Hill, Elisabeth L. and Khanem, Fateha

The development of hand preference in children: The effect of task demands and links with manual dexterity

Originally published in Brain and CognitionThe publisher's version is available at: http://dx.doi.org/10.1016/j.bandc.2009.04.006

Brain and Cognition 71 (2009) 99–107

Contents lists available at ScienceDirect

Brain and Cognition

journal homepage: www.elsevier.com/locate/b&c

The development of hand preference in children: The effect of task demands and links with manual dexterity

Elisabeth L. Hill *, Fateha Khanem

Department of Psychology, Goldsmiths, University of London, New Cross, London SE14 6NW, United Kingdom

A R T I C L E I N F O

Article history:
Accepted 10 April 2009
Available online 19 May 2009

Keywords:
Handedness
Hand preference
Laterality
Manual dexterity
Midline crossing
Motor development

A B S T R A C T

Lateralisation of hand preference and manual dexterity are known to develop over childhood, while in adulthood strength of hand preference has been shown to interact with extrinsic task demands. Some evidence exists to suggest that strength of hand preference and motor skill may be related. In the current study a handedness inventory, midline crossing (QHP) and peg-moving tasks were used to investigate: (1) the development of hand preference between 4 and 11 years; (2) whether extrinsic task demands affect strength of hand preference, and (3) whether strength of hand preference was associated with manual dexterity. Younger children (4–5 years) showed weak hand preference in comparison to older children (8–11 years), and extrinsic task demands influenced willingness to cross the body's midline with the preferred hand. Age and peg-moving speed were associated with midline crossing in certain task conditions. Overall, results suggest a coupling between manual dexterity and brain maturation in typical development.

1. Introduction

Numerous studies of hand preference have been published over the decades, focusing on a range of issues including heritability, developmental disorders and brain organisation (lateralisation). For the most part, researchers have used preferred hand for writing, or handedness questionnaires to assess an individual's hand preference. Overall, some people have a higher degree of hand preference than others and tend to use one hand exclusively for all activities. Others, although pre-dominantly right- or left-handed, will use their non-preferred hand for some activities.

Traditionally, questionnaires were used to evaluate hand preference by asking people to specify hand preference across a range of activities (e.g., Edinburgh Handedness Inventory; Oldfield, 1971). While this can provide useful information, there are some drawbacks since questionnaires are subjective, may contain items associated with social pressure and may have different meanings for left- and right-handers. To get round these factors, Bishop, Ross, Daniels, and Bright (1996) developed an objective measure in which a behavioural continuum was used to measure strength of hand preference. This measure is known as the quantification of hand preference (QHP) task. In the first version of this task, participants were observed picking up cards placed at each of seven locations in extrapersonal space, with one location set at the body midline, three locations placed in contralateral space and three locations in ipsilateral space (see Fig. 1). The hand used to make each reach was recorded and the number of right-hand reaches (in right-handers) summed and used as an index of strength of hand preference (100% of reaches would be made using the right-hand by an exclusive right-hander, and 50% of reaches would be made with the right-hand in somebody with no hand preference). In this task, willingness to use the preferred hand to cross the midline and reach to cards in contralateral space is thus an indication of strength of hand preference. Bishop et al. showed that their task discriminates between degrees of handedness within the right-handed population (i.e., discriminating between strong and weak right-handers). Furthermore, Calvert and Bishop (1998) showed that the QHP task discriminated additionally within groups of left-handers, as well as between groups of left- and right-handers.

A number of studies have reported tasks of midline crossing in children and these have shown that older children, like adults, cross the body midline more frequently when reaching for cards than younger children (e.g., Carlier, Doyen, & Lamard, 2006; Cermak, Quintero, & Cohen, 1980; Hill & Bishop, 1998; Stilwell, 1987), although only the two most recent of these studies have used the QHP task.

According to Fagard and Lockman (2005), task constraints influence the expression of handedness, especially in children. When grasping requires precision, the variability of the hand used decreases, and use of the preferred hand is more clearly observed. Calvert and Bishop (1998) illustrated this in adults by carrying out three variations of the QHP task: reaching (the original QHP

* Corresponding author. Fax: +44 (0)20 7919 7873.
E-mail address: e.hill@gold.ac.uk (E.L. Hill).

0278-2626/$ - see front matter © 2009 Elsevier Inc. All rights reserved.
doi:10.1016/j.bandc.2009.04.006

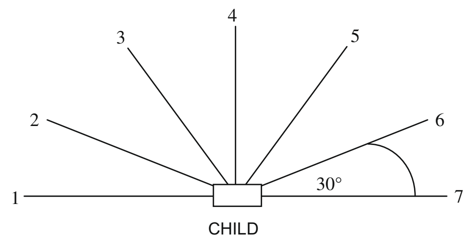

Fig. 1. Set-up for the QHP tasks. Position 4 = midline, child faces this. For right-handed participants, positions 1–3 = contralateral; positions 5–7 = ipsilateral.

task, reach for a card at one of seven locations and place in a central box), pointing (point to a card at one of seven locations) and posting (pick up a marble from a central location and place into a container at one of seven locations). In this study the spatial position of an object and the task demands affected strength of hand preference (i.e., how often a midline crossing was made). Given the evidence of increases in midline crossing on a reaching task with age in typical children (Carlier et al., 2006; Hill & Bishop, 1998), the question is raised as to whether task demands affect hand choice in typical development, and if so, what mechanism might support this change.

A number of strands of evidence point to manual dexterity as a potential correlate. Bishop (1990) suggested that the development of a consistent hand preference might depend on maturation of skilled motor performance. This suggestion is supported in two ways. First, manual dexterity improves with age in typical development (e.g., Kilshaw & Annett, 1983). Second, children with developmental coordination disorder (DCD), which is diagnosed on the basis of poor motor skill, showed weak hand preference on the QHP reaching task in comparison to age and IQ matched controls (Hill & Bishop, 1998). In the same study, children with specific language impairment (SLI) showed weak hand preference in comparison to the control group. It should be noted that this was true both of children with SLI who performed poorly and those performing in the normal range on a standardised test used to identify motor impairment. However, given that motor performance can vary from task to task (Calvert & Bishop, 1998), it is not totally clear that those children who did well on the motor test battery would be considered unimpaired motorically if assessed on a larger range of tasks.

Genetic evidence may also hint at an influence of motor skill. In a twin study in which twin pairs with and without language difficulties were assessed on the QHP reaching task, Bishop (2005) showed that the QHP task, but not a handedness inventory, showed modest, but significant heritability. In an earlier study Bishop (2002) reported a shared genetic influence of motor skill (assessed using a tapping task) and speech production in a twin sample of children with and without SLI. Furthermore, Francks and colleagues have reported two molecular genetic studies showing linkage of relative hand skill on a peg-moving task to a quantitative trait locus on the short arm of chromosome 2 (sib-pairs sample, Francks et al., 2002; left-handed brothers sample, Francks et al., 2003a). Taken together, such findings suggest potential for manual dexterity to be a causal factor in the development of strength of hand preference. While the current study was underway, Doyen, Dufour, Caroff, Cherfouh, and Carlier (2008) published a study in which they compared performance on Annett's peg-moving task with performance on the QHP card reaching task in participants aged 6–51 years of age. Younger children showed an increase in willingness to make midline crossings with the preferred hand but after 12 years, this performance dropped off. Doyen et al. argued that this finding suggests that initially the development of manual dominance is an important contributor to the decision to reach across the body's midline. However, with age the task becomes simple and participants are equally willing to reach into ipsilateral space with each hand. This account is supported by findings on the QHP reaching task from individuals with neurodevelopmental disorders associated with immature motor skill such as DCD (Hill & Bishop, 1998), SLI (Hill & Bishop, 1998), Down syndrome (Groen, Yasin, Laws, Barry, & Bishop, 2008) and Trisomy 21/Williams Beuren syndrome (Gérard-Desplanches et al., 2006). However, all of the studies cited above focused only on the card-reaching QHP task. In the current study, all three QHP task conditions (pointing–reaching–posting) were used in order to establish whether the altered task demands of these three QHP conditions would require varying levels of manual dexterity skill for successful completion. If performance across these conditions is shown to change over the course of development, it is plausible that commensurate improvements in manual dexterity skill will be associated with this. To the best of our knowledge, no direct study has been conducted to consider this possibility within the typical population.

Understanding the mechanisms that support the development of strength of hand preference is an important research question since it can shed light not only on the mechanisms associated with increased lateralisation (indexed by midline crossing), but also provide some insight into the nature and causes of poor lateralisation in those with neurodevelopmental disorders (e.g., Bishop, 2005; Groen et al., 2008; Gérard-Desplanches et al., 2006; Hill & Bishop, 1998). To this end, the current study built on previous studies of reaching tasks using midline crossing. It had three aims. First, the study aimed to replicate the finding of age-related changes in strength of hand preference when completing the QHP reaching task. Second, developmental changes in strength of hand preference were investigated when the QHP task demands were varied, involving greater or lesser degrees of fine motor control (post, reach, point, respectively). Third, the relationship between strength of hand preference and manual dexterity skill, indexed through a peg-moving task, was investigated. It was hypothesised that reduced variability in children's hand preference would be associated with increasing manual dexterity, particularly in the posting condition which requires a greater degree of manual dexterity (indexed by a greater likelihood of midline crossing with the preferred hand in this condition).

2. Method

2.1. Participants

A total of 100 typically developing children participated in the study. All were recruited from an ethnically diverse East London primary school (UK). Children were aged between 4 and 11 years (mean 7.9 years, SD 2.1), and were grouped into four age bands: 4–5 years, 6–7 years, 8–9 years, and 10–11 years. All children were typically developing physically and academically as judged by their teachers. None showed exceptional skills in any domain and none had been diagnosed with any form of neurodevelopmental disorder. Not all children had English as their native language, but all children were proficient in English and understood the task instructions. Participant details, including gender and hand preference are shown in Table 1.

2.2. Materials and methods

2.2.1. Handedness assessment

2.2.1.1. Writing hand. The child was asked to write his/her name at the start of the experiment. Hand used to hold the pencil was recorded as the preferred hand.

Table 1
Participant characteristics.

	Mean age, years (SD)	Male (female)	Hand preference[a]		
			Right (left) handed	Right (left) handed males	Right (left) handed females
Total group (n = 100)	7.56 (0.48)	39 (61)	88 (12)	34 (5)	54 (7)
4–5 years (n = 17)	4.7 (0.4)	9 (8)	15 (2)	7 (2)	8 (0)
6–7 years (n = 25)	6.6 (0.5)	13 (12)	20 (5)	10 (3)	10 (2)
8–9 years (n = 30)	8.4 (0.5)	11 (19)	28 (2)	11 (0)	17 (2)
10–11 years (n = 28)	10.5 (0.5)	6 (22)	25 (3)	6 (0)	19 (3)

[a] Indexed as preferred hand for writing.

2.2.1.2. Handedness questionnaire. Parents were asked to complete a handedness questionnaire, based on the Edinburgh Handedness Questionnaire (Oldfield, 1971), for their children. This involved indicating whether a child used the left- or right-hand "always", "usually" or "both equally" for each of nine tasks; writing, drawing, throwing, using scissors, a toothbrush, knife (without fork), using a spoon and broom, and opening the lid of a box. One item from Oldfield's original questionnaire, striking a match, was excluded because it was considered to be unsuitable for children. Data were converted to laterality quotients using the formula provided by Oldfield: $LQ = 100(R - L)/(R + L)$.

2.2.1.3. Quantification of hand preference (QHP) task. This test was designed by Bishop et al. (1996) to provide a behavioural measure of degree of hand preference. Seven positions each placed 30 degrees apart from one another and within the child's reach (this varied according to the length of the arms of each child), were marked on a cardboard template (see Fig. 1). The template was placed on a table. Children stood in front of the template in the centre of the baseline. Three separate conditions of the task were conducted, following Calvert and Bishop (1998). The order of spatial position at which an action was completed was random, but the sequence of positions was the same for all participants. Order of task conditions was counterbalanced across the children in each age group. The child was not informed of the experimental interest in hand preference. No time constraints were imposed. The experimenter recorded the hand used to act at each location on each task.

2.2.1.3.1. Pointing QHP task. This task involved minimal motor skill. One picture card was placed at each spatial position. Children were asked by the experimenter to point to a specified card. Each card was named three times (total of 21 trials).

2.2.1.3.2. Reaching QHP task. Three picture cards showing easily nameable items were placed at each of the seven spatial positions. Children were asked by the experimenter to pick up a specified card and to place it in a box located directly in front of them (total of 21 trials).

2.2.1.3.3. Posting QHP task. This task involved the greatest degree of motor skill. A cup (diameter 5 cm) with a small hole in its lid (diameter 2 cm) was placed at each of the seven spatial positions. Each cup was identifiable by a different coloured sticker: red, yellow, blue, green, pink, orange, and black. A small box holding 21 marbles was positioned at the midpoint of the baseline (i.e., directly in front of the child). The experimenter named a cup and the child had to pick up a marble and post it into that cup. Each cup was named three times (total of 21 trials).

The QHP tasks were analysed in four ways: (1) data for right-handed participants were analysed in terms of number of right-(preferred) hand reaches, (2) a TOTCROS variable (see Carlier et al., 2006) was calculated for responses of both right- and left-handed participants, (3) midline crossings were evaluated in terms of distance from the midline position for right- and left-handeders (see Carlier et al.) and (4) data for right-handed participants were evaluated in a categorical analysis as reported by Calvert and Bishop (1998). The calculation of the latter three variables is described below.

2.2.2. Manual dexterity

2.2.2.1. Peg-moving. Children placed 12 pegs into a pegboard as quickly as possible. Three trials were completed with each hand. The hand used was alternated trial by trial and each child chose the hand s/he used on the first trial (all children chose to use their dominant hand first). Time taken (ms) to place the 12 pegs was recorded and averaged for each hand. A difference score (average RH time minus average LH time) was then calculated.

2.3. General procedure

Children were tested individually in a quiet room in their school by the same experimenter (FK). After a task was explained to a child, s/he was asked to repeat the instructions (in his/her own words) to ensure that instructions had been understood and to resolve any uncertainties about the tasks. Two of the youngest children were unclear about the QHP task instructions but understood the instructions after they had been repeated once again. Tasks were completed in a fixed order: (1) assessment of writing hand, (2) QHP task, with the order of conditions counterbalanced across participants, and (3) peg-moving. A parent completed the handedness questionnaire and returned it to the experimenter at the school. The project had received ethics approval from the Ethics Committee of the Department of Psychology, Goldsmiths, University of London, in accordance with the guidelines of the British Psychological Society and the ESRC.

3. Results

3.1. Writing hand

There was no significant difference in hand preference either between the four age groups [$\chi^2(3) = 2.34$, $p = .504$] or the two gender groups [$\chi^2(1) = 0.41$, $p = .84$] (see Table 1).

3.2. Handedness questionnaire

The mean laterality quotient (LQ), and distribution of LQs calculated from the Edinburgh Handedness Inventory are shown in Table 2. There was no significant difference in the LQ scores between either the age groups [$\chi^2(3) = 5.758$, $p = .124$] or the two gender groups [$\chi^2(1) = 15.51$, $p = .488$].

3.3. Quantification of hand preference tasks (QHP)

The frequency of right-hand reaches was plotted for the seven different spatial positions for each age group, gender and each of the QHP task conditions (see Fig. 2).

Table 2
Mean, SD and distribution of laterality quotients for each age group and gender [*M* (F)].

	4–5 years	6–7 years	8–9 years	10–11 years
−100		1 (2)		
−86.70			(1)	
−80.00		1		
−73.40		1		
−70.00				(1)
−60.00			(1)	
−50.00		1		(1)
−20.00		1		
0	2			
33.40				(1)
46.70				(1)
77.80	1 (1)	1	1	(1)
80.00				1
84.60		(1)		
86.70	(1)	(1)		
87.50				(1)
100.00	6 (6)	8 (8)	10 (17)	5 (16)
Mean LQ				
Total	84.84	49.92	87.70	82.34
M (F)	75.31 (95.56)	36.66 (64.28)	97.98 (81.75)	96.67 (78.43)
S.D.				
Total	32.84	80.90	44.11	43.46
M (F)	43.31 (8.55)	85.25 (76.93)	6.69 (54.84)	8.16 (48.35)

Note. LQ less than zero indicates a left-handed writer, LQ above zero indicates a right-handed writer.

A repeated measures ANOVA with 2 between factors (age group; gender) and 2 within factors (spatial position; task) was applied to the data. There were significant effects of age group [$F(3, 80) = 5.23, p < .01$], gender [$F(1, 80) = 6.25, p < .02$], spatial position [$F(6, 480) = 42.26$, $p < .001$] and task [$F(2, 160) = 12.25$, $p < .001$]. Three interactions were significant: age × gender [$F(3, 80) = 2.96$, $p < .05$], position × task [$F(12, 960) = 19.4$, $p < .001$], and the three way interaction between age, position and task [age × position × task: $F(36, 960) = 1.55$, $p < .02$; see Fig. 2]. No other interactions reached significance [remaining p values .154–.631].

Planned comparisons were used to evaluate the main effects. For age, children in the 4–5 age group were significantly more variable in their hand preference than the two older age groups [8–9 and 10–11 years, $p < .01$ in both cases]. There was no difference in preferred hand in other comparisons. For gender, females were significantly more likely to make right-hand reaches than males (proportion of RH reaches, .9 vs. .8, respectively). For task, there was no significant difference in the strength of hand preference in the reaching vs. pointing task conditions [$t(87) = -.71$, $p = .48$], but significant differences in strength of hand preference in comparisons of the reaching vs. posting [$t(87) = -4.86$, $p < .001$] and pointing vs. posting tasks [$t(87) = -4.94$, $p < .001$]. This finding suggests that the task demands do influence choice of hand used when reaching in both contralateral (positions 1–3) and ipsilateral (positions 5–7) space, and their reliability were further supported by the significant interaction between task and position (see Fig. 3). A series of paired t-tests to explore this interaction (Bonferroni corrected p value set at $p < .002$) revealed significant differences between preferred hand use in contralateral space (positions 1–3) for comparisons of reaching vs. posting and pointing vs. posting (all $p < .0001$), as well as for the same comparisons at the midline position (position 4; both $p < .002$).

Further planned comparisons were used to investigate the significant age × sex interaction. A one way ANOVA to compare performance of the females at each age group showed no significant age-related changes [$F(3, 53) = .482$, $p = .696$]. However, there was a significant difference for the males [$F(3, 33) = 3.882$, $p < .02$]. Bonferroni post-hoc tests revealed a significant difference

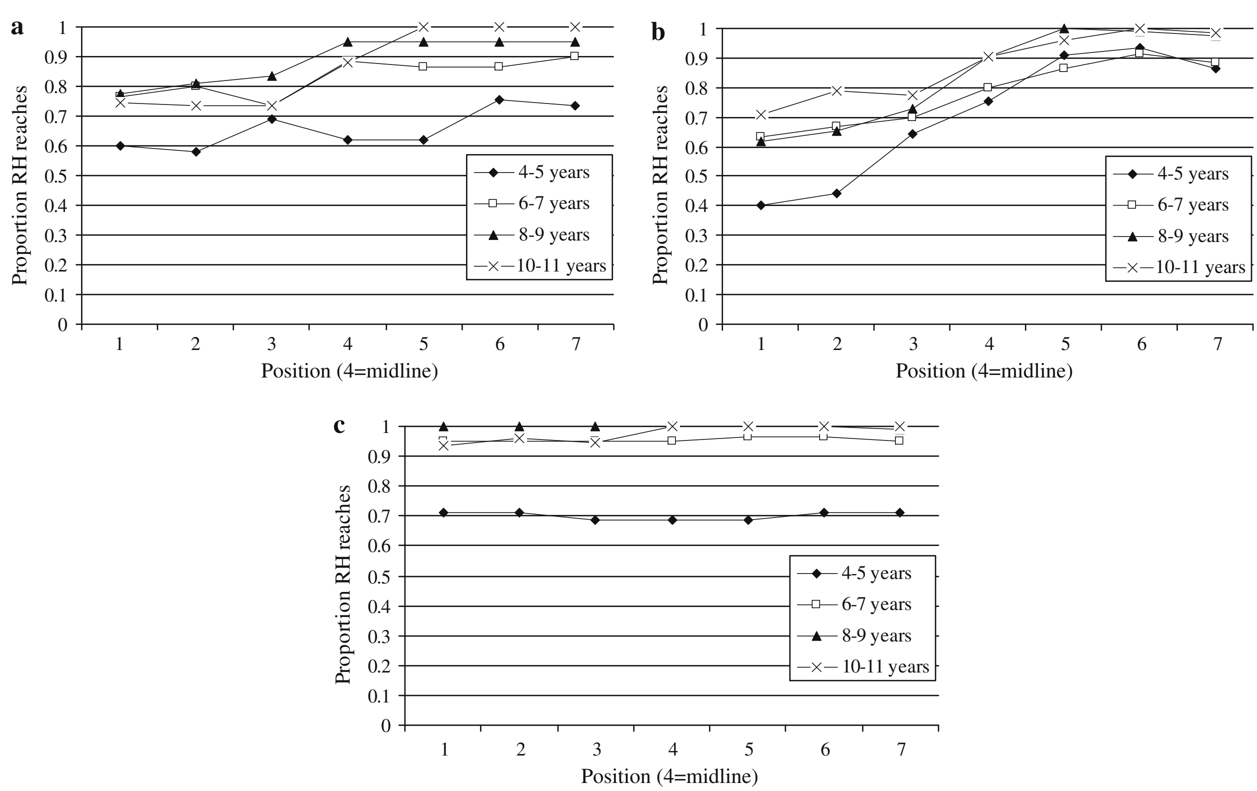

Fig. 2. Proportion of right-hand reaches (right-handed participants only) for each spatial position, age group and QHP task: (a) pointing task (standard error range .037–.108); (b) reaching task (standard error range .034–.076) and (c) posting task (standard error range .002–.112).

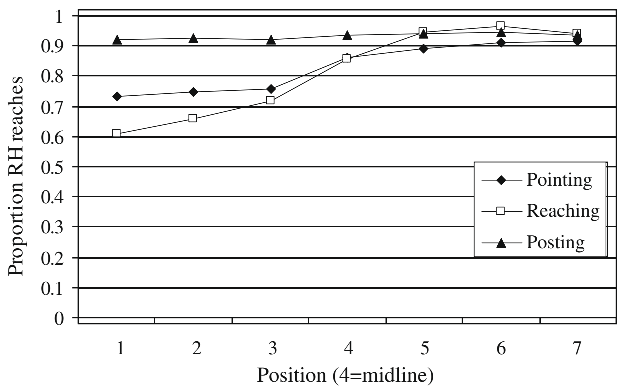

Fig. 3. Proportion of right-hand reaches (right-handed participants only) for each spatial position and QHP task (average standard error: pointing .032; reaching .027; posting .03).

in the 4–5 vs. 8–9 year olds ($p < .05$). Thus 4–5 year old males were less likely to use their right (preferred) hand to reach consistently across positions on the QHP tasks than their female peers (see Fig. 4).

With regard to the significant three-way interaction between age, task and spatial position (see Fig. 2), a series of paired *t*-tests were used to explore this interaction for each age group separately. Using strict Bonferroni corrections ($p < .0006$), this interaction arose from significant differences in the use of the preferred (right) hand in the 8–9 year old group only for reaching vs. posting in all three of the contralateral spatial positions (positions 1–3).

Following Carlier et al. (2006), a TOTCROS variable was calculated for responses of both right- and left-handed participants ($n = 100$) by totalling the number of preferred hand reaches across the body midline (right-handers positions 1–3, left-handers positions 5–7). These data are broken down by task, age and gender in Table 3. A repeated measures ANOVA with 2 between factors (age group; gender) and 1 within factor (task) was applied to the data. Only the main effect of task achieved significance [$F(2, 184) = 25.98$, $p < .001$]. In line with Carlier et al.'s findings, all other main effects and their interactions were not significant (all $p > .1$, most $p > .5$). Planned comparisons revealed significant differences in the TOTCROS variable between each combination of the three QHP tasks. Specifically, participants were significantly more likely to reach across the body midline with their preferred hand (recorded from observation of the child writing, and corroborated by parent report for the pencil item on the handedness questionnaire) in the posting, then pointing, then reaching tasks (see Table 3).

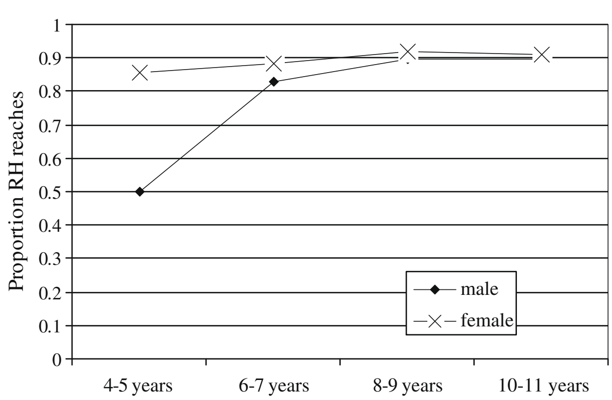

Fig. 4. Proportion of right-hand reaches (right-handed participants only) for each male and female age group across the QHP tasks combined (standard error range: male 8.385–9.191; female 2.855–3.604).

The subsequent analysis of the full participant data considered the number of midline crossings made (TOTCROS) as a function of their distance from the midline position (see Carlier et al., 2006). Three distance variables were created: far (right-handers position 1, left-handers position 7), medium (right-handers position 2, left-handers position 6) and near (right-handers position 3, left-handers position 5). These data are broken down by task, distance, age and gender in Fig. 5. A repeated measures ANOVA with 2 between factors (age group; gender) and 2 within factors (task; distance) was applied to the data. There was a significant main effect of task [$F(2, 184) = 37.17$, $p < .001$], described above, as well as a significant main effect of distance [$F(2, 184) = 13.67$, $p < .001$], indicating that the number of midline crossings was higher when reaching near the body midline (mean 2.37, SD .4 for near positions; mean 2.28, SD .49 for medium positions, mean 2.23, SD .55 for far positions). A significant interaction between task and distance [$F(4, 368) = 6.34$, $p < .001$] was identified. This arose from the finding that children were significantly less likely to use their preferred hand to reach to the position near to the body's midline in the reach condition. Finally, a significant interaction between sex, age and distance was identified [$F(6, 184) = 2.39$, $p < .03$], revealing that females in the younger age groups were more willing to reach across the body midline than their male peers (see Fig. 5). No other effects or interactions achieved significance [$p > .09$–$p > .9$].

Finally, in line with Calvert and Bishop (1998), results on the QHP task were considered using a categorical analysis, since the general willingness of children to use their non-preferred (left) hand to reach in contralateral space – at least in certain QHP task conditions – is strikingly different from the findings of the handedness inventory, where the majority of children were strongly right-handed. For this analysis, right-handed children were classified in terms of whether the left- or right-hand was used more often when reaching into contra- vs. ipsilateral space. This yielded three groups: LL (left-hand preferred for contra- and ipsilateral reaches), LR (left-hand preferred for contralateral, right-hand for ipsilateral reaches) and RR (right-hand used more often for both contra- and ipsilateral reaches). The percentage of children in each of these categories at each age group for each QHP task condition is shown in Fig. 6. Kruskal Wallis analysis revealed a significant effect of age in the QHP posting task [$\chi^2(3)$ 17.08, $p < .001$], but not in the QHP pointing or reaching tasks [pointing, $\chi^2(3)$ 3.66, $p = .3$; reaching, $\chi^2(3)$ 7.37, $p = .061$]. Post-hoc Mann Whitney tests were conducted to compare each pairing of age groups on the QHP posting task in order to evaluate the nature of these differences. Using Bonferroni corrections ($p < .01$), one comparison reached significance (4–5 vs. 10–11, $p < .01$).

3.4. Manual dexterity

Average peg-moving times across three trials for each hand, as well as the difference between the average scores of the two hands (see Calvert & Bishop, 1998) are shown for each age group in Table 4. As expected, speed of peg-moving was faster with the preferred hand, and it decreased with age. A repeated measures ANOVA with 2 between factors (age group; gender) and 1 within factor (hand) was applied to the data. There was a significant main effect of age group [$F(3, 92) = 102.23$, $p < .001$], reflecting significantly faster performance between all age groups except between the age groups 8–9 and 10–11 years ($p < .001$ in all cases). A significant main effect of gender was also found [$F(1, 92) = 4.20$, $p < .05$], reflecting significantly faster performance in the girls vs. boys (38.81s vs. 41.59s, respectively). Finally, a significant main effect of hand was found [$F(1, 92) = 62.65$, $p < .001$], reflecting significantly faster peg-moving with the preferred hand across all age groups (preferred hand, 37.24s; non-preferred hand, 43.16s). The

Table 3
Mean (SD) midline crossings made (TOTCROS variable, max = 9) by each age for right- and left-handed participants (split by gender) for each QHP task.

	Pointing			Reaching			Posting		
	All children	Male	Female	All children	Male	Female	All children	Male	Female
4–5 years	6.12 (4.03)	5.0 (4.74)	7.38 (2.83)	4.88 (3.62)	4.67 (4.21)	5.13 (3.09)	6.65 (3.92)	5.0 (4.74)	8.5 (1.41)
Range	0–9	0–9	0–9	0–9	0–9	0–9	0–9	0–9	5–9
6–7 years	6.2 (3.69)	6.0 (4.24)	6.42 (3.14)	5.56 (3.73)	4.69 (4.05)	6.5 (3.26)	8.0 (2.57)	7.15 (3.39)	8.92 (0.29)
Range	0–9	0–9	0–9	0–9	0–9	1–9	0–9	0–9	8–9
8–9 years	6.83 (3.30)	7.0 (3.13)	6.74 (3.48)	5.73 (3.57)	5.0 (3.41)	6.16 (3.69)	8.4 (2.28)	9.0 (0)	8.05 (2.84)
Range	0–9	0–9	0–9	0–9	0–9	0–9	0–9	9	0–9
10–11 years	6.39 (3.63)	6.17 (4.40)	6.46 (3.51)	6.07 (3.67)	5.83 (4.22)	6.14 (3.62)	8.25 (2.12)	9.0 (0)	8.05 (2.36)
Range	0–9	0–9	0–9	0–9	0–9	0–9	0–9	9	0–9

4–5 years, $n = 17$; 6–7 years, $n = 25$; 8–9 years, $n = 30$; 10–11 years, $n = 28$.

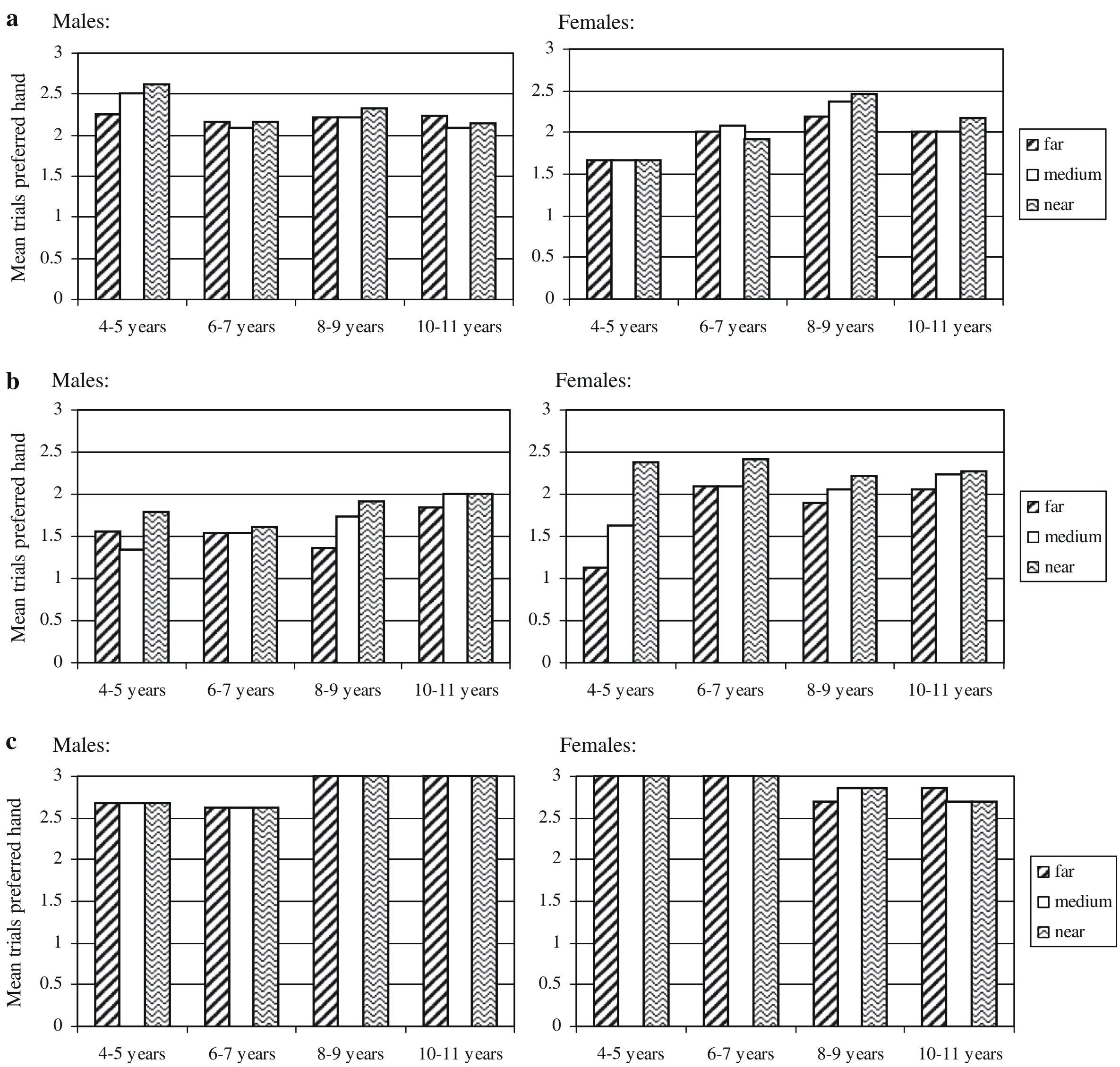

Fig. 5. Number of midline crossings made by each age group to near, medium and far positions for right- and left-handed participants (split by gender) for each QHP task: (a) pointing task; (b) reaching task and (c) posting task.

age × hand interaction was also significant [$F(3, 92) = 2.83$, $p < .05$], indicating a greater difference between the speed of peg-moving of the two hands in the younger vs. older age groups. Finally, there was a significant interaction between sex and hand [$F(1, 92) = 4.27$, $p < .05$], but no interaction between sex, age and hand ($p = .638$).

3.5. Relationship between QHP and peg-moving

In order to evaluate whether strength of hand preference was associated with manual dexterity, a multiple regression was conducted to establish whether age, gender and/or peg-moving were significant predictors of the criterion variable (total number of

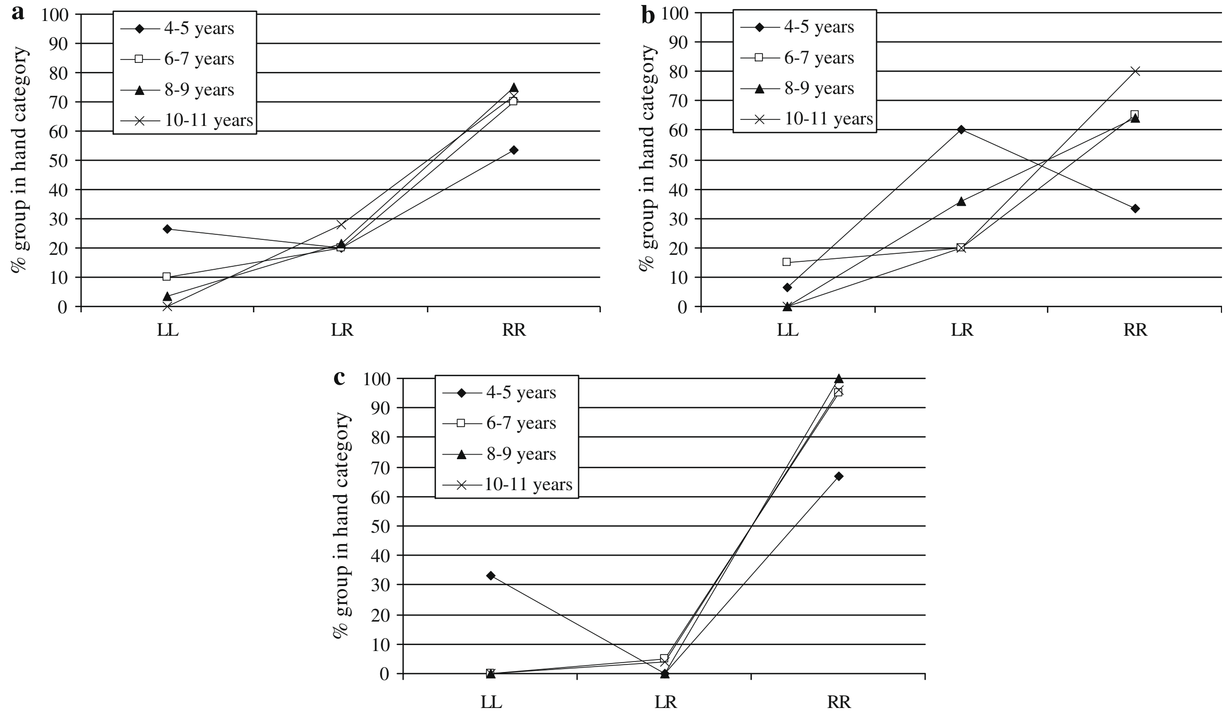

Fig. 6. Percentage of each age group in each handedness category (LL, LR, RR) for each QHP task: (a) pointing task; (b) reaching task and (c) posting task.

Table 4
Mean (SD) and range of scores on the peg-moving task (ms). Data represent average speed across three trials for each hand, and the difference between average times (preferred hand minus non-preferred hand).

	Preferred hand (P)			Non-preferred hand (NP)			Preferred minus non-preferred		
	All children	Male	Female	All children	Male	Female	All children	Male	Female
4–5 years	56.51 (8.60)	59.19 (9.50)	53.51 (6.81)	65.85 (11.38)	65.54 (11.5)	66.2 (12.02)	−9.34 (8.94)	−6.36 (9.36)	−12.7 (7.63)
Range	42.18–76.39	47.26–76.39	42.18–63.03	50.09–87.75	50.09–83.12	53.57–87.75	−24.72–12.2	−22.25–12.2	−24.72–.94
6–7 years	36.73 (9.27)	39.85 (8.34)	33.35 (9.30)	43.01 (9.56)	44.48 (10.7)	41.42 (8.30)	−6.28 (9.16)	−4.63 (8.41)	−8.07 (9.97)
Range	10.79–51.80	29.25–51.80	10.79–41.92	30.55–72.11	32.96–72.11	30.55–56.29	−23.18–8.19	−20.47–8.19	−23.18–5.73
8–9 years	29.27 (5.88)	32.27 (7.91)	27.53 (3.49)	33.64 (5.14)	35.61 (4.73)	32.51 (5.13)	−4.38 (5.53)	−3.34 (6.64)	−4.98 (4.87)
Range	21.32–53.06	24.06–53.06	21.32–34.22	23.77–42.43	27.44–40.05	23.77–42.43	−13.98–14.7	−11.07–14.7	−13.98–2.51
10–11 years	26.01 (2.66)	26.29 (1.79)	25.93 (2.88)	29.93 (4.70)	29.47 (4.45)	30.06 (4.86)	−3.92 (4.16)	−3.18 (3.87)	−4.13 (4.30)
Range	22.16–32.42	24.97–29.75	22.16–32.42	21.83–43.61	24.43–35.91	21.83–43.61	−12.05–7.75	−9.35–.90	−12.05–6.75

4–5 years, $n = 15$; 6–7 years, $n = 20$; 8–9 years, $n = 28$; 10–11 years, $n = 25$.
NB. Negative value indicates preferred hand *faster* than non-preferred hand.

RH reaches) for each QHP task (see Table 5). The RH minus LH peg-moving difference score was entered, as were age and gender. Using the Enter method, a significant model emerged for the age and peg-moving, but not gender predictor variables in all three QHP tasks (with the exception of peg-moving in the posting condition where $p = .82$). Thus a child's age and peg-moving speed had a significant influence on the likelihood of their using their preferred hand to point and reach, with age only being a significant predictor for likelihood of preferred hand use on the posting task.

4. Discussion

The current study was set up to investigate the development of hand preference in children, and whether task constraints affect reliance on the preferred hand. The first aim of the current study was to replicate Carlier et al.'s (2006) finding of age-related changes in strength of hand preference when completing the QHP reaching task. This finding was replicated in a sample of 4–11 year old, typically developing children. Like Carlier et al., our data also replicate findings using other midline crossing tasks (e.g., Cermak et al., 1980; Pryde, Bryden, & Roy, 2000; Stilwell,

Table 5
Statistical results for the multiple regression analysis. Age, gender and R-L peg-moving scores were entered as predictor variables for each criterion variable (total number of RH reaches) for each QHP task.

	F statistic	Adjusted r^2	Beta	*p*
Pointing	$F(3, 84) = 3.89$, $p < .01$	.091		
Age			−.341	.004
Gender			−.003	.976
Pegs			−.272	.019
Reaching	$F(3, 84) = 7.12$, $p < .001$	.174		
Age			−.343	.002
Gender			−.151	.143
Pegs			−.339	.002
Posting	$F(3, 84) = 6.85$, $p < 001.$	.168		
Age			−.397	.000
Gender			−.162	.118
Pegs			−.191	.082

1987). In the current study, age-related changes in strength of hand preference were also seen across the three QHP tasks. Significant differences in strength of hand preference were seen between the 4–5 year olds and the two older age groups (8–9 and 10–11 years).

The second aim of the study involved assessing whether altered task demands would affect strength of hand preference. To this end, we asked children to complete the three versions of the QHP task previously administered to adults by Calvert and Bishop (1998). The prediction here was that altered task demands would affect strength of hand preference. Task demands did affect strength of hand preference across the whole sample, although these differences were only significant between the reaching vs. posting and pointing vs. posting tasks, and were shown in contralateral space (positions 1–3) and at the midline position (see Fig. 3). An effect of distance from the midline was also a factor in willingness to cross the midline with the preferred hand, as evidenced in the analysis of the TOTCROS variable, with greatest midline crossings seen in the post vs. point vs. reach conditions. This difference was evident for the two positions closest to the body's midline only (as reported by Carlier et al. (2006) in their analysis of performance on the QHP reaching task). Results of the categorical analysis also supported this. Here, children were categorised into one of three groups: LL (left-hand preferred for contra- and ipsilateral reaches), LR (left-hand preferred for contralateral, right-hand for ipsilateral reaches) and RR (right-hand used more often for both contra- and ipsilateral reaches). This analysis was conducted since the general willingness of children to use their non-preferred hand to reach in contralateral space – at least in certain QHP task conditions – is strikingly different from the findings of the handedness inventory, where the majority of children were strongly right-handed. This could arise for one of three reasons. First, there may be a general trend for younger children to be more influenced by extrinsic spatial position than by intrinsic biases when selecting which hand to use (Calvert & Bishop, 1998). This would result in these children making fewer midline crossings (more LR in the younger age group). Second, younger children may be more random in their hand choice overall, and so be inclined to use the non-preferred hand, even when reaching into ipsilateral space (more LL in the younger age group). Third, younger children may be more 'fixed' in their hand choice such that they stick to using one hand, but do not yet show a preference for manipulating cards/marbles with the preferred hand (more LL and/or RR in the younger age group). Age effects were seen in the two QHP task conditions in which higher task demands are required, that is reaching (where a card must be picked up and placed in an open box) and posting (where a marble must be posted through a slot), but not in the simplest task, pointing. Furthermore, the degree of age-related significance was larger in the QHP posting task, which involves the greatest manipulation. Evaluation of Fig. 6b (reaching) and c (posting) suggests that the former is true in the reaching task. Here, children in the youngest age group showed a reverse pattern to those in the three older age groups, showing a reliable difference between categorisation groups in relation to the 10–11 year olds. Thus 4–5 year olds appeared more influenced by extrinsic spatial position than by intrinsic biases when selecting which hand to use, leading to a larger number of LR categorisations in this group. In the posting task, the pattern of performance of this youngest age group more clearly resembled that of the older age groups, but this time with no 4–5 year olds performing in the LR pattern, some in the LL and a greater number in the RR category. The 4–5 year olds showed a reliable difference in their categorisation in comparison to both the oldest age group (10–11 years) and the next oldest age group (8–9 year olds). This pattern of findings suggests that at least some of the younger children were relatively fixed in their hand choice preferring to reach with either one hand or the other when completing a task when a greater degree of manual dexterity was required, but not having yet selected their preferred hand to necessarily be this fixed manipulator.

It should be noted that gender did not, on the whole, have a large influence on performance on the QHP tasks, with the greatest gender differences seen on the peg-moving task. Where they did exist, significant effects of gender across the test battery indicated a more mixed pattern of responding in males vs. females. Given the relevance of the work reported here to studies of neurodevelopmental disorders, and the increased prevalence of these in males, this is a factor that should be investigated further in future studies of both typical and atypical development.

The third aim of the study was to investigate the prediction of a relationship between peg-moving skill, as an assessment of manual dexterity, and strength of hand preference. This prediction arose because of suggestions that motor immaturity is associated with weaker strength of hand preference (e.g., Bishop, 1990; Bishop, 2002; Bishop, 2005; Francks et al., 2002; Francks et al., 2003a, 2003b; Hill & Bishop, 1998; see discussion above). Some support for this prediction was found in that age and peg-moving skill were found to be significant predictors of strength of hand preference on the QHP pointing and reaching tasks. Contrary to predictions, peg-moving speed was not a predictor of strength of hand preference in the QHP posting task. This was, perhaps, surprising since the QHP posting task had been predicted to have the greatest reliance on good manual dexterity. It will be important to investigate this further to establish what might explain this finding. If the mechanism underlying motor control generally, or manual dexterity more specifically is involved in determining strength of hand preference, then the weaker than predicted finding of the current study may arise for a number of reasons. First, this study needs to be repeated in a larger sample of children spanning a broader age range and including adult participants. Second, it is known that individual performance across motor tasks can vary widely (see Calvert & Bishop, 1998) and thus additional, varied motor tasks should be included in a subsequent study. Peg-moving was included in the current study because it is a unimanual task, popular with children and known to produce age-related performance differences. The skills associated with peg-moving may not, however, be the same manual skills associated with the QHP tasks. In a future study, additional motor tasks such as dotting, tapping and handwriting should also be included. Tests of balance may also be worthwhile since good balance will be important in the completion of a whole range of tasks (good postural control may contribute to stable hand preference because of more stable balance; e.g., Balasubramaniam & Wing, 2005). Finally, it is possible that the motor demands of all three QHP tasks are minimal (Leconte & Fagard, 2004). In this case, any link between peg-moving and strength of hand preference would have been masked in the current study.

What additional variables might account for changes in strength of hand preference? Studies of neurodevelopmental disorders have pointed to the possibility of a link with language skill. Bishop (2005) reported a weak, but significant link between language and strength of hand preference on the QHP reaching task in a sample of children with specific language impairment, but not in responses to a handedness questionnaire in the same sample. Task complexity, attentional information required from the object to be reached (e.g., Bryden, Roy, Rohr, & Egilo, 2007; Gabbard, Helbig, & Gentry, 2001), genetic (Francks et al., 2002; Francks et al., 2003a), environmental (see Francks et al., 2003b) and/or cultural factors (Connolly & Bishop, 1992) may also be related. These variables should be considered in future studies.

In conclusion, the findings of the current study add to past findings that strength of hand preference can be measured well using a behavioural test of hand preference that requires a participant to act at positions in both contralateral and ipsilateral extrapersonal space. This is true in an academically and physically typically developing group of children attending one east London primary school based in an area with an ethnically diverse demographic. Using a method that does not rely on parent perception of a child's hand preference, we have shown that the QHP task conditions are sensitive to changes in typical development, and have provided some evidence to highlight the need to further investigate the mechanisms underlying the development of strength of hand preference. The results suggest a coupling between manual dexterity and brain maturation in typical development and therefore motor control and perhaps manual dexterity more specifically, may be one of a number of candidates for further investigation.

Acknowledgments

We are grateful to the headteacher, staff, parents and children of Malmesbury Primary School, Tower Hamlets, London for their willing participation in this study.

References

Balasubramaniam, R., & Wing, A. M. (2005). The dynamics of standing balance. *Trends in Cognitive Sciences, 6*, 531–536.

Bishop, D. V. M. (1990). *Handedness and developmental disorder*. Hove: Lawrence Erlbaum Associates.

Bishop, D. V. M. (2002). Motor immaturity and speech and language impairment: Evidence for a common genetic basis. *American Journal of Medical Genetics (Neuropsychiatric Genetics), 114*, 56–63.

Bishop, D. V. M. (2005). Handedness and specific language impairment: A study of 6-year old twins. *Developmental Psychobiology, 46*, 362–369.

Bishop, D. V. M., Ross, V., Daniels, M. S., & Bright, P. (1996). The measurement of hand preference: A validation study comparing three groups of right-hander's. *British Journal of Psychology, 87*, 269–285.

Bryden, P. J., Roy, E. A., Rohr, L. E., & Egilo, S. (2007). Task demands affect manual asymmetries in pegboard performance. *Laterality, 12*, 364–377.

Calvert, G. A., & Bishop, D. V. M. (1998). Quantifying hand preference using a behavioural continuum. *Laterality, 3*, 225–268.

Carlier, M., Doyen, A. L., & Lamard, C. (2006). Midline crossing: Developmental trend from 3 to 10 years of age in a preferential card-reaching task. *Brain and Cognition, 61*, 255–261.

Cermak, S. A., Quintero, E. J., & Cohen, P. M. (1980). Developmental age trends in crossing the body midline in normal children. *American Journal of Occupational Therapy, 34*, 313–319.

Connolly, K. J., & Bishop, D. V. M. (1992). The measurement of handedness: A cross-cultural comparison of samples from England and Papua New Guinea. *Neuropsychologia, 30*, 13–26.

Doyen, A-L., Dufour, T., Caroff, X., Cherfouh, A., & Carlier, M. (2008). Hand preference and hand performance: Cross-sectional developmental trends and family resemblance in degree of laterality. *Laterality, 13*, 179–197.

Fagard, J., & Lockman, J. J. (2005). The effect of task constraint on infants' (bi)manual strategy for grasping and exploring objects. *Infant Behavior and Development, 28*, 305–315.

Francks, C., Fisher, S. E., MacPhie, I. L., Richardson, A. J., Marlow, A. J., Stein, J. F., et al. (2002). A genomewide linkage screen for relative hand skill in sibling pairs. *American Journal of Human Genetics, 70*, 800–805.

Francks, C., DeLisi, L. E., Fisher, S. E., Laval, S. H., Rue, J. E., Stein, J. F., et al. (2003a). Confirmatory evidence for linkage of relative hand skill to 2p12-q11. *American Journal of Human Genetics, 72*, 499–502.

Francks, C., Fisher, S. E., Marlow, A. J., MacPhie, I. L., Taylor, K. E., Richardson, A. J., et al. (2003b). Familial and genetic effects on motor coordination, laterality, and reading-related cognition. *American Journal of Psychiatry, 160*, 1970–1977.

Gabbard, C., Helbig, C. R., & Gentry, V. (2001). Lateralized effects on reaching by children. *Developmental Neuropsychology, 19*, 41–51.

Gérard-Desplanches, A., Deruelle, C., Stefanini, S., Ayoun, C., Volterra, V., Vicari, S., et al. (2006). Laterality in persons with intellectual disability II. Hand, foot, ear and eye lateralities in children or adolescent and adult persons with trisomy 21 and Williams Beuren syndrome. *Developmental Psychobiology, 48*, 482–491.

Groen, M. A., Yasin, I., Laws, G., Barry, J. G., & Bishop, D. V. M. (2008). Weak hand preference in children with Down syndrome is associated with language deficits. *Developmental Psychobiology, 50*, 242–250.

Hill, E. L., & Bishop, D. V. M. (1998). A reaching test reveals weak hand preference in specific language impairment and developmental co-ordination disorder. *Laterality, 3*, 255–268.

Kilshaw, D., & Annett, M. (1983). Right- and left-hand skill I: Effects of age, sex and hand preference showing superior skill in left-handers. *British Journal of Psychology, 74*, 253–268.

Leconte, P., & Fagard, J. (2004). Influence of object spatial location and task complexity on children's use of their preferred hand depending on their handedness consistency. *Developmental Psychobiology, 45*, 51–58.

Oldfield, R. C. (1971). The assessment and analysis of hand preference: The Edinburgh Inventory. *Neuropsychologia, 9*, 97–113.

Pryde, K. M., Bryden, P. J., & Roy, E. A. (2000). A developmental analysis of the relationship between hand preference and performance: I. Preferential reaching into hemispace. *Brain and Cognition, 43*, 370–374.

Stilwell, J. L. (1987). The development of manual midline crossing in 2- to 6-year old children. *The American Journal of Occupational Therapy, 41*, 783–789.