, infant primate doll,

42 proto-face pillow and no-face pillow. Mean social and communication ability scores

43 were obtained via a survey completed by each child's key teacher. We found a

44 population-level LCB for holding an infant human doll that was not influenced by

45 hand dominance, sex, age or experience of having a younger sibling. Children

46 demonstrating a LCB, did however, obtain a significantly higher mean social ability

47 score compared with their right side cradling counterparts. Like the infant human

48 doll, the proto-face pillow's schematic face symbol was sufficient to elicit a

49 population-level LCB. By contrast, the infant primate doll elicited a population-level

50 right side cradling bias, influenced by both hand dominance and sex. The findings

51 suggest that the LCB is present and visible early in development and is likely

52 therefore, to represent evolutionarily old domain-specific organisation and function

53 of the right cerebral hemisphere. Additionally, results suggest that a LCB requires

54 minimal triggering but can be reversed in some situations, possibly in response to

55 species-type or levels of novelty or stress as perceived by the viewer. Patterns of

56 behavioral biases within the context of social stimuli and their associations with

57 cognitive ability are important for understanding how socio-communication abilities

58 emerge in developing children.

59

60 **Abbreviations:**

61 Left cradling bias (LCB)

62

63 **Key words**:

64 behavioral bias, cerebral lateralization, cognition, left cradling bias (LCB)

1. Introduction

At the population-level, approximately 70% of mothers prefer to cradle their infants on the left side of their own bodies regardless of a number of factors including: activity type (e.g., calming, feeding, baby positioning: lateral, upright) (Bourne & Todd, 2004; Bundy, 1979; de Château, Holmberg, & Winberg, 1978; Donnot, 2007; Ginsburg, Fling, Hope, Musgrove, & Andrews, 1979; Hopkins, 2004; Matheson & Turnbull, 1998; Reissland, 2000; Reissland, Hopkins, Helms, & Williams, 2009; Salk, 1973; Sieratzki, Roy, & Woll, 2002; Sieratzki & Woll, 2002, 2004; Thompson & Smart, 1993; Todd & Banerjee, 2016; Tomaszycki, Cline, Griffin, Maestripieri, & Hopkins, 1997; Turnbull & Bryson, 2001; Turnbull & Lucas, 1991, 1996; Turnbull, Rhys-Jones, & Jackson, 2001; Vauclair & Donnot, 2005; Woll & Sieratzki, 2002), mother's handedness (Previc, 1991; Sieratzki & Woll, 1996, 2002; Vauclair & Donnot, 2005; but see van der Meer & Husby, 2006) or mother's culture (Bourne & Todd, 2004; Richards & Finger, 1975). The population-level *left side cradling bias* (LCB) tends to persist for at least the first 12 weeks of the baby's life (Todd & Banerjee, 2016).

1.1 Cerebral Lateralization

The causal nature of the LCB is debated, but the most parsimonious theory relies on cerebral lateralization of function. Cerebral lateralization is the dissociation of specialized processes of left and right hemispheres of the cerebral cortex (for a review see Rogers & Vallortigara, 2013). Because the nerve fibers of the motor cortices are contralaterally innervated, these dominant hemisphere processes can manifest as contralateral motor behaviors (Hellige, 1993). Although quite recently cerebral lateralization and associated contralateral motor biases was thought to be a human unique traits, non-human animal studies suggest that its origins date back to the rise of vertebrates (Rogers & Andrew, 2002; Vallortigara & Rogers, 2005) and possibly even earlier (Anfora et al., 2011; Bell & Niven, 2016; Frasnelli, Vallortigara, & Rogers, 2012). It is theorized that cerebral lateralization of brain function affords advantages to the organism. Strong cerebral lateralization may increase neural efficiency by allowing different functions to operate in parallel across hemispheres, decreasing duplication of functioning across hemispheres and eliminating the

96   initiation of simultaneous and potentially incompatible behavioral responses

97   (Rogers, 2002; Vallortigara, 2000).

98

99   Patterns of motor dominances in a wide range of animal species suggest that

100   throughout evolution, the right hemisphere became dominant for urgent responses

101   to the environment (e.g., predators) (e.g., Bonati, Csermely, & Sovrano, 2013;

102   Franklin & Lima, 2001; Koboroff, Kaplan, & Rogers, 2008; Lippolis, Bisazza, Rogers, &

103   Vallortigara, 2002; Martin, Lopez, Bonati, & Csermely, 2010; Rogers, 2000), while the

104   left hemisphere emerged as dominant for routine and structured motor sequencing

105   (e.g., feeding) (e.g., Alonso, 1998; Hopkins, 2007; Rutldige & Hunt, 2003;

106   Westergaard & Suomi, 1996). Through human evolution, these hemispheric

107   dominances (e.g., responding to novel and threatening stimuli) may have provided a

108   platform for more sophisticated human cognitive capabilities (e.g., social emotional

109   behaviors like infant cradling).

110

111   Research suggests that humans share a right hemisphere and left gaze bias for face

112   perception (for a review see Demaree, Everhart, Youngstrom, & Harrison, 2005)

113   (e.g., looking time of centrally presented faces) with sheep (Peirce, Leigh, &

114   Kendrick, 2000), dogs and rhesus monkeys (Guo, Meints, Hall, Hall, & Mills, 2009)

115   and chimpanzees (Morris & Hopkins, 1993). Additionally, the left side of the face in

116   both humans and nonhuman primates has been reported to display emotive

117   expression earlier and more intensely than the right side of the face, for example in

118   chimpanzees (Fernandez-Carriba, Loeches, Morcilla, & Hopkins, 2002); macaques:

119   (Hauser, 1993); marmosets: (Hook-Costigan & Rogers, 1998) and baboons (Wallez &

120   Vauclair, 2011). These findings suggest that a human bias for both comprehending

121   and producing facial expressions (identity and emotive expressions) dominated by

122   the right hemisphere is an inherited primate trait. Although this manuscript focuses

123   on the visual channel, human nonverbal, evolutionarily urgent vocalizations (e.g.,

124   cries and shouts) associated with threat or danger in the environment, elicit greater

125   right-hemisphere activation compared with the left hemisphere (for a review, see

126   Scott, Sauter, & McGettigan, 2009) suggesting that a right hemisphere dominance

127   for social emotional processing in humans is not specific to a single sensory modality.

128

Cerebral lateralization of function interpreted through contralateral motor biases allows us to understand better how populations behave in the real world. For example, a left visual preference (right hemisphere) for detecting and monitoring conspecific behavior has ramifications for social positioning during natural human and non-human animal behavior. A study of chimpanzees and gorillas revealed that individuals navigate around conspecifics with a bias for keeping social partners to their left side (Quaresmini, Forrester, Spiezio, & Vallortigara, 2014). The study was later replicated with school children across a range of ages (Forrester, Crawley, & Palmer, 2014). The findings suggest that the right hemisphere may provide an advantage for monitoring the threat levels of conspecifics. However, human social emotional abilities go far beyond locomoting through social spaces. In human (and presumably many non-human animal species) the right hemisphere and left visual field play a critical role in discriminating between social companions and recognition of individuals based on familiarity (for a review, see Vallortigara & Versace, 2017).

1.2 Left Visual Field (LVF) Bias for Human Face Processing

Research suggests that a left visual field (LVF) bias for social stimuli is directly related to human population-level right hemisphere specialization for processing faces. Cognitive and behavioral studies consistently report LVF superiority for processing face stimuli, and these findings align with fMRI and ERP face processing responses, shown to be strongly associated with a LVF and right hemisphere superiority for face stimuli (for a review, see Yovel, 2016). Information presented to the LVF has a direct path to the right hemisphere of the brain and numerous brain imaging studies have reported an anatomically larger fusiform gyrus in the right hemisphere with heightened activation when processing faces compared with non-face stimuli (for a review, see Haxby & Gobbini, 2011). For example, a longitudinal study that implemented both brain imaging (fMRI) and behavioral (eye-tracking) methods demonstrated a positive association between an individual's LVF bias and the strength of right lateralized hemisphere activation during face processing (Yovel, Tambini & Brandman, 2008). The study also indicated that the level of hemispheric bias for face processing remained stable over time. Additional functional imaging

160　research has demonstrated that the right hemisphere is not only dominant for
161　processing faces in general, but it is also selectively dominant for perceiving *human*
162　face identity and strength of facial expressions (Gorno-Tempini & Price, 2001).
163　Clinical studies also support a LVF and right hemisphere advantage for face
164　processing. Individuals with right hemisphere damage demonstrated no LVF
165　advantage and decreased ability to recognize faces (De Renzi, Perani, Carlesim,
166　Silveri & Fazio, 1994). Furthermore, interference in face processing is found when
167　the right (but not the left fusiform gyrus) is disrupted via intracranial electrodes
168　(Jonas et al., 2015; Parvizi et al., 2012). Taken together, these studies converge to
169　suggest that a population-level LVF bias for social stimuli reflects a right hemisphere
170　specialization for attending to and processing social stimuli. As such, visual field
171　biases for faces can act as behavioral markers of anatomical and functional cortical
172　organization of domain specific social processing.

173

174　*1.3 Social Laterality in Mother Baby Dyads*
175　At no time would it seem more critical for animals to develop social bonds than
176　during the rearing of offspring. Recent research has reported that a myriad of animal
177　species possess social positioning biases, during mother-baby interactions, that favor
178　the right hemisphere and the left eye (Giljov, Karenina, & Malashichev, 2018;
179　Karenina, Giljov, Ingram, Rowntree, & Malashichev, 2017). This orientation of social
180　positioning whilst nurturing offspring has also been identified in great apes
181　(chimpanzees: Nishida, 1993; gorillas: Manning, Heaton, & Chamberlain, 1994). This
182　behavior is likely to be akin to human cradling, supporting an evolutionary
183　continuum of cerebral lateralization for processing social-emotional stimuli.

184

185　For the majority of the human population, the LCB facilitates a mutual (mother-
186　baby) right hemisphere advantage for producing and perceiving social signals across
187　visual and auditory social stimuli (Scola & Vauclair, 2010a; Sieratzki & Woll, 2002).
188　The LCB creates a direct route to the right hemisphere through the left visual field of
189　the mother, supporting rapid identification of facial identity and emotional state of
190　the infant (Manning & Chamberlain, 1991). Consequently, the infant is provided with
191　the more expressive left side of the mother's face (Vauclair & Donnot, 2005), which

192   may have the potential to facilitate bonding and social development (Huggenberger,

193   Suter, Reijnen, & Schächinger, 2009). Early social development research suggests

194   that even though neonates have underdeveloped sensory processing channels

195   (Simion, Macchi Cassia, Turati, & Valenza, 2001) faces are still salient stimuli from

196   birth (e.g., Farroni et al., 2005). Regardless of an underdeveloped visual system,

197   neonates preferentially attend to patterns that contain the basic configuration of

198   high-contrast areas of a face (e.g., Johnson, 2007). Moreover, neonates tested at

199   birth demonstrate a preference for faces above other types of stimuli (Bower, 2001;

200   Goren, Sarty, & Wu, 1975; Leppanen, Moulson, Vogel-Farley, & Nelson, 2007; Macchi

201   Cassia, Valenza, Simion, & Leo, 2008; Simion et al., 2001; Umiltà, Simion, & Valenza,

202   1996; Valenza, Leo, Gava, & Simion, 2006). Johnson, Dziurawiec, Ellis, and Morton

203   (1991) created a schematic illustration of the stimuli that might be optimal for

204   eliciting a face-related preference in neonates. Consistent patterns of results were

205   obtained across investigations of chicks (*Gallus gallus*) and human newborns. These

206   two evolutionarily disparate species demonstrated similar behavioral biases toward

207   face stimuli shortly after hatching or birth, supporting an evolutionary continuity in

208   social orienting (Rosa Salva, Farroni, Vallortigara & Johnson, 2011).

209

210   Owing to the rate of cortical development, one might predict that newborns would

211   not benefit from early exposure to visual social stimuli, however, brain imaging

212   findings suggest that neonates may possess face sensitive subcortical neural regions

213   (Johnson, Senju, & Tomalski, 2015; Umiltà et al., 1996), linked to an evolutionarily

214   early predisposition to proto faces. New evidence suggests that basic visual face

215   orienting abilities are in place prenatally as early as 30 weeks of gestations (Reid et

216   al., 2017) and are not dissimilar to the filial responses demonstrated in chicks (Di

217   Giorgio, Loveland, Mayer, Rosa-Salva, Versace, & Vallortigara, 2017). These early

218   behavioral and neural attributes coupled with a reflexive rightward head-turning

219   bias (in the final weeks of gestation through the first six months after birth;

220   Güntürkün, 2003) and a mother's inclination to exhibit a LCB, create ideal conditions

221   for both the infant's survival and developing a social brain.

222

223   *1.4 Sex, Age and Experience*

224   Evolutionary explanations set up an expectation that the LCB would appear early in
225   ontogeny among both males and females and also without any prior experience of
226   holding infants (e.g. Saling & Bonert, 1983; Todd & Banerjee, 2016). Although the
227   methods used to elicit cradling have been extremely varied across studies, the choice
228   of experimental approach does not appear to influence the robust cradling LCB
229   found in women. However, evidence of a LCB in men has been mixed (Bundy, 1979;
230   Harris, Almerigi, & Kirsch, 2000; Harris, Spradlin, & Almerigi, 2006; Manning, 1991;
231   Nakamichi & Takeda, 1995; Turnbull & Lucas, 1991). Some studies have reported
232   that in men, the LCB is restricted to fathers (Bogren, 1984; Dagenbach, Harris, &
233   Fitzgerald, 1988; Scola & Vauclair, 2010b) and men whose professions required
234   infant care (de Château, 1983). These findings suggests that gender could be an
235   influential LCB factor and additionally that there might be a developmental or
236   experiential component to the LCB. However, to date, it is unclear if any gender bias
237   is mediated by experience or innate predisposition, nor do we understand what
238   exactly it is that makes the LCB emerge in both men and women.
239
240   Evidence from cradling studies of girls and boys suggest that a propensity to cradle
241   left is present and visible in children. Girls and boys (aged 2-16 years) demonstrated
242   an LCB using a doll (Pileggi, Malcolm-Smith, & Solms, 2015; Souza-Godeli, 1996; but
243   see de Château & Andersson, 1976). However, Manning and Chamberlain (1991)
244   found that the proportion of left cradling increased with age in girls, only becoming
245   biased to the left by six years of age. In contrast to the findings associated with men
246   suggesting that experience of babies is required to elicit a LCB, boys demonstrated a
247   later developmental trajectory, with a LCB becoming visible not before 16 years of
248   age (de Château & Andersson, 1976).
249
250   Across cultures, gender-specific socialisation and family experience might impact the
251   presence of the LCB in young male and female children. In western countries, girls
252   are preferentially socialized to interact with dolls (considered a female-stereotyped
253   toy) from a young age "and may gain formative experience through these
254   interactions" (Todd & Banerjee, 2016). Culturally, boys may be discouraged from
255   interacting with female-stereotyped toys and therefore gain less experience then

256   their female counterparts for developing a cradling bias (Todd, Barry, &

257   Thommessen, 2017). Additionally, experience of sibling care, (as measured by birth

258   order), may also provide important experiences triggering or influencing the strength

259   or propensity for a cradling bias in children. To date, the implementation of non-

260   gender-stereotyped cradling stimuli and the influence of sibling experience have yet

261   to be addressed in systematic fashion to explore how they might contribute to a

262   population-level LCB.

263

264   *1.5 Motor Biases as a Marker of Cognitive Ability*

265   Motor biases act not only as markers of brain organization, but have also been

266   shown to correlate significantly with subsequent cognitive outcomes (Toga &

267   Thompson, 2003). For instance, at the population-level, strong right hand dominance

268   in children corresponds with the typical development of fine motor skills and

269   subsequent attainment of typical language abilities (left hemisphere dominant; Leask

270   & Crow, 2001). Conversely, weak hand dominance (ambidexterity) is associated with

271   the development of poorer fine motor abilities and weaker language ability

272   (compared with strongly handed individuals) in addition to a rise in

273   neurodevelopmental and mental health disorders (e.g., Rodriguez et al., 2010).

274

275   There is currently no evidence suggesting an association between the side of the

276   mother's body on which babies were cradled during the early weeks of infancy and

277   the level of subsequent socio-communicative development. Moreover, population

278   patterns do not necessarily translate to the individual because at the individual level,

279   we cannot be certain of brain organization based on motor biases. However, one

280   retrospective study of healthy adults revealed that individuals who were held with a

281   LCB (derived from family photos) developed a typical left visual field (right

282   hemisphere) bias for responding to chimeric faces, whereas adults that were cradled

283   with a right-arm bias did not (Vervloed, Hendricks, & van den Eijnde, 2011). While all

284   participants could effectively identify the identity and emotional expression of face

285   stimuli, those individuals who were cradled on the left were significantly faster at

286   doing so. The findings suggest that there is significant 'typical' variation in the

287   population and that babies cradled on the left may develop an enhanced right

288 hemisphere bias for processing social emotional stimuli. In fact, one study has even

289 suggested that faces of right-cradlers were less visible from the "infant viewpoint"

290 compared to those of left-cradlers (Hendriks, van Rijswijk, & Omtzigt, 2011).

291 However, at this time it is impossible to reconcile if right side cradled babies were

292 predisposed through heritability (for a genetic account of cradling, see Manning &

293 Denman, 1994) to decreased cerebral lateralization or if the cradling side influenced

294 development.

295

296 Although visual and motor biases for social positioning of mother-baby dyads during

297 cradling appear to be rooted in an evolutionarily old right hemisphere advantages

298 for processing social-emotional stimuli, we do not yet understand what features of

299 the baby elicits the LCB in the mother; or if gender, age or experience are

300 contributing factors. Additionally, we seek to better understand better the link

301 between motor biases, cerebral lateralization of function and association with

302 cognitive developmental ability (e.g., Forrester, Pegler, Thomas, & Mareschal, 2014;

303 Lindell & Hudry, 2013).

304

305 In the current study, we employed a range of manual motor tasks that explored:

306 hand dominance, cognitive control (impulsivity) and cradling behavior in young

307 typically developing young children. This research takes steps towards addressing

308 some of the gaps in the literature regarding the LCB, motor biases in general and

309 their relationship with cognition. With respect to the cradling results, we predicted:

310 1) children will demonstrate a preference to hold a doll representing a human infant

311 on their left side, 2) gender, age and experience may influence cradling side bias of

312 the infant human doll; 3) children will demonstrate a preference to hold a non-

313 gender-stereotyped doll (infant primate doll) on their left side because the

314 introduction of the infant primate doll will eradicate socially induced effects of

315 gender, age or experience; 4) no cradling side bias will be found when children hold

316 a control object of the same weight and dimensions as the doll(s) but without social

317 features; 5) the addition of rudimentary facial features to the control object will be

318 sufficient to elicit a left cradling bias in children. With respect to the relationship

319 between motor biases and cognitive ability scores, we predicted: 1) there will be a

320 difference in social ability scores based on cradling side bias and 2) there will be a

321 relationship between the strength of hand dominance for manual motor tasks and

322 communication ability scores.

323

324 **2. Material and Methods**

325

326 *2.1 Participants*

327 Ninety-eight typically developing children (54 girls, 44 boys) attending reception or

328 year 1 participated in this study (mean age = 69.95 months, SD = 10.64). All children

329 attended a mainstream primary school in central London. Children at this

330 developmental age were chosen because both handedness (e.g., Gudmundsson,

331 1993) and the cerebral processes associated with hand preference (Bates, O'Connell,

332 Vaid, Sledge, & Oakes, 1986; Fagard & Marks, 2000) have stabilized by then, while

333 also minimizing the amount of time that children have been exposed to socially

334 defined lateralized behaviors. This is also the age used by similar work in this area

335 (e.g., Forrester, Pegler, Thomas, & Mareschal, 2014). For each child, the number of

336 younger siblings living in the home was recorded in order to assess the extent to

337 which exposure to a younger sibling may impact cradling bias.

338

339 **Table 1.** Demographic information of participants

Participant	N	Mean Age in Months	Standard Error	Age Range in Months	Self Report Handedness	Younger Sibling
Girls	54	69.44	1.52	34	7 (L), 47 (R)	17
Boys	44	67.05	1.70	34	8 (L), 36 (R)	9

340

341 *2.2 Testing Conditions*

342 Children were tested in a small (approximately 2 x 4 metres) quiet room with plain

343 walls. Participants alternated between two testing stations at opposite ends of the

344 room. Each testing station was operated by a different researcher. Each child was

345 presented with three manual-based motor tasks, interspersed with three cradling

346 trials. The tasks were counterbalanced to avoid order effects. Participants began

347 testing at the manual motor station. When the child was at one testing station, the

348 researcher at the other testing station was responsible for coding behavior. The
349 objectivity of coding was high due to the categorical coding of tasks and cradling
350 trials (left, right, correct, incorrect). Inter-rater reliability was performed for 10%
351 participants, resulting in 100% reliability ($r = 1.0$).

352

353 The number of participants varied across tasks (see section 2.4.1). All children
354 participated in the *Knock and Tap, Peg Board and Card-Lacing* tasks however three
355 children's data from the survey tasks were not completed by key teachers. For
356 cradling trials, only those trials where children followed task instructions and held
357 stimuli in an upright or lateral position were included in analyses. Lower participant
358 numbers for proto-face and no-face pillow stimuli were the result of a between-
359 participant contrast, compared with within-participant contrast for other cradling
360 stimuli (see section 2.4.1).

361

362 **Table 2** Sample characteristics as a function of task.

Tasks	N	N by Sex	Mean Age (months)	Hand Classification	Younger Siblings
Knock and Tap	98	Girls (54)	69.44	7 (L), 47 (R)	17
		Boys (44)	70.40	8 (L), 36 (R)	9
Peg Board	98	Girls (54)	69.44	7 (L), 47 (R)	17
		Boys (44)	70.40	8 (L), 36 (R)	9
Card Lacing	98	Girls (54)	69.44	7 (L), 47 (R)	17
		Boys (44)	70.40	8 (L), 36 (R)	9
Social Survey Items	95	Girls (53)	69.32	7 (L), 46 (R)	17
		Boys (42)	70.74	8 (L), 34 (R)	9
Communication Survey Items	95	Girls (53)	69.32	7 (L), 46 (R)	17
		Boys (42)	70.74	8 (L), 34 (R)	9
Cradling Trials	N	N by Sex	Mean Age (months)	Hand Classification	Younger Siblings
Infant Human Doll	80	Girls (49)	69.96	6 (L), 43 (R)	17
		Boys (31)	71.68	6 (L), 25 (R)	8
Infant Primate Doll	74	Girls (42)	68.95	6 (L), 36 (R)	13
		Boys (32)	70.74	6 (L), 26 (R)	7
Proto-Face Pillow	37	Girls (21)	74.91	3 (L), 18 (R)	7
		Boys (16)	70.69	3 (L), 13 (R)	4
No-Face Pillow	44	Girls (25)	66.32	4 (L), 21 (R)	7
		Boys (19)	70.26	3 (L), 16 (R)	5

363

364 *2.3 Manual Motor Tasks*

365

366   *2.3.1 Knock and Tap task:*

367   Each participant began with the *Knock and Tap* task was taken from the NEPSY

368   neuropsychological test battery (Kemp, Kirk, & Korkman, 2001; Korkman, Kirk, &

369   Kemp, 2000). The *Knock and Tap* task was introduced to assess attention and

370   effortful control in young children, as it requires the inhibition of a prepotent action.

371   In this task, the experimenter sat opposite the child (across a table) with hands laid

372   flat on the table. The child was asked to mirror their hand position. Next, the child

373   was asked to indicate their 'favorite hand for writing'. This was taken as indicative of

374   the dominant hand for fine motor actives. There was a 96% concurrence between

375   the child's chosen hand and the hand classification based on the subsequent motor

376   tasks described. The researcher told the child that they would play the game with

377   the indicated (dominant) hand and the other hand (non-dominant) would remain

378   still on the table. The experimenter always conducted the task with the hand that

379   mirrored the child's dominant hand. The researcher provided participants with the

380   following instructions and an accompanying demonstration: "When I knock on the

381   table (closed fist makes contact with the table with an audible sound), you tap on

382   the table (opened palm makes contact with the table with an audible sound). And, if

383   I tap on the table, you knock." Two practice trials were given to make sure that the

384   child understood the task instructions. Fifteen test trials followed as specified in the

385   NEPSY manual (Knock-Knock-Tap-Knock-Knock-Tap-Tap-Knock-Tap-Tap-Knock-Tap-

386   Tap-Tap-Knock). Hesitations were scored as breaks in the flow of the rhythmic trials,

387   and incorrect responses were also recorded.

388

389   We used two different manual motor tasks (*Pegboard* and *Card-lacing, see Figure 1*)

390   to assess actual hand dominance. Unimanual actions are typically used to assess

391   hand dominance for fine motor control, thus we introduced the *Pegboard* task.

392   However, unimodal actions (actions that require a single hand to perform an action)

393   are often simple enough that participants may perform the task efficiently with

394   either hand, increasing the likelihood of ambi-preferent scores. Evidence from the

395   laterality literature suggests that bimanual actions (actions that require the use of

396   both hands, such that one hand is holding an object whilst the other hand performs

397   manipulations of the object) demonstrates greater sensitivity as a measure of hand

398   dominance (for a review of hand dominance measures, see Forrester, 2017) Thus,

399   we also introduced the *Card-lacing* task.

400

401   *2.3.2 Pegboard task:*

402   Participants sat across a table directly opposite the researcher. The researcher

403   produced a white 10 x 10 holed plastic pegboard (*Invicta*[©] pegboard: 17 x 17 cm, 739

404   grams). The pegboard and a bowl of multicolored plastic pegs (red, blue, green,

405   yellow) were placed at the child's midline with the pegboard in front of the child and

406   bowl of pegs behind the pegboard from the child's perspective, affixed to the table

407   using Blu Tack[©]. The pegboard possessed a red outline of a square drawn on the

408   board measuring 6 x 6 holes.

409

410   The children were asked to select only red pegs and complete the outline of the 6 x 6

411   red square. This task required the placement of 20 red pegs. Participants were asked

412   to work as quickly and as accurately as possible. Participants were given a maximum

413   of ninety seconds to complete the task. The researcher scored the number of left

414   handed and right handed peg placements. Errors in the form of: 1) failed attempts to

415   place a peg in a hole and 2) the use of the wrong-colored pegs were recorded. A

416   laterality index scores (LIS) was calculated for each participant using data from the

417   pegboard task. LIS were calculated using the formula [LI = (R − L)/(R+L)], with R and L

418   corresponding to the frequency of events resulting in scores ranging between -1.0

419   and +1.0 where greater positive values reflect an increasing right hand preference

420   and greater negative values represent an increasing left hand preference.

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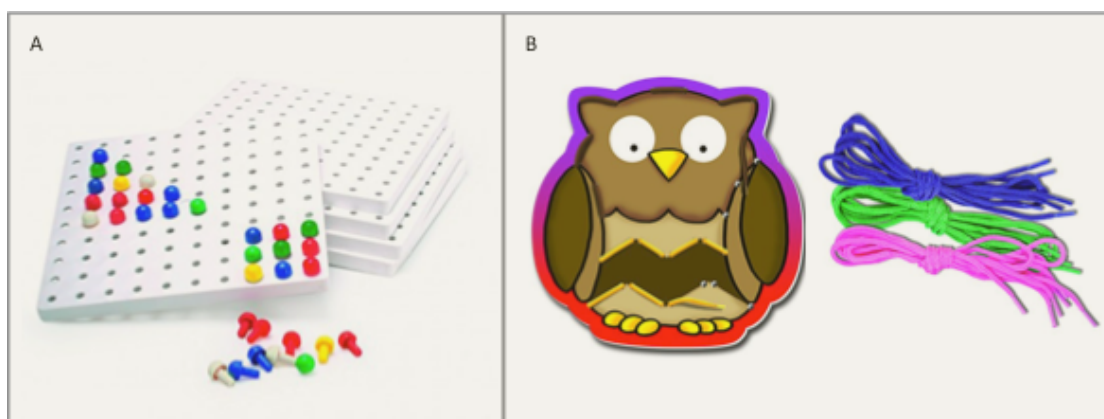
422

423   *Figure 1*. Task stimuli for (A) the Pegboard and (B) Card-lacing tasks.

424

425   *2.3.3 Card lacing task stimuli*

426   This task was used to assess bimanual coordinated hand dominance. Participants sat

427   at a table, across from the researcher. The researcher provided the child with a

428   lacing card and a jumbo lace with a bound end (*Early Learning Centre$^{©}$ My First*

429   *Lacing Pictures*). To control for the number and position of holes across participants

430   the same lacing card was used for all participants. Children were instructed to weave

431   the lace through all of the holes in the card. The researcher first provided a

432   demonstration with their own lacing card and did not begin the task until the child

433   had successfully threaded two practice holes. The children were then given ninety

434   seconds to complete as much of the card as possible in no particular order. The

435   number of holes completed and the number of errors (failed attempts to place the

436   head of the lace through a hole) were recorded. LIS scores were also calculated for

437   the card-lacing task.

438

439   *2.4 Cradling Task*

440   Cradling trials were conducted to assess if children demonstrated a preference for

441   holding different types of social stimuli and a control item with a bias to one side of

442   their body. Cradling stimuli consisted of: an infant human doll, an infant primate

443   (orang-utan) doll, a proto-face pillow and a no-face pillow (Figure 2). All cradling

444   stimuli were altered using fishing weights such that the head portion weighed 2 lbs.

445   and the posterior weighed 1.5 lbs. and the total weight was 5 lbs. All cradling stimuli

446   were 22 inches in length except for the infant human doll, which was 18 inches in

447   length. Doll stimuli wore newborn-sized nappies under unisex, cream-colored one-

448   piece playsuit with a marl-grey pattern. A zip fastening was concealed on the back.

449   The proto-face and no-face pillows were wider at the top than at the bottom and

450   covered with the identical one-piece playsuit fabric and back zip fastening. These

451   stimuli were stuffed with a contained bag of plastic beads positioned in the posterior

452   region to match the posterior region of the dolls. The beads were wrapped in fleece

453   fabric and padded out with polyester cushion filling. The only difference between the

454   proto-face and no-face pillow stimuli was that the proto-face pillow was embellished

455 with a basic configuration of a face, equal to the mean size of the doll stimuli and

456 consistent with the proportions identified by Johnson and collaborators (1991).

457

458

459 *Figure 2*. Illustrations of (A) the infant human doll, (B) infant primate doll, (C) proto-

460 face pillow and (D) no-face pillow.

461

462 *2.4.1 Procedure and Behavioral Coding*

463 The cradling task comprised of three trials. Participants began with one of either the

464 proto-face pillow or the no-face pillow. The pillow trial was always presented as the

465 initial cradling trial so that the cradling trials involving the infant human and primate

466 dolls did not 'contaminate' these stimuli with a notion of 'animacy' or 'dollness'.

467 Each participant engaged in only one of these conditions because counterbalancing

468 the stimuli would have resulted in some children cradling the proto-face pillow

469 before the no-face pillow. In these cases there was concern that the proto-face

470 pillow would contaminate the subsequent no-face pillow with a quality of 'animacy'.

471 All participants were then presented with both the infant human and primate dolls

472 in a counterbalanced fashion. The type of pillow used (face vs. no face) was

473 therefore a between-participant contrast, whereas the type of stimulus (pillow,

474 human infant doll or primate infant doll) was a within-participant contrast.

475

476 Each cradling trial was conducted with identical procedures to assess whether

477 children would demonstrate a left or right side cradling (see Figure 3). To begin a

478 cradling trial, the child was asked to stand up from the manual motor station, walk

479 to the back of the room and sit in a chair located equidistant from the walls on either

480 side. The researcher then approached the child centrally and said: "I'm going to give

481 you something to hold. Can you take it and hold it like this?" A symmetrical cradling
482 gesture without holding anything was then made (Pileggi et al., 2015; and see panel
483 B, Figure 4). Next, the researcher walked back to the manual motor station with their
484 back to the participant to retrieve the cradling stimulus from a concealed bag under
485 the testing station. The stimulus was held centrally and upright against the
486 researcher's chest so as not to be visible to the participant until the researcher
487 turned back to walk towards the child. The researcher approached the child and
488 extended the stimulus to the child in an upright position towards the child's midline.
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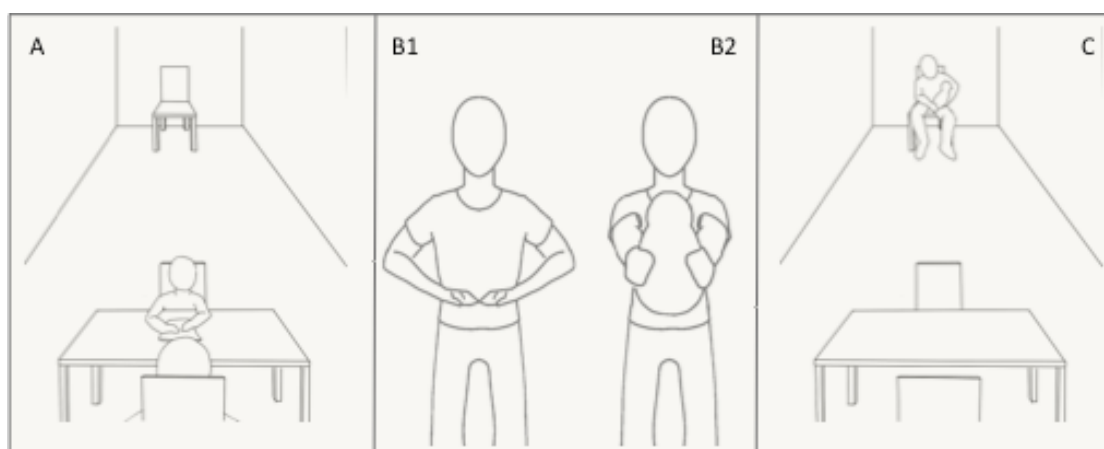
490

491 *Figure 3.* Schema of the testing room layout with the manual motor testing station in
492 the foreground and the cradling station (chair) in the background. Panel A illustrates
493 the child facing the researcher engaged in a task at the manual motor station. Panel
494 B1 illustrates the researcher providing the cradling gesture to the child in advance of
495 producing the cradling stimuli. B2 demonstrates the researcher presenting the
496 cradling stimulus upright and midline to the participant and panel C depicts a
497 successful cradling trial whereby the child cradles a doll in a side-biased lateral or
498 upright position.
499

500 If the child did not hold the stimulus in one of the desired positions (lateral or
501 upright), the researcher re-iterated the cradling gesture. When a stimulus had been
502 cradled for approximately 30 seconds, the cradling side was recorded. If the child
503 held the doll in any other position (face down, above the head, on the floor) or
504 rejected the stimulus, the trial was excluded from the analyses below.
505

2.5 Socio-communication Survey

507 The key teacher for each child was asked to complete a 14-item socio-

508 communicative survey. The survey was developed specifically for this investigation

509 to provide a basic social ability score (items 2, 3, 5, 7, 9, 11, 13) and a basic

510 communication ability score (items 1, 4, 6, 8, 10, 12, 14) for five year-old children

511 (see Table 4). The survey was scored by the key teacher of each participant using a

512 Likert scale for the categorical descriptions: 'strongly disagree', 'disagree', 'neutral',

513 'agree' and 'strongly agree'. Categorical selections were transcribed into scores of 1-

514 5 where high scores equated to stronger ability levels. Communication items were

515 developed to reflect speech, language and communication milestones for five year

516 olds. Information about milestones were derived from *Talking Point,* a website about

517 children's speech, language and communication. *Talking Point* is run by I CAN, and

518 receives funding from The Communication Trust. The Communication Trust is a

519 coalition of over 50 not-for-profit organization that support people who work with

520 children in England to support their speech, language and communication needs

521 (SLCN). Social items were developed to reflect social milestones for five year olds.

522 Information about milestones were derived from the United States Center for

523 Disease Control and Prevention's Milestone Tracker: 'Your Child at 5 Years'

524 Social/Emotional checklist.

525

526 All descriptive and statistical analyses were conducted using SPSS (Version 24). Alpha

527 was set at 0.05 and all tests were two-tailed.

528

529 **3. Results**

530 Although 98 children participated in the study, not all children completed all tasks.

531 Table 2 (below) illustrates the number of participants that completed each task, the

532 mean scores for: the manual motor tasks (*Pegboard* and *Card-lacing*), the task for

533 effortful control/impulsivity (*Knock and Tap*) and the frequency of left and right

534 cradling trials for the *Cradling Task* trials (infant human doll, infant primate doll,

535 proto-face pillow, no-face pillow).

536

537

538   **Table 2** Group mean scores for each of the 10 study measures.

Manual Motor and Socio-Communicative Tasks	N	Maximum Score	Mean Score	SE
Knock and Tap: Number of Errors	98	15	2.01	.286
Knock and Tap: Number of Hesitations	98	15	1.20	.142
Peg Board: Laterality Index Score	98	-1/+1	.504	.051
Card Lacing Laterality Index Score	98	-1/+1	.476	.054
Social Ability Survey Scores	95	5	4.27	.048
Communication Ability Survey Scores	95	5	4.29	.059
Cradling Trials	N	Trials per Child	Left	Right
Infant Human Doll	80	1	52	28
Infant Primate Doll	74	1	25	49
Proto-Face Pillow	37	1	27	10
No-Face Pillow	44	1	19	25

539

540   *3.1 Cradling Task*

541   Cradling results are reported in Table 3 and Figure 4. We begin by considering the

542   effects of Gender then turn to considering the impact of motor and stimulus

543   variables on cradling behaviors. Binomial tests were conducted to determine

544   significant cradling side biases.

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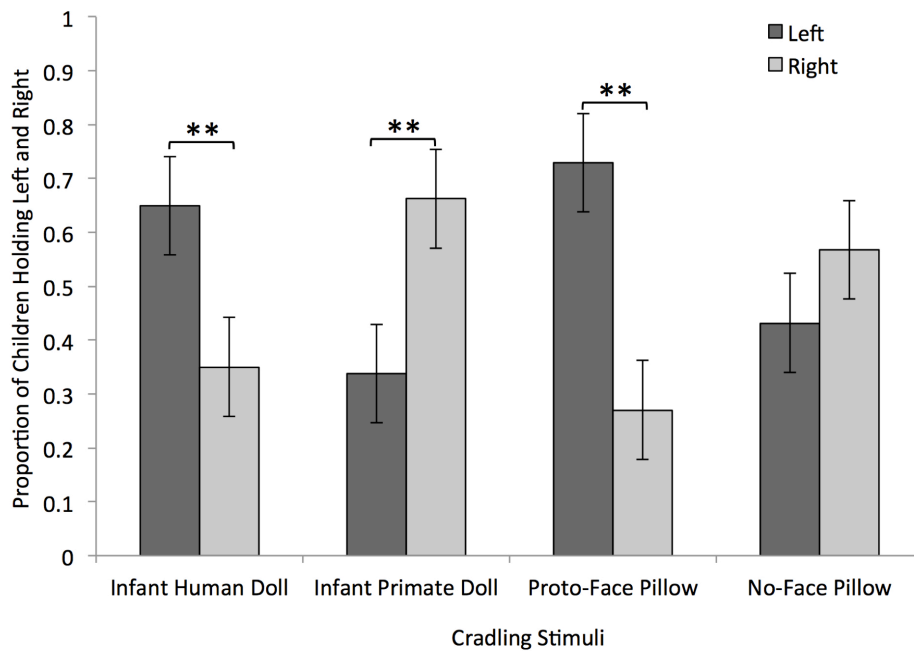
546

547   *Figure 4.* Over all proportion of cradling side for each stimulus type.

548

549   *3.1.1 Infant Human Doll*

550   Children held the human infant doll significantly more often in a left cradling position

551   than a right cradling position (P < .01). Although there were no significant differences

552   between boys' and girls' cradling behaviors, only Girls showed a significant LCB (P <

553   .05) with the reduced Ns that occur when splitting the sample into two independent

554   groups.

555

556   *3.1.2 Infant Primate Doll*

557   Children held the infant primate doll significantly more often in a right than in a left

558   cradling position (P < .01). However, boys were significantly more likely than girls to

559   hold the infant primate doll in a right side cradling position (P < .05). Moreover, only

560   boys demonstrated a significant right-sided cradling bias (P < .01) with the reduced

561   participant numbers that occurred when splitting the sample into two independent

562   groups.

563

564   *3.1.3 Proto Face Pillow*

565   Children held the proto-face pillow significantly more often in a left cradling position

566   than a right cradling position (P< .01). There were no significant differences between

567   Boys' and Girls' cradling behaviors however, only girls demonstrated a significant LCB

568   (P < .05) with the reduced participant numbers that occur when splitting the sample

569   into two independent groups.

570

571   *3.1.4 No Face Pillow*

572   Neither girls nor boys held the no-face pillow with a significant side bias.

573   Additionally, girls and boys did not differ significantly in their cradling behavior of

574   this stimulus.

575

576   No effects of trial order were identified with respect to the condition sequence in

577   which holding stimuli were presented to participants.

578

579   **Table 3** Frequencies, laterality indices and two-tailed p-values of sign-tests for

580   holding side across cradling conditions broken down by gender.

581

Condition	Infant Human Doll	Infant Primate Doll	Proto Face Pillow	No Face Pillow
Girls Left	33	18	16	12
Girls Right	16	24	5	13
Laterality Index	-.347	.143	-.524	.040
P-Value	0.0213*	NS	0.0266*	NS
Boys Left	19	7	11	7
Boys Right	12	25	5	12
Laterality Index	-.226	.563	-.375	.263
P-Value	NS	.0021*	NS	NS
Group Left	52	25	27	19
Group Right	28	49	10	25
Laterality Index	-.300	.324	-.460	.136
P-Value	.0097**	.0071**	0.0076**	NS

582

583 A chi-squared test of association indicated a significant interaction between holding

584 sides for the infant human and primate dolls, χ^2 (1, N = 67) = 8.735, p = .004.

585 Children who held the infant human doll on the left were equally likely to hold the

586 infant primate doll on the left (n = 21) or right side of their bodies (n = 20). However,

587 children who held the infant human doll on the right were significantly more likely to

588 hold the infant primate doll on the right side (n = 22) compared to the left side (n =

589 4) of their body.

590

591 *3.2 Sex, Age and Experience*

592 Statistical analyses indicated that neither school year nor mean age in months

593 interacted with holding side of the human doll for girls. However, a Mann-Whitney *U*

594 test showed that boys who held the infant human doll on the left side of their bodies

595 (Mean = 68.21, SE = 2.42) were significantly younger than boys who held the infant

596 human doll on the right side of their bodies (Mean = 77.17, SE = 2.30) (U = 56, p=

597 .018). A similar pattern was identified for Boys holding the infant primate doll. Boys

598 who held the infant primate doll on their left side (Mean = 63.57, SE = 3.48) were

599 significantly younger than Boys who held the primate doll on their right side (Mean =

600 72.83, SE = 2.04) (U = 56, p = .040). A Chi-squared test of association, however

601 indicated that boys' holding side and school year were not significant for either the

602 infant human or primate dolls, suggesting that age in months is a more sensitive

603   measure of experience than school year.

604

605   Chi-squared tests of association revealed no significant interactions between the

606   holding side of any of the cradling stimuli (infant human doll, infant primate doll,

607   proto-face pillow, no-face pillow) and experience (with or without younger sibling/s).

608   Thus, sibling experience did not appear to moderate cradling behavior in this sample

609   of children.

610

611   *3.3 Cradling side and Hand Dominance*

612   Cradling side for any of the four kinds of test stimuli was not associated with hand

613   dominance (as measured in the *Knock and Tap* task, nor was it associated with

614   laterality indices (LIS) derived from the *Pegboard task.* A Mann-Whitney *U* test

615   indicated that laterality indices derived from the *Card-lacing* task did associate with

616   cradling bias for the primate doll whereby children who held the infant primate doll

617   on the left were significantly more right-handed (Mean = .689, SE = .074) than

618   children who held the infant primate doll on the right (Mean = .351, SE = .081)

619   (U=391, p=.01). LIS did not associate with cradling bias for any of the other cradling

620   stimuli.). There were no sex differences across the hand dominance scores.

621

622   *3.4 Cradling Biases and Socio-communicative Scores*

623   A Pearson test of correlation indicated that mean scores for the social and

624   communicative survey items were highly correlated with each other, r(95) = .645, p <

625   .001. Additionally, a Pearson test of correlation indicated that social ability scores

626   were positively correlated with the frequency of correct trials from the *Knock and*

627   *Tap* task r(95) = .293, p = .004. Communicative ability scores were marginally

628   associated with the number of correct trials in the *Knock and Tap* task r(95) = .186, p

629   < .07. *Knock and Tap* and communicative ability survey scores did not significantly

630   differ between left and right infant human doll cradlers. However, a Mann-Whitney

631   *U* test indicated that children who held the infant human doll with a LCB (n=51) had

632   a significantly higher social ability score (Mean = 4.31, SE.073), compared with those

633   that held the infant human doll on the right (n = 28) (Mean = 4.14, SE.070) (U=497, p

634   = .025). Finally, infant primate doll, proto-face pillow and no-face pillow stimuli

635 cradling side did not associate with *Knock and Tap* task, social survey or
636 communication survey scores. There were no sex differences across the socio-
637 communicative scores.

638

639 **Table 4** Social and communication survey items, mean scores, and standard
640 deviations (SD) as a function of cradling the infant human doll on the left and right
641 side.

Item	Statement	Side	N	Mean	SD
1	Can talk about things that have already happened or will happen in the future with a good understanding of time, for example 'yesterday we went to visit a museum'	Left	51	4.55	0.61
		Right	28	4.36	0.73
2	Wants to please their teacher	Left	51	4.43	0.67
		Right	28	4.18	0.55
3	Is likely to follow rules	Left	51	4.29	0.73
		Right	28	4.00	0.82
4	Can use long and detailed sentences for example " We went to the park, but we came home because Mary hurt herself"	Left	51	4.41	0.75
		Right	28	4.25	0.89
5	Will share with others on their own accord	Left	50	4.28	0.67
		Right	28	4.18	0.67
6	Can communicate easily with familiar adults and with other children	Left	51	4.45	0.70
		Right	28	4.25	0.89
7	Can tell the difference between real and imaginary/pretend	Left	51	4.47	0.58
		Right	28	4.25	0.65
8	Can speak of imaginary conditions and says things like "I hope...."	Left	51	4.24	0.71
		Right	28	4.07	0.81
9	Likes to sing, dance and act	Left	51	3.94	0.76
		Right	27	3.70	0.54
10	Can take turns in longer conversations and stay on the same topic	Left	51	4.37	0.66
		Right	28	4.14	0.89
11	Prefers to play interactively with others (cooperative play), rather than playing alone (solitary play) or next to others but without interaction (parallel play)	Left	51	4.41	0.61
		Right	28	4.36	0.62
12	Engages in pretend play (e.g., role-playing alone or with others and/or using one object to represent another – for example: "This block is a telephone".)	Left	51	4.25	0.56
		Right	28	4.07	0.60
13	Engages in eye contact when speaking to others	Left	51	4.55	0.61
		Right	28	4.43	0.57
14	Describes objects and events with lots of detail	Left	50	4.26	0.85
		Right	28	4.14	0.93

642 Note: Shaded rows denote social items and non-shaded rows denote communication
643 items.

644

645 **4. Discussion**

646

647 *4.1 Cradling Behavior*
648 Despite the fact that the present results reflect children from an isolated school and
649 could represent a micro-culture specific to this school, the children who participated

650   in this study attended a Central London primary school, which drew from a diverse

651   multicultural catchment area. Moreover, the findings are consistent with previous

652   research across a range of schools and ages (see Jones, 2017). Findings from the

653   present study demonstrated a population-level LCB, supporting an early evolutionary

654   propensity for population-level left visual field and right hemisphere dominance for

655   social-emotional processing (Bourne & Todd, 2004). The presence of an early and

656   visible LCB in children was further supported by results from the proto-face and no-

657   face pillows. The proto-face pillow elicited a population-level LCB while the no-face

658   pillow (control stimulus) did not. The current findings suggest that the salience of the

659   most rudimentary face configuration (e.g., Johnson et al., 1991) is sufficient to elicit

660   a LCB in children. This finding prompts the need for further infant research, to

661   understand the role of cerebral lateralization during typical development. Neonates,

662   from birth, demonstrate a preference for faces above other types of visual stimuli

663   (Bower, 2001; Goren, Sarty, & Wu, 1975; Leppanen et al., 2007; Macchi Cassia et al.,

664   2008; Simion et al., 2001; Umiltà et al., 1996; Valenza et al., 2006), yet no studies

665   have yet to establish if a visual field bias for social stimuli exists early in

666   development.

667

668   In direct contrast to our hypothesis, children held the infant primate doll significantly

669   more often in a right versus left cradling position. One possible interpretation of this

670   finding comes from adult cradling studies, which have reported an association

671   between affective symptoms and the strength of the LCB. For example, mothers who

672   held their infants on the right side reported higher stress levels than those holding

673   on the left (Reissland et al., 2009; Vauclair & Scola, 2009). The immediate effect of

674   stress is also associated with right-holding; women who undertook a bilateral cold

675   pressor task, which significantly increased their blood pressure and heart rate, were

676   more likely to hold a doll on the right than controls (Suter, Huggenberger, &

677   Schächinger, 2007). Therefore a decline in, or reversal of, the typical LCB is

678   evidenced in adults undergoing stress, possibly, as Harris (2010) discusses, because

679   positioning the stimulus in the right visual field/left hemisphere of the holder may

680   reflect an "inaction-withdrawal" response rather than approach and engagement.

681

682 Cradling the unfamiliar primate doll might have aroused mild anxiety in our
683 participants. Indeed, some boys and girls indicated that they had found the primate
684 doll "scary". Several children were reluctant or even refused to pick it up, a response
685 not found in the 'baby doll' or 'pillow' conditions. Whilst we did not envisage that
686 the commercially available primate doll would appear frightening, it was perhaps
687 unexpected in the experimental situation and therefore increased children's anxiety.
688 Consequently, stress may have been responsible for the increased rates of right side
689 cradling in this condition.
690
691 There are other alternative interpretations. It is possible that a LCB is present only
692 for those social stimuli that represent infancy. Todd and Banjeree (2015) reported
693 that the LCB was robust for new mothers the first 12 weeks of their child's
694 development. However, evidence of a LCB became greatly reduced or disappeared
695 after approximately three months. Babies are born with underdeveloped sensory
696 and motor systems and their survival is reliant on the mother's perception of their
697 wellbeing. It is possible that children perceived the infant human doll as less than 12
698 week-old, but perceived the infant primate doll as older than 12 weeks of age.
699 Alternatively, it is possible that the LCB is triggered by species-specific stimuli. A right
700 hemisphere dominance, manifesting as a LVF advantage for social stimuli, may be a
701 response to well-familiarized stimuli. The 'expertise hypothesis' suggests that right
702 biased fusiform gyrus activity is positively correlated with the level of speciality of
703 the individual and can be elicited by face and non-face stimuli (Gauthier, Skudlarski,
704 Gore, & Anderson, 2000). Thus, it is possible that since human faces are more
705 familiar than non-human primate faces, the less familiar infant primate doll did not
706 elicit the LCB in children. However, with this interpretation, it should be taken into
707 consideration that the non-conspecific and unfamiliar proto-face pillow *did* elicit a
708 LCB in children rather than a decrease or reversal in LCB.
709
710 We found an interaction between cradling sides for the infant human and primate
711 dolls. Children who held the infant human doll on the left were equally likely to hold
712 the infant primate doll on the left or the right. However, children who held the infant
713 human doll on the right were also more likely to hold the infant primate doll on the

714   right. These findings illustrate that child behavior was sensitive to the nature of the

715   cradling stimuli. Furthermore, this pattern of results illustrates the possibility that

716   robust but disparate behavioral phenotypes can emerge in a population of typically

717   developing children.

718

719   *4.2 Sex, Age and Experience*

720   Holding side for any of the cradling stimuli was not associated with age or experience

721   of having a younger sibling, however sex difference were revealed. Boys

722   demonstrated a weaker LCB than girls for both the infant human doll and the proto

723   face pillow. Although boys held these stimuli proportionately with a left side bias,

724   the results for boys as an independent group were not significant. One

725   interpretation is that these findings represent a question of power and that larger

726   sample sizes may reveal a significant, yet reduced LCB in boys compared with girls. A

727   weaker LCB in boys may be the result from a variety of circumstances including

728   differences in sex, developmental rate and experience. Todd and Banerjee (2016)

729   suggested an effect of gender-stereotyped infant human doll, whereby boys may be

730   less inclined to interact with a baby doll. De Château and Andersson (1976)

731   suggested that girls and boys might have different developmental trajectories such

732   that boys develop an LCB later than girls. Because evidence of a LCB in men has

733   been reported in studies of fathers (Bogren, 1984; Dagenbach et al., 1988; Scola &

734   Vauclair, 2010b) and men whose professions required infant care (de Château,

735   1983), experience may play a critical role in triggering the LCB. However, in the

736   present study, boys, demonstrated an effect of age that was contrary to the

737   prediction that the occurrence of the LCB would increase with increasing age, as a

738   result of increased experience. Boys, but not girls, demonstrated a significant age

739   difference for left and right side holding of both the infant human doll and the infant

740   primate doll. Boys who held the infant human doll on the left were significantly

741   younger than those who held it on the right. The same was true for boys holding the

742   infant primate doll. The decrease in the LCB with age may reflect boys' increasing

743   disinclination to play with female-gender-typed toys. A meta-analysis conducted by

744   Todd and colleagues (2018) demonstrated that older boys played more with male-

745   gender-stereotyped toys than with female-gender-stereotyped toys compared with

746   younger boys. Future studies should consider longitudinal approaches to disentangle

747   confounds of age, experience and perhaps cultural features (e.g. school, family) that

748   may contribute to holding biases in young boys.

749

750   A significant interaction between sex and cradling side for the infant primate doll

751   revealed that boys, but not girls held the infant primate doll with a significant right

752   side cradling bias. In this study the inclusion of a doll representing an infant primate

753   doll was presented as a control stimulus for the possible reluctance of boys to

754   breach gender norms by engaging with a typical 'baby' doll (Todd & Banerjee, 2016).

755   The interpretation of a right side bias for holding the infant primate doll is discussed

756   above, however, the reason why girls revealed a significantly weaker right side bias

757   compared with boys is unclear. The weaker right side cradling bias in girls for the

758   infant primate doll may again result represent a question of power. Larger sample

759   sizes may reveal a significant right side cradling bias in girls, but why it would be

760   weaker than in boys remains to be explored. Further investigations are required to

761   better understand if and when development and experience impacts the strength of

762   a population-level LCB in males and females.

763

764   *4.3 Cradling Behavior and Hand Dominance*

765   Overall, hand classification (self report) and strength (as derived by the *Pegboard*

766   and *Cared-lacing* tasks) were not associated with cradling side of the human infant

767   doll proto-face and no-face pillows. These finding are consistent with previous

768   research demonstrating that neither self-report of hand classification, nor strength

769   of hand dominance (LIS scores) are associated with population-level LCB (Previc,

770   1991; Sieratzki & Woll, 1996, 2002; Vauclair & Donnot, 2005). Children who were not

771   right handed were equally likely as their right-handed counterparts to hold the infant

772   human doll on the left. Studies of hand dominance report that approximately 70% of

773   left-handed adults and children alike have dominant language processes in the left

774   hemisphere (e.g., Knecht et al., 2000; Szaflarski et al., 2013). These individuals, like

775   95% of right-handers will possess right hemispheres that are dominant for producing

776   and perceiving social-emotional stimuli. Therefore, the majority of right-handed and

777   left-handed individuals will express a dominant left visual field preference for

778   viewing social stimuli that is influenced by the dominant right hemisphere for

779   processing social-emotional stimuli.

780

781   Infant primate cradling side did not interact with hand classification, but did elicit

782   significantly different strength laterality index scores (LIS) for only the *Card-lacing*

783   task. Children who held the infant primate doll with a right cradling bias were

784   significantly more right-handed than children who held the infant primate doll with a

785   LCB. As an example of a bimanual coordination task, the *Card-lacing* task may be

786   revealing the more sensitive measure of hand dominance in children compared with

787   the LIS derived from the *Pegboard task* (e.g., unimanual task) (Fagard & Marks,

788   2000). One interpretation is that children perceived the infant primate doll as 'less

789   animate' and more of an object. It is possible that the infant primate doll was

790   considered an inanimate object to be held and/or manipulated by the dominant

791   hand. In support of this interpretation, the no-face pillow was also held with a right

792   side bias, although not significantly more than chance in the current sample.

793

794   *4.4 Cradling Behavior and Socio-Communicative Ability*

795   Holding side for any of the cradling stimuli was not associated with communication

796   survey scores or inhibition scores. In contrast, social ability scores were positively

797   correlated with inhibition scores, such that as social ability scores increased, so did

798   the number of correct trials for the *Knock and Tap* task. This finding suggests that

799   children with higher social ability scores possessed enhanced impulsivity control

800   compared with children with lower social ability scores. Moreover, children who held

801   the infant human doll with a LCB had significantly higher mean social ability scores

802   than children who held the infant human doll with a right cradling bias. Those

803   individuals with a predisposition to employ the left visual field for viewing social

804   stimuli may develop enhanced social processing abilities compared with their right

805   cradling biased counterparts. It is important to note that mean scores for both

806   groups of children were representative of a typically developing population. Thus the

807   difference in mean scores may represent two distinct motor/cognitive phenotypes

808   based on laterality of brain function. Further investigations of behavioral biases may

809   hold the key to a better understanding of the links between brain organization and

810 function. Interestingly, the cradling side of only the infant human doll was associated
811 with social ability scores, suggesting that conspecifics cradled on the left are
812 processed with enhanced salience, potentially resulting in enhanced social ability
813 compared with right side cradlers.

814

815 Although previous research draws an association between hand dominance and
816 hemispheric lateralization for language (e.g., Knecht et al., 2000), and reports
817 suggest that as child hand dominance increases, so does verbal ability (Leask & Crow,
818 2001), we did not find a relationship between hand dominance and the socio-
819 communication survey scores. For the present investigation, we did not test
820 specifically language ability or vocabulary size. It is likely that the communication
821 survey items did not reflect the elements of language production and
822 comprehension that are sensitive to hand dominance for manual motor tasks that
823 are cited in the literature (see Lindell & Hudry, 2013). Moreover, social and
824 communication ability survey scores were strongly positively correlated, suggesting
825 that these measures may not have revealed discrete cognitive domains.

826

827 **5. Conclusion**
828 Our results suggest that even the most basic face stimuli can elicit population-level
829 LCB in children, preferentially engaging the left visual field and the right hemisphere.
830 The robust cradling behaviors found across stimuli supports an early developmental
831 or innate predisposition for faces (for a review, see Johnson et al., 2015). However,
832 in some cases, unfamiliar or stressful stimuli can cause the LCB to be reversed.
833 Interestingly, the side of holding for *only* the conspecific face stimuli was associated
834 with social ability scores, suggesting that the exposure to *human* faces is important
835 for social cognitive development in children.

836

837 The findings from this study may have reach beyond cradling investigations.
838 Research into specific populations with difficulties perceiving faces have found
839 decreased attention to face stimuli (Jones & Klin, 2013) and disrupted right
840 hemisphere activity during face processing (Keehn, Vogel-Farley, Tager-Flusberg &
841 Nelson, 2015). Individuals diagnosed with autistic spectrum disorders have been

842 reported to demonstrate face processing deficits associated with diminished

843 activation of the right fusiform gyrus (for review, see Curby, Willenbockel, Tanaka &

844 Schultz; 2010) and the absence of a LVF bias for face faces in infants (Dundas,

845 Gastgeb & Strauss, 2012). Going forward, a better understanding of the associations

846 between behavioral biases, brain organization/function and cognitive ability during

847 childhood is important identifying and tracking behavioral phenotypes to allow us to

848 make predictions about developmental trajectories across both typical and atypical

849 populations.

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877   **<u>References</u>**

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