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1 Social environment elicits lateralized navigational paths in two populations of
2 typically developing children

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25

26 **Abstract**

27 The current study provides the first evidence of human lateralized navigation of a
28 social space within a naturalistic environment. We employed a quantitative,
29 observational approach and report on a detailed set of nearly 700 independent
30 navigational routes from two separate child populations consisting of over 300
31 typically developing children, aged five to fourteen years. The navigational path was
32 considered across the sagittal plane (left, right) around three distinct target types
33 (peer, adult and object). Both child populations expressed a significant bias for
34 choosing a rightward navigational path around a human target (e.g. peer, adult) and no
35 lateral preference for navigation around fixed, inanimate objects. A rightward
36 navigational path provides an advantage for the left visual field and the right
37 hemisphere, facilitating both the production and perception of social-emotion stimuli.
38 The findings are consistent with evidence from studies of non-human animal species
39 demonstrating that the social environment elicits predictable lateralized behavior, and
40 support an early evolutionary delineation of functional processing by the two
41 hemispheres.

42

43

44 **Keywords**

45 Laterality, Cerebral Lateralization, Social Environment, Children

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51 **1. Introduction**

52

53 A growing body of evidence across a range of animal species demonstrates a bias to
54 keep conspecifics situated on their left side. A left eye bias to monitor conspecifics is
55 widespread across a range of vertebrates including: fish (De Santi, et al., 2001;
56 Sovrano et al., 2001), toads (Robins et al., 1998), lizards (Deckel, 1995; Hews and
57 Worthington, 2001), pigeons (Nagy et al., 2010), chicks (Vallortigara, 1992;
58 Vallortigara and Andrew, 1991) and beluga whales (Karenina et al., 2010), and may
59 represent a common evolutionary behavioral manifestation reflective of a right
60 hemisphere dominance for processing social stimuli and arousing situations (for a
61 review, see Rosa Salva et al., 2012). The findings from these studies support a
62 hypothesis that lateralized perceptual behaviors may have derived from an early
63 delineation of a right hemisphere dominance for responding to unexpected and
64 behaviorally relevant stimuli (e.g. predator) and a left hemisphere dominance for well
65 learned sequences of actions (e.g. feeding) (MacNeilage et al., 2009; Rogers, 2000a;
66 Rogers et al., 2013). This type of asymmetric behavioral activity might have an
67 adaptive value, facilitating simple reflexive and automatic responses to increase the
68 survival of individuals (Rutherford and Lindell, 2011). The appropriation of
69 specialized processing to operate in parallel within the left and right hemispheres is
70 thought to facilitate neural efficiency: allowing different functions to operate in
71 parallel, decreasing the duplication of functioning across hemispheres and eliminating
72 the initiation of simultaneous and incompatible responses (Rogers et al., 2004;
73 Tommasi, 2009; Vallortigara and Rogers, 2005).

74

75 Right hemisphere dominance patterns have been reported for face perception and
76 social recognition in a range of animal species. For example, a left gaze bias for face
77 perception (e.g. looking time of centrally presented faces) has been reported in: sheep
78 (Peirce et al., 2000), dogs and rhesus monkeys (Guo et al., 2009), chimpanzees
79 (Morris and Hopkins, 1993), and humans (behavioral study: Burt and Perret, 1997;
80 neuro-imaging: Kanwisher et al., 1998). A left motor bias (right hemisphere
81 dominance) has also been reported for the production of facial expressions in
82 marmosets (Hook-Costigan and Rogers, 1998) macaques (Hauser, 1993), baboons
83 (Wallez and Vauclair, 2011) and in chimpanzees (Fernández-Carriba et al., 2002),
84 indicating that both the perception and production of emotions may be preferentially
85 controlled by the right hemisphere.

86

87 Nonhuman primates demonstrate an excellent animal model for understanding the
88 evolutionary emergence of lateralized behaviors related to the social environment.
89 There is little naturalistic evidence from field studies to align with those from other
90 animal species discussed earlier. However, studies that consider spontaneous
91 naturalistic, species-specific encounters in nonhuman primates have reported a left
92 visual preference (right hemisphere dominance) during aggressive encounters in
93 gelada baboons (Casperd and Dunbar, 1996) and in a zoo-housed group of mangabeys
94 during spontaneous approach behaviors (Baraud et al., 2009), suggesting that
95 rudimentary primitive avoidance behaviors controlled by the right hemisphere may
96 have contributed to the emergence of negative emotions (Vallortigara and Rogers,
97 2005; Vallortigara et al., 2011).

98

99 Evidence from great ape studies has highlighted the importance of the social
100 environment in modulating behavior during social interactions and situations
101 involving increased arousal. High-ranking chimpanzees were approached significantly
102 more frequently from their left visual hemifield suggesting the facilitation for the
103 rapid identification of facial expressions and predictability of behaviors by the right
104 hemisphere (Fernández-Carriba et al., 2002). Left biased motor asymmetries have
105 also been associated with self-directed behaviours. For example, rehabilitated
106 orangutans exhibited a significant group-level lateralized preference for left-handed
107 scratching and for the fine manipulation of parts of the face (Rogers and Kaplan,
108 1995), and while self-directed scratching showed no hand preference in chimpanzees,
109 there was a significant bias for scratching on the left side of the body (Hopkins,
110 2006). Forrester and colleagues (2011; 2012) noted an increase in left hand (right
111 hemisphere) activity during the observation of naturalistic unimanual hand actions for
112 self-directed behaviors and hand actions directed towards social partners compared
113 with hand actions directed towards objects. In all cases, the authors postulated a right
114 hemisphere dominant role in the processing of emotive and arousal-increasing stimuli.
115

116 A recent study by Quaresmini et al. (2014) aligns most closely with the evolution of
117 social lateralization studies that indicate a preference to keep conspecifics proximally
118 situated with a left visual field advantage during spontaneous natural behaviors.

119 Observational focal sampling of spontaneous social behaviors in a family group of
120 western lowland gorillas (*Gorilla gorilla gorilla*) and in a colony of captive zoo-living
121 chimpanzees (*Pan troglodytes*), revealed group-level biases in both gorillas and
122 chimpanzees (trend) for keeping conspecifics proximally situated to the left side of
123 the focal individual compared with the right side. The authors suggest that lateral

124 positioning is likely to reflect a right hemisphere specialization for a heightened state
125 of arousal associated with the detection of faces and facial expressions. These studies
126 support the evolutionary perspective that the right hemisphere retains dominant
127 control for behaviors associated with individual recognition, decoding other's
128 intentions, and navigating the social hierarchical system (for a review, see Rosa Salva,
129 et al., 2012). Moreover, findings from these studies suggest that the social
130 environment may have been a critical pressure in aligning population behavior for
131 predator defense and for cooperation (Ghirlanda et al., 2009; Ghirlanda and
132 Vallortigara, 2004; Vallortigara and Rogers, 2005).

133

134 The study of human emotion processing has a long history in the literature, dominated
135 by two prevailing theories of cerebral lateralization. The right hemisphere hypothesis
136 (e.g. Borod et al., 1998; Campbell, 1982) proposes that the right hemisphere is solely
137 responsible for the processing of emotion. Alternatively, the valence hypothesis (e.g.
138 Davidson, 1995) purports that both the right and the left hemispheres are involved in
139 affect processing, such that the left hemisphere is dominant for positive affect and the
140 right hemisphere is dominant for negative affect. Although animal studies do not
141 contradict the right hemisphere theory from an evolutionary perspective, evidence
142 from non-human animal approach/avoidance behaviors tend to be more parsimonious
143 with the valence theory. For example, birds (Franklin III and Lima, 2001; Koboroff et
144 al., 2008; Rogers, 2000b), lizards (in the laboratory: Bonati et al., 2013; in the wild:
145 Martín et al., 2010), and toads (Lippolis et al., 2002), have all been shown to manifest
146 a left eye preference for well-learned sequences of actions (e.g. predator monitoring),
147 but conversely, they demonstrate a rightward preference for responding to urgent
148 situations (e.g. escaping from the dangerous stimulus). Additionally, in great apes, a

149 recent eye preference study found a left visual field /right hemisphere advantage for
150 negative stimuli and right visual field/left hemisphere advantage for positive stimuli
151 for viewing pictures (Braccini et al., 2012).

152

153 In humans, the valence theory model has gained some support from laboratory
154 investigations. For example, the right hemisphere demonstrated greater activation
155 than the left hemisphere in the region of the superior temporal sulcus associated with
156 the processing of an approaching stranger with directed mutual gaze (Pelphrey et al.,
157 2004). Additionally, right-handed people have been shown to respond more quickly to
158 unexpected stimuli with their left hand compared with their right hand (e.g. Fox et al.,
159 2006 reference). And, nonverbal, emotional vocalizations (e.g. cries and shouts) have
160 demonstrated a right-hemisphere activation dominance in contrast to emotionally
161 neutral vocalizations, which were biased to the left hemisphere (for a review see,
162 Scott et al., 2009). Moreover, studies of brain damaged individuals suggest that
163 people who incur left hemisphere trauma are more likely to become depressed than
164 those who incur injury to the right hemisphere (e.g. MacHale et al., 1998). One theory
165 is that the right hemisphere possesses a sensitive attentional system that responds
166 selectively for novel and dangerous stimuli in the environment (for a review see Fox
167 et al., 2006).

168

169 Social laterality has been little studied in the naturalistic behaviours of humans. The
170 data that exists in this area suggest that mothers and fathers prefer to position their
171 offspring on left side of their bodies (Nakamichi and Takeda, 1995; Scola and
172 Vauclair, 2010a; Vauclair and Scola, 2009). While it is not proven that left arm
173 cradling is associated with cerebral lateralization for the perception of emotion, the

174 physical positioning is thought to enable social-emotional feedback stimuli (e.g. gaze,
175 facial expression) to maintain a direct route to the right hemisphere (for a review, see
176 Scola and Vauclair, 2010b). This interpretation gains support from a study that
177 indicated that children who were held with a left arm preference demonstrated a
178 typical left visual field (right hemisphere) bias for faces on chimeric face tests,
179 whereas individuals who were held with a right-arm lacked a visual field bias
180 (Vervloed, et al., 2011). The ramification of hemispheric bilateralization for social-
181 emotional processing has yet to be explored within the scope of cognitive
182 development.

183

184 The influence of the social environment on lateralized behaviors has now been
185 investigated across a wide variety of animal species. New evidence suggests that the
186 social environment elicits lateralized motor behavior. Currently, there is a paucity of
187 data relating to how humans navigate their environmental space, and investigations
188 that consider the naturalistic context of the individual are rare. The current study
189 provides the first report of lateralized social behaviors elicited by two populations of
190 human children during naturalistic play. Extending upon human and animal studies of
191 social laterality, this study observed the natural and spontaneous lateral navigational
192 routes of children around adults, peers and objects in order to consider cerebral
193 lateralization and lateralized motor action within the social environment.

194

195 **2. Methods**

196

197 *2.1 Participants*

198

199 All of the participants were observed unobtrusively in a naturalistic environment
200 using an opportunity sampling method. Data relating to gender, age and handedness
201 were not recorded. Only children were included in the study because it limits the
202 influence of learnt social and cultural conventions. The procedures for this study
203 involving human participants were in accordance with ethical standards of the
204 responsible committee on human experimentation (institutional and national) and with
205 the spirit of the Helsinki Declaration of 1975, as revised in 2000.

206

207 *2.1.1 Participants C-Population*

208

209 C-Population consisted of 101 individuals. Individuals were observed within a public
210 play area, which contained equipment suitable for children up to a maximum of
211 fourteen years of age.

212

213 *2.1.2 Participants M-Population*

214

215 M-Population consisted of approximately 200 children aged between four and eleven
216 years. Individuals were observed within a school playground, (St Catherine's Primary
217 School, Kent) which contained equipment suitable for children school children aged
218 between 5-11 years.

219

220 *2.2 Data capture*

221

222 The study considered the observed naturalistic play behaviours of two separate
223 populations of children (C-Population and M-Population) at different sites on

224 different dates and independently coded by two different raters (C and M). Data for
225 C-Population were collected between March and April in 2013, while data for M-
226 Population were collected between the January and February 2014.

227

228 Children were observed during naturalistic play for the assessment of navigational
229 behaviours within the social environment. C-Population data were recorded over 3
230 visits for an average of 60 minutes visit, equalling a total of approximately 180
231 minutes and 340 events. M-Population data were recorded over 7 visits for an average
232 of 25 minutes per visit equalling a total of 175 minutes and 348 events.

233

234 *2.3 Data Coding*

235

236 Two independent raters recorded observational data (C, M). Only information
237 specifically related to lateral direction on a sagittal plane was recorded. A pen and
238 paper recording method was adopted using a preformatted spread-sheet indicating
239 variables to be recorded. The lateral path (left, right) that the observed child chose to
240 navigate around stationary target (peer, adult, object) on order to reach a position
241 accessible by a clear path on both sides and of approximately equal distance achieved
242 by a left or right path was noted (Figure 1).

243

244 Figure 1.

245

246 - Insert Figure 1 -

247

248 Figure 1 illustrates the two possible navigational paths (left, right) of the observed
249 child around a target (in this case a peer). A left or right navigational path inherently
250 dictates the side of the body that will be presented to the individual around which the
251 observed child navigates. In this case, a left navigational path presents the right side
252 of the body and right visual field to the peer. A right navigational path presents the
253 left side of the body and the left visual field to the peer.

254

255 Navigation around both peers and adults was considered. Additionally, a control
256 condition was employed utilizing fixed, inanimate objects (e.g. large rubbish bin) in
257 order to create the following 2x3 factor design: navigate left (adult), navigate left
258 (peer), navigate left (object), navigate right (adult), navigate right (peer), navigate
259 right (object). To control for confounding factors, each navigational path of an
260 observed child began at a neutral point (approximately equidistant left or right from
261 the desired location), and proceeded around (left or right) one of the target categories
262 (adult, peer, object). The observed child and the target (peer, adult) were required to
263 have directed gaze. If the observed child was navigating around a peer or adult that
264 was facing away (gaze averted or obscured), the trial was excluded. Additionally, if a
265 child began navigation from an ambiguous position (i.e. not equidistant from the
266 desired goal location), the event was excluded from the analysis. Each navigational
267 path was equal to one frequency point. In line with Quaresmini et al. (2014), to ensure
268 that the relative presence of the social partner was influencing the positioning of the
269 focal subject, we adopted an approximate distance of less than 3 m or less between the
270 child being observed and the social partners.

271

272 Data collection method varied slightly between the two populations of children. For
273 C-Population, a focal sampling approach was employed. Each focal follow lasted two
274 minutes in duration. Data were included to the dataset if two minutes of continuous
275 observation was completed. Stationery object targets consisted of a tree, a rubbish bin
276 and an ornamental rock and remained consistent across all data collection visits.
277 These objects were fixed at the entry point of the playground and required lateral
278 navigation to access the playground equipment. These fixed items were chosen
279 because they presented equal opportunity for navigation around both sides.
280
281 M-Population data collection consisted of an opportunity sampling of an entire school
282 population. Each data point was collected based around a stationery target (adult,
283 peer, object) used as a reference location. It was necessary that animate targets
284 remained stationery throughout the observed child's navigational path to their desired
285 location. Stationery object target was a rubbish bin. This object and its location
286 remained consistent throughout all seven data collection visits. The bin was located at
287 the intersection of two discrete segments of the playground, such that it was
288 circumnavigated by the majority of the children during any given play session.

289

290 *2.4 Data Analysis*

291

292 A laterality index (LI), binomial tests, z-scores approximations of the binomial scores
293 and a chi-square test were performed to assess population-level lateral biases.

294 Additionally, peer and adult frequencies were collapsed within and between the two
295 populations in order to consider the influence of animate and inanimate targets (e.g.

296 Forrester et al. 2011; 2012; 2013). LI scores were calculated using the formula [LI =

297 $(R-L)/(R+L)$], with R and L being the frequency counts for right and left navigational
298 path frequency counts. LI values vary on a continuum between -1.0 and +1.0, where
299 the sign indicates the direction of hand preference. When R=L, then LI is zero.
300 Positive values reflect a right navigational path preference while negative values
301 reflect a left navigational path preference. The absolute value depicts the strength of
302 hand preference. The directional strength of navigational path for each population was
303 calculated using z-scores such that a population were left navigational path biased
304 when $z \leq -1.96$, right navigational path biased when $z \geq 1.96$ and ambi-preferent for
305 path direction when $-1.96 < z < 1.96$. All statistical tests were two-tailed ($\alpha < .05$).

306

307 **3. Results**

308

309 Raw frequencies, binomial approximations of z-scores for each population and HI
310 scores are presented in Table 1 by population (M Population, C Population and
311 populations combined). Factors are displayed by target condition (peer, adult, object)
312 and side (left, right).

313

314 Table 1 demonstrates raw frequencies, binomial approximations of z-scores and HI
315 scores of unimanual lateralized hand actions.

316

317 - Insert Table 1 -

318

319 Because the binomial tests indicated that children navigated around both peers and
320 adults with a significant bias of presenting their left side, in both populations, these
321 two levels were collapsed for further statistical tests. A 2x2 chi-square test was

322 conducted on each population to consider target (human, object) and side (left, right).
323 The M-Population revealed a significant interaction between target and side such that
324 the children were biased towards a rightward navigational path around a peer, where
325 as navigation around an object did not elicit a lateral bias $\chi^2(1, N = 101) = 5.27, p =$
326 $.022$. Likewise, the C-Population revealed a significant interaction between target and
327 side such that the children were biased towards a rightward navigational path around a
328 peer, where as navigation around an object did not elicit a lateral bias $\chi^2(1, N = 200)$
329 $= 11.7, p = .001$ (Figure 2).

330

331 Figure 2.

332

333 - Insert Figure 2 -

334

335 Figure 2 demonstrates the total frequencies by each population for target type (human,
336 object) and navigation path (left, right).

337

338 Since both populations resulted in a significant bias for children choosing a right path
339 to navigate human targets, a further chi-square test was conducted on the pooled data
340 from both populations to demonstrate the robustness of the pattern, $\chi^2(1, N = 301) =$
341 $20.22, p < .000$ (Figure 3).

342

343 Figure 3.

344

345 - Insert Figure 3 -

346

347 Figure 3 illustrates the total frequencies by the combined population for target type
348 (human, object) and navigation path (left, right).

349

350 **4. Discussion**

351

352 The present study considered the lateral navigational paths of children within a
353 naturalistic setting to align with investigations of social lateralization in observational
354 animal studies. Two populations of children were assessed by different observers at
355 different locations, and at different times. Analyses revealed that both populations
356 expressed a significant population-level bias for choosing a rightward navigational
357 path around a human compared with a leftward navigational path. Additionally,
358 neither population expressed a significant bias for a lateral preference when
359 navigating around an object. These findings are to be considered in light of
360 evolutionary theories for cerebral lateralization.

361

362 A bias for a right navigational path inherently implies that the navigating child is
363 presenting the stationary target with the left side of the body. This social positing
364 could impact upon both the production and perception of emotion processing. In the
365 first instance, a bias to keep conspecifics on the left side inherently provides an
366 advantage for viewing social stimuli with the left visual field. The left visual field
367 would provide the most efficient route to the right hemisphere for processing identity,
368 intention and angry or fearful facial expressions. This is consistent with animal
369 studies that have demonstrated a left eye/right hemisphere preference bias for to
370 monitoring familiar versus unfamiliar conspecifics (domestic chick: Deng and Rogers,
371 2002; Vallortigara and Andrew, 1991; Vallortigara et al., 2001; fish: Brown et al.,

372 2007; Sovrano, 2004; chimpanzees and gorillas: Quaresmini et al. 2014).

373 Additionally, a bias of the left visual field/right hemisphere has been reported in

374 recognizing faces and facial expressions in both apes (Morris and Hopkins, 1993) and

375 humans (De Renzi et al., 1994; Kanwisher et al., 1998). Within this context, exposing

376 the left side of the body to conspecifics might be advantageous during novel or urgent

377 situations to execute physical behaviors for protection and locomotion escape

378 behaviors. In the second instance, the left side of the face in non-human primates has

379 been reported to display emotive expression both earlier and more intensely than the

380 right side of the face (Fernández-Carriba et al., 2002; Hauser, 1993; Hook-Costigan

381 and Rogers, 1998). This lateral positioning may reflect a strategy to clearly display

382 arousal status in order to inhibit extreme aggressive behavioral responses (Baraud et

383 al., 2009).

384

385 Although approaching and withdrawing behaviours are well documented across

386 animal species (Davidson et al., 1990; Quaranta et al., 2007; Siniscalchi et al., 2013),

387 little is still known about how this behavior manifests in modern humans. Modern

388 humans represent an animal species with an extremely complex social system. Many

389 of our conscious motor actions related to approaching individuals are shaped and

390 influenced by culture and social convention (e.g. hand shakes, kissing, etc.). However,

391 our automatic motor actions may still represent evolutionary primitive patterns of

392 behavior that are underpinned by cerebral specialization of the two hemispheres.

393 Moreover, the display of these population-level lateralized behaviours (e.g. bias for

394 keeping conspecifics in the left visual field) may be rooted in social species and

395 facilitates the social communication and the prediction of social responses (Ghirlanda

396 and Vallortigara, 2004; Vallortigara and Rogers, 2005).

397

398 Studies of cerebral lateralization indicate that the dominant functions are not solely
399 processed by a single hemisphere. For example, studies of processing social stimuli
400 also indicate small contributions from the left hemisphere: Meng et al., 2012),
401 monkeys (Broad et al., 2000; Guo et al., 2009; Hamilton and Vermeire, 1988; Pinsk et
402 al., 2005), dogs (Guo et al., 2009), and sheep (Peirce et al., 2000; Peirce and Kendrik,
403 2002). Therefore, there are limitations to the extent with which we can attribute a
404 single function to a single hemisphere. Additionally, more detailed studies on
405 lateralized motor biases are necessary at the individual level to shed further light on
406 the association between cerebral lateralization of function and contralateral motor
407 action. Nevertheless, evidence from a wide range of animal species of hemispheric
408 dominance for specific functions has proven to be an informative behavioral marker
409 of brain organization (e.g. MacNeilage et al. 2009).

410

411 Understanding how individuals navigate social networks may shed light on how and
412 which environmental pressures helped to shape modern human social behavior.

413 Specifically, the environment may have been a critical pressure in aligning population
414 behavior for social actions requiring cooperation (Ghirlanda et al., 2009; Ghirlanda
415 and Vallortigara, 2004; Vallortigara and Rogers, 2005). Additionally, future studies
416 may consider the evaluation of the cognitive abilities of individuals with lateralized
417 social navigation behaviors compared with individuals who do not express lateralized
418 social navigation behaviors. It has been reported that stronger lateral motor
419 dominance (e.g. handedness) correlates with the successful hemispheric specialization
420 for language (Toga and Thompson, 2003). The present findings suggest that the
421 environment elicits predictable behavior for social navigation that facilitates both the

422 production and perception of social-emotion stimuli in typically developing children.
423 Therefore, the identification of individuals lacking lateralized social navigations
424 behaviors may allow for the early targeting of individuals with cognitive delays
425 and/or disorders.

426

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432

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1 Social environment elicits lateralized navigational paths in two populations of
2 typically developing children

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25

26 **Abstract**

27 The current study provides the first evidence of human lateralized navigation of a
28 social space within a naturalistic environment. We employed a quantitative,
29 observational approach and report on a detailed set of nearly 700 independent
30 navigational routes from two separate child populations consisting of over 300
31 typically developing children, aged five to fourteen years. The navigational path was
32 considered across the sagittal plane (left, right) around three distinct target types
33 (peer, adult and object). Both child populations expressed a significant bias for
34 choosing a rightward navigational path around a human target (e.g. peer, adult) and no
35 lateral preference for navigation around fixed, inanimate objects. A rightward
36 navigational path provides an advantage for the left visual field and the right
37 hemisphere, facilitating both the production and perception of social-emotion stimuli.
38 The findings are consistent with evidence from studies of non-human animal species
39 demonstrating that the social environment elicits predictable lateralized behavior, and
40 support an early evolutionary delineation of functional processing by the two
41 hemispheres.

42

43

44 **Keywords**

45 Laterality, Cerebral Lateralization, Social Environment, Children

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51 **1. Introduction**

52

53 A growing body of evidence across a range of animal species demonstrates a bias to
54 keep conspecifics situated on their left side. A left eye bias to monitor conspecifics is
55 widespread across a range of vertebrates including: fish (De Santi, et al., 2001;
56 Sovrano et al., 2001), toads (Robins et al., 1998), lizards (Deckel, 1995; Hews and
57 Worthington, 2001), pigeons (Nagy et al., 2010), chicks (Vallortigara, 1992;
58 Vallortigara and Andrew, 1991) and beluga whales (Karenina et al., 2010), and may
59 represent a common evolutionary behavioral manifestation reflective of a right
60 hemisphere dominance for processing social stimuli and arousing situations (for a
61 review, see Rosa Salva et al., 2012). The findings from these studies support a
62 hypothesis that lateralized perceptual behaviors may have derived from an early
63 delineation of a right hemisphere dominance for responding to unexpected and
64 behaviorally relevant stimuli (e.g. predator) and a left hemisphere dominance for well
65 learned sequences of actions (e.g. feeding) (MacNeilage et al., 2009; Rogers, 2000a;
66 Rogers et al., 2013). This type of asymmetric behavioral activity might have an
67 adaptive value, facilitating simple reflexive and automatic responses to increase the
68 survival of individuals (Rutherford and Lindell, 2011). The appropriation of
69 specialized processing to operate in parallel within the left and right hemispheres is
70 thought to facilitate neural efficiency: allowing different functions to operate in
71 parallel, decreasing the duplication of functioning across hemispheres and eliminating
72 the initiation of simultaneous and incompatible responses (Rogers et al., 2004;
73 Tommasi, 2009; Vallortigara and Rogers, 2005).

74

75 Right hemisphere dominance patterns have been reported for face perception and
76 social recognition in a range of animal species. For example, a left gaze bias for face
77 perception (e.g. looking time of centrally presented faces) has been reported in: sheep
78 (Peirce et al., 2000), dogs and rhesus monkeys (Guo et al., 2009), chimpanzees
79 (Morris and Hopkins, 1993), and humans (behavioral study: Burt and Perret, 1997;
80 neuro-imaging: Kanwisher et al., 1998). A left motor bias (right hemisphere
81 dominance) has also been reported for the production of facial expressions in
82 marmosets (Hook-Costigan and Rogers, 1998) macaques (Hauser, 1993), baboons
83 (Wallez and Vauclair, 2011) and in chimpanzees (Fernández-Carriba et al., 2002),
84 indicating that both the perception and production of emotions may be preferentially
85 controlled by the right hemisphere.

86

87 Nonhuman primates demonstrate an excellent animal model for understanding the
88 evolutionary emergence of lateralized behaviors related to the social environment.
89 There is little naturalistic evidence from field studies to align with those from other
90 animal species discussed earlier. However, studies that consider spontaneous
91 naturalistic, species-specific encounters in nonhuman primates have reported a left
92 visual preference (right hemisphere dominance) during aggressive encounters in
93 gelada baboons (Casperd and Dunbar, 1996) and in a zoo-housed group of mangabeys
94 during spontaneous approach behaviors (Baraud et al., 2009), suggesting that
95 rudimentary primitive avoidance behaviors controlled by the right hemisphere may
96 have contributed to the emergence of negative emotions (Vallortigara and Rogers,
97 2005; Vallortigara et al., 2011).

98

99 Evidence from great ape studies has highlighted the importance of the social
100 environment in modulating behavior during social interactions and situations
101 involving increased arousal. High-ranking chimpanzees were approached significantly
102 more frequently from their left visual hemifield suggesting the facilitation for the
103 rapid identification of facial expressions and predictability of behaviors by the right
104 hemisphere (Fernández-Carriba et al., 2002). Left biased motor asymmetries have
105 also been associated with self-directed behaviours. For example, rehabilitated
106 orangutans exhibited a significant group-level lateralized preference for left-handed
107 scratching and for the fine manipulation of parts of the face (Rogers and Kaplan,
108 1995), and while self-directed scratching showed no hand preference in chimpanzees,
109 there was a significant bias for scratching on the left side of the body (Hopkins,
110 2006). Forrester and colleagues (2011; 2012) noted an increase in left hand (right
111 hemisphere) activity during the observation of naturalistic unimanual hand actions for
112 self-directed behaviors and hand actions directed towards social partners compared
113 with hand actions directed towards objects. In all cases, the authors postulated a right
114 hemisphere dominant role in the processing of emotive and arousal-increasing stimuli.
115

116 A recent study by Quaresmini et al. (2014) aligns most closely with the evolution of
117 social lateralization studies that indicate a preference to keep conspecifics proximally
118 situated with a left visual field advantage during spontaneous natural behaviors.

119 Observational focal sampling of spontaneous social behaviors in a family group of
120 western lowland gorillas (*Gorilla gorilla gorilla*) and in a colony of captive zoo-living
121 chimpanzees (*Pan troglodytes*), revealed group-level biases in both gorillas and
122 chimpanzees (trend) for keeping conspecifics proximally situated to the left side of
123 the focal individual compared with the right side. The authors suggest that lateral

124 positioning is likely to reflect a right hemisphere specialization for a heightened state
125 of arousal associated with the detection of faces and facial expressions. These studies
126 support the evolutionary perspective that the right hemisphere retains dominant
127 control for behaviors associated with individual recognition, decoding other's
128 intentions, and navigating the social hierarchical system (for a review, see Rosa Salva,
129 et al., 2012). Moreover, findings from these studies suggest that the social
130 environment may have been a critical pressure in aligning population behavior for
131 predator defense and for cooperation (Ghirlanda et al., 2009; Ghirlanda and
132 Vallortigara, 2004; Vallortigara and Rogers, 2005).

133

134 The study of human emotion processing has a long history in the literature, dominated
135 by two prevailing theories of cerebral lateralization. The right hemisphere hypothesis
136 (e.g. Borod et al., 1998; Campbell, 1982) proposes that the right hemisphere is solely
137 responsible for the processing of emotion. Alternatively, the valence hypothesis (e.g.
138 Davidson, 1995) purports that both the right and the left hemispheres are involved in
139 affect processing, such that the left hemisphere is dominant for positive affect and the
140 right hemisphere is dominant for negative affect. Although animal studies do not
141 contradict the right hemisphere theory from an evolutionary perspective, evidence
142 from non-human animal approach/avoidance behaviors tend to be more parsimonious
143 with the valence theory. For example, birds (Franklin III and Lima, 2001; Koboroff et
144 al., 2008; Rogers, 2000b), lizards (in the laboratory: Bonati et al., 2013; in the wild:
145 Martín et al., 2010), and toads (Lippolis et al., 2002), have all been shown to manifest
146 a left eye preference for well-learned sequences of actions (e.g. predator monitoring),
147 but conversely, they demonstrate a rightward preference for responding to urgent
148 situations (e.g. escaping from the dangerous stimulus). Additionally, in great apes, a

149 recent eye preference study found a left visual field /right hemisphere advantage for
150 negative stimuli and right visual field/left hemisphere advantage for positive stimuli
151 for viewing pictures (Braccini et al., 2012).

152

153 In humans, the valence theory model has gained some support from laboratory
154 investigations. For example, the right hemisphere demonstrated greater activation
155 than the left hemisphere in the region of the superior temporal sulcus associated with
156 the processing of an approaching stranger with directed mutual gaze (Pelphrey et al.,
157 2004). Additionally, right-handed people have been shown to respond more quickly to
158 unexpected stimuli with their left hand compared with their right hand (e.g. Fox et al.,
159 2006 reference). And, nonverbal, emotional vocalizations (e.g. cries and shouts) have
160 demonstrated a right-hemisphere activation dominance in contrast to emotionally
161 neutral vocalizations, which were biased to the left hemisphere (for a review see,
162 Scott et al., 2009). Moreover, studies of brain damaged individuals suggest that
163 people who incur left hemisphere trauma are more likely to become depressed than
164 those who incur injury to the right hemisphere (e.g. MacHale et al., 1998). One theory
165 is that the right hemisphere possesses a sensitive attentional system that responds
166 selectively for novel and dangerous stimuli in the environment (for a review see Fox
167 et al., 2006).

168

169 Social laterality has been little studied in the naturalistic behaviours of humans. The
170 data that exists in this area suggest that mothers and fathers prefer to position their
171 offspring on left side of their bodies (Nakamichi and Takeda, 1995; Scola and
172 Vauclair, 2010a; Vauclair and Scola, 2009). While it is not proven that left arm
173 cradling is associated with cerebral lateralization for the perception of emotion, the

174 physical positioning is thought to enable social-emotional feedback stimuli (e.g. gaze,
175 facial expression) to maintain a direct route to the right hemisphere (for a review, see
176 Scola and Vauclair, 2010b). This interpretation gains support from a study that
177 indicated that children who were held with a left arm preference demonstrated a
178 typical left visual field (right hemisphere) bias for faces on chimeric face tests,
179 whereas individuals who were held with a right-arm lacked a visual field bias
180 (Vervloed, et al., 2011). The ramification of hemispheric bilateralization for social-
181 emotional processing has yet to be explored within the scope of cognitive
182 development.

183

184 The influence of the social environment on lateralized behaviors has now been
185 investigated across a wide variety of animal species. New evidence suggests that the
186 social environment elicits lateralized motor behavior. Currently, there is a paucity of
187 data relating to how humans navigate their environmental space, and investigations
188 that consider the naturalistic context of the individual are rare. The current study
189 provides the first report of lateralized social behaviors elicited by two populations of
190 human children during naturalistic play. Extending upon human and animal studies of
191 social laterality, this study observed the natural and spontaneous lateral navigational
192 routes of children around adults, peers and objects in order to consider cerebral
193 lateralization and lateralized motor action within the social environment.

194

195 **2. Methods**

196

197 *2.1 Participants*

198

199 All of the participants were observed unobtrusively in a naturalistic environment
200 using an opportunity sampling method. Data relating to gender, age and handedness
201 were not recorded. Only children were included in the study because it limits the
202 influence of learnt social and cultural conventions. The procedures for this study
203 involving human participants were in accordance with ethical standards of the
204 responsible committee on human experimentation (institutional and national) and with
205 the spirit of the Helsinki Declaration of 1975, as revised in 2000.

206

207 *2.1.1 Participants C-Population*

208

209 C-Population consisted of 101 individuals. Individuals were observed within a public
210 play area, which contained equipment suitable for children up to a maximum of
211 fourteen years of age.

212

213 *2.1.2 Participants M-Population*

214

215 M-Population consisted of approximately 200 children aged between four and eleven
216 years. Individuals were observed within a school playground, (St Catherine's Primary
217 School, Kent) which contained equipment suitable for children school children aged
218 between 5-11 years.

219

220 *2.2 Data capture*

221

222 The study considered the observed naturalistic play behaviours of two separate
223 populations of children (C-Population and M-Population) at different sites on

224 different dates and independently coded by two different raters (C and M). Data for
225 C-Population were collected between March and April in 2013, while data for M-
226 Population were collected between the January and February 2014.

227

228 Children were observed during naturalistic play for the assessment of navigational
229 behaviours within the social environment. C-Population data were recorded over 3
230 visits for an average of 60 minutes visit, equalling a total of approximately 180
231 minutes and 340 events. M-Population data were recorded over 7 visits for an average
232 of 25 minutes per visit equalling a total of 175 minutes and 348 events.

233

234 *2.3 Data Coding*

235

236 Two independent raters recorded observational data (C, M). Only information
237 specifically related to lateral direction on a sagittal plane was recorded. A pen and
238 paper recording method was adopted using a preformatted spread-sheet indicating
239 variables to be recorded. The lateral path (left, right) that the observed child chose to
240 navigate around stationary target (peer, adult, object) on order to reach a position
241 accessible by a clear path on both sides and of approximately equal distance achieved
242 by a left or right path was noted (Figure 1).

243

244 Figure 1.

245

246 - Insert Figure 1 -

247

248 Figure 1 illustrates the two possible navigational paths (left, right) of the observed
249 child around a target (in this case a peer). A left or right navigational path inherently
250 dictates the side of the body that will be presented to the individual around which the
251 observed child navigates. In this case, a left navigational path presents the right side
252 of the body and right visual field to the peer. A right navigational path presents the
253 left side of the body and the left visual field to the peer.

254

255 Navigation around both peers and adults was considered. Additionally, a control
256 condition was employed utilizing fixed, inanimate objects (e.g. large rubbish bin) in
257 order to create the following 2x3 factor design: navigate left (adult), navigate left
258 (peer), navigate left (object), navigate right (adult), navigate right (peer), navigate
259 right (object). To control for confounding factors, each navigational path of an
260 observed child began at a neutral point (approximately equidistant left or right from
261 the desired location), and proceeded around (left or right) one of the target categories
262 (adult, peer, object). The observed child and the target (peer, adult) were required to
263 have directed gaze. If the observed child was navigating around a peer or adult that
264 was facing away (gaze averted or obscured), the trial was excluded. Additionally, if a
265 child began navigation from an ambiguous position (i.e. not equidistant from the
266 desired goal location), the event was excluded from the analysis. Each navigational
267 path was equal to one frequency point. In line with Quaresmini et al. (2014), to ensure
268 that the relative presence of the social partner was influencing the positioning of the
269 focal subject, we adopted an approximate distance of less than 3 m or less between the
270 child being observed and the social partners.

271

272 Data collection method varied slightly between the two populations of children. For
273 C-Population, a focal sampling approach was employed. Each focal follow lasted two
274 minutes in duration. Data were included to the dataset if two minutes of continuous
275 observation was completed. Stationery object targets consisted of a tree, a rubbish bin
276 and an ornamental rock and remained consistent across all data collection visits.
277 These objects were fixed at the entry point of the playground and required lateral
278 navigation to access the playground equipment. These fixed items were chosen
279 because they presented equal opportunity for navigation around both sides.

280

281 M-Population data collection consisted of an opportunity sampling of an entire school
282 population. Each data point was collected based around a stationery target (adult,
283 peer, object) used as a reference location. It was necessary that animate targets
284 remained stationery throughout the observed child's navigational path to their desired
285 location. Stationery object target was a rubbish bin. This object and its location
286 remained consistent throughout all seven data collection visits. The bin was located at
287 the intersection of two discrete segments of the playground, such that it was
288 circumnavigated by the majority of the children during any given play session.

289

290 *2.4 Data Analysis*

291

292 A laterality index (LI), binomial tests, z-scores approximations of the binomial scores
293 and a chi-square test were performed to assess population-level lateral biases.

294 Additionally, peer and adult frequencies were collapsed within and between the two
295 populations in order to consider the influence of animate and inanimate targets (e.g.

296 Forrester et al. 2011; 2012; 2013). LI scores were calculated using the formula [LI =

297 $(R-L)/(R+L)$], with R and L being the frequency counts for right and left navigational
298 path frequency counts. LI values vary on a continuum between -1.0 and +1.0, where
299 the sign indicates the direction of hand preference. When R=L, then LI is zero.
300 Positive values reflect a right navigational path preference while negative values
301 reflect a left navigational path preference. The absolute value depicts the strength of
302 hand preference. The directional strength of navigational path for each population was
303 calculated using z-scores such that a population were left navigational path biased
304 when $z \leq -1.96$, right navigational path biased when $z \geq 1.96$ and ambi-preferent for
305 path direction when $-1.96 < z < 1.96$. All statistical tests were two-tailed ($\alpha < .05$).

306

307 **3. Results**

308

309 Raw frequencies, binomial approximations of z-scores for each population and HI
310 scores are presented in Table 1 by population (M Population, C Population and
311 populations combined). Factors are displayed by target condition (peer, adult, object)
312 and side (left, right).

313

314 Table 1 demonstrates raw frequencies, binomial approximations of z-scores and HI
315 scores of unimanual lateralized hand actions.

316

317 - Insert Table 1 -

318

319 Because the binomial tests indicated that children navigated around both peers and
320 adults with a significant bias of presenting their left side, in both populations, these
321 two levels were collapsed for further statistical tests. A 2x2 chi-square test was

322 conducted on each population to consider target (human, object) and side (left, right).
323 The M-Population revealed a significant interaction between target and side such that
324 the children were biased towards a rightward navigational path around a peer, where
325 as navigation around an object did not elicit a lateral bias $\chi^2(1, N = 101) = 5.27, p =$
326 $.022$. Likewise, the C-Population revealed a significant interaction between target and
327 side such that the children were biased towards a rightward navigational path around a
328 peer, where as navigation around an object did not elicit a lateral bias $\chi^2(1, N = 200)$
329 $= 11.7, p = .001$ (Figure 2).

330

331 Figure 2.

332

333 - Insert Figure 2 -

334

335 Figure 2 demonstrates the total frequencies by each population for target type (human,
336 object) and navigation path (left, right).

337

338 Since both populations resulted in a significant bias for children choosing a right path
339 to navigate human targets, a further chi-square test was conducted on the pooled data
340 from both populations to demonstrate the robustness of the pattern, $\chi^2(1, N = 301) =$
341 $20.22, p < .000$ (Figure 3).

342

343 Figure 3.

344

345 - Insert Figure 3 -

346

347 Figure 3 illustrates the total frequencies by the combined population for target type
348 (human, object) and navigation path (left, right).

349

350 **4. Discussion**

351

352 The present study considered the lateral navigational paths of children within a
353 naturalistic setting to align with investigations of social lateralization in observational
354 animal studies. Two populations of children were assessed by different observers at
355 different locations, and at different times. Analyses revealed that both populations
356 expressed a significant population-level bias for choosing a rightward navigational
357 path around a human compared with a leftward navigational path. Additionally,
358 neither population expressed a significant bias for a lateral preference when
359 navigating around an object. These findings are to be considered in light of
360 evolutionary theories for cerebral lateralization.

361

362 A bias for a right navigational path inherently implies that the navigating child is
363 presenting the stationary target with the left side of the body. This social positing
364 could impact upon both the production and perception of emotion processing. In the
365 first instance, a bias to keep conspecifics on the left side inherently provides an
366 advantage for viewing social stimuli with the left visual field. The left visual field
367 would provide the most efficient route to the right hemisphere for processing identity,
368 intention and angry or fearful facial expressions. This is consistent with animal
369 studies that have demonstrated a left eye/right hemisphere preference bias for to
370 monitoring familiar versus unfamiliar conspecifics (domestic chick: Deng and Rogers,
371 2002; Vallortigara and Andrew, 1991; Vallortigara et al., 2001; fish: Brown et al.,

372 2007; Sovrano, 2004; chimpanzees and gorillas: Quaresmini et al. 2014).
373 Additionally, a bias of the left visual field/right hemisphere has been reported in
374 recognizing faces and facial expressions in both apes (Morris and Hopkins, 1993) and
375 humans (De Renzi et al., 1994; Kanwisher et al., 1998). Within this context, exposing
376 the left side of the body to conspecifics might be advantageous during novel or urgent
377 situations to execute physical behaviors for protection and locomotion escape
378 behaviors. In the second instance, the left side of the face in non-human primates has
379 been reported to display emotive expression both earlier and more intensely than the
380 right side of the face (Fernández-Carriba et al., 2002; Hauser, 1993; Hook-Costigan
381 and Rogers, 1998). This lateral positioning may reflect a strategy to clearly display
382 arousal status in order to inhibit extreme aggressive behavioral responses (Baraud et
383 al., 2009).

384

385 Although approaching and withdrawing behaviours are well documented across
386 animal species (Davidson et al., 1990; Quaranta et al., 2007; Siniscalchi et al., 2013),
387 little is still known about how this behavior manifests in modern humans. Modern
388 humans represent an animal species with an extremely complex social system. Many
389 of our conscious motor actions related to approaching individuals are shaped and
390 influenced by culture and social convention (e.g. hand shakes, kissing, etc.). However,
391 our automatic motor actions may still represent evolutionary primitive patterns of
392 behavior that are underpinned by cerebral specialization of the two hemispheres.
393 Moreover, the display of these population-level lateralized behaviours (e.g. bias for
394 keeping conspecifics in the left visual field) may be rooted in social species and
395 facilitates the social communication and the prediction of social responses (Ghirlanda
396 and Vallortigara, 2004; Vallortigara and Rogers, 2005).

397

398 Studies of cerebral lateralization indicate that the dominant functions are not solely
399 processed by a single hemisphere. For example, studies of processing social stimuli
400 also indicate small contributions from the left hemisphere: Meng et al., 2012),
401 monkeys (Broad et al., 2000; Guo et al., 2009; Hamilton and Vermeire, 1988; Pinsk et
402 al., 2005), dogs (Guo et al., 2009), and sheep (Peirce et al., 2000; Peirce and Kendrik,
403 2002). Therefore, there are limitations to the extent with which we can attribute a
404 single function to a single hemisphere. Additionally, more detailed studies on
405 lateralized motor biases are necessary at the individual level to shed further light on
406 the association between cerebral lateralization of function and contralateral motor
407 action. Nevertheless, evidence from a wide range of animal species of hemispheric
408 dominance for specific functions has proven to be an informative behavioral marker
409 of brain organization (e.g. MacNeilage et al. 2009).

410

411 Understanding how individuals navigate social networks may shed light on how and
412 which environmental pressures helped to shape modern human social behavior.
413 Specifically, the environment may have been a critical pressure in aligning population
414 behavior for social actions requiring cooperation (Ghirlanda et al., 2009; Ghirlanda
415 and Vallortigara, 2004; Vallortigara and Rogers, 2005). Additionally, future studies
416 may consider the evaluation of the cognitive abilities of individuals with lateralized
417 social navigation behaviors compared with individuals who do not express lateralized
418 social navigation behaviors. It has been reported that stronger lateral motor
419 dominance (e.g. handedness) correlates with the successful hemispheric specialization
420 for language (Toga and Thompson, 2003). The present findings suggest that the
421 environment elicits predictable behavior for social navigation that facilitates both the

422 production and perception of social-emotion stimuli in typically developing children.
423 Therefore, the identification of individuals lacking lateralized social navigations
424 behaviors may allow for the early targeting of individuals with cognitive delays
425 and/or disorders.

426

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432

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Navigation Path	C-Population	M-Population	Combined
Left around peer	39	32	71
Right around peer	122	65	187
Laterality index	.52	.34	.45
z-score	6.46	3.25	7.16
Binomial	$p < .000^*$	$p = .001^*$	$p < .000^*$
Left around an adult	32	36	68
Right around an adult	77	58	135
Laterality index	.42	.23	.33
z-score	4.21	2.17	4.63
Binomial	$p < .000^*$	$p = .029^*$	$p < .000^*$
Left around an object	34	75	109
Right around an object	38	82	120
Laterality index	0.06	0.05	0.05
z-score	0.35	0.48	0.66
Binomial	$p = .724, ns$	$p = .632, ns$	$p = .509, ns$

B = binomial approximation of z-score, z = z-score, LI = laterality index (* significant, $p < .05$, two-tailed)

Figure2

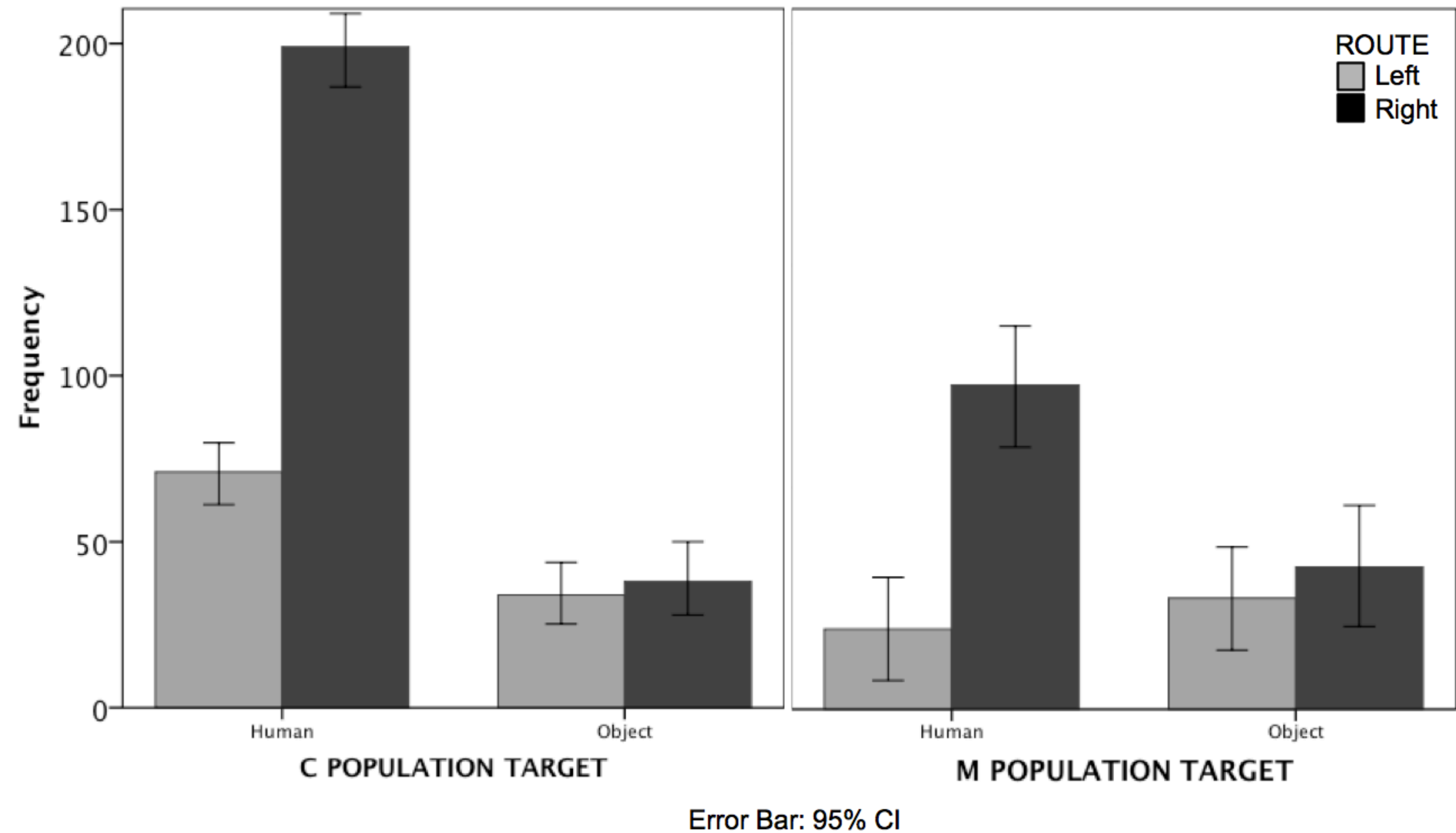
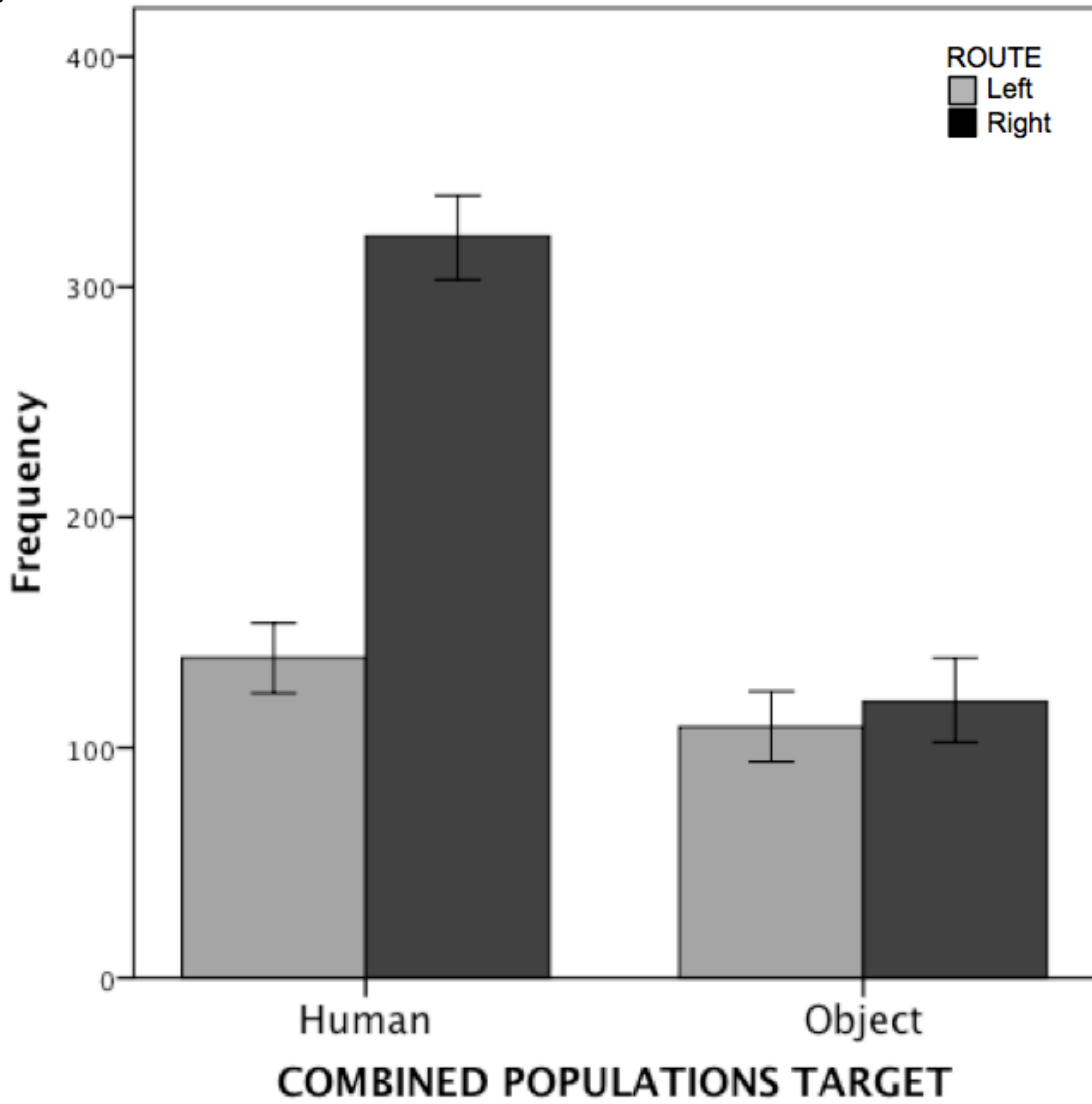


Figure3



Error Bar: 95% CI