Midline crossing: Developmental trend from 3 to 10 years of age in a preferential card-reaching task

M. Carlier a,b,*, A.-L. Doyen c, C. Lamard a

a Centre of Research PsychÉ (EA3273), University of Provence, Aix en Provence, France
b University Institute of France, France
c IUFM Orleans Tours, Orleans, France

Accepted 22 January 2006
Available online 2 March 2006

Abstract

We assessed 110 left-handed and 322 right-handed children aged from 3 to 10 years, using Bishop’s card-reaching task. Manual body midline crossings were observed. A regular developmental trend was observed from 3 to 10 years: older children crossed the body midline more frequently when reaching for cards than did younger children. The factor age explained 4.9% of the variance. Significant differences appeared between 3–4 years old children and 8–10 years old children. The effect of the spatial position of the cards was also significant: the contralateral hand was used less often to reach cards at the most extreme positions. These findings in this task demonstrate that the development of the degree of handedness follows a long developmental trend.

Keywords: Handedness; Laterality; Development; Reaching; Children

1. Introduction

Manual midline crossing occurs when an individual, extending one hand to grasp an object, reaches across the body midline. A developmental trend in crossing the midline of the body for unimanual movements has been described in typically developing children aged 4–8 (Cermak, Quintero, & Cohen, 1980), aged 2–6 (Stilwell, 1987), and 4–12 (Schofield, 1976). The frequency of the crossings decreases as the distance from the body midline increases (Atwood & Cermak, 1986; Stilwell, 1987). More recently it has been shown that this spatial effect was task-related (Calvert & Bishop, 1998; Gabbard & Helbig, 2004; Helbig & Gabbard, 2004; Mamolo, Roy, Bryden, & Rohr, 2004, 2005). In 1996, Bishop and her team proposed a card-reaching test to assess hand preference. The test gives a behavioral measurement of the degree and direction of hand preference in a task where participants have the option of crossing the body midline. The test can discriminate participants classified according to a classical handedness inventory: left- and right-handers, exclusive right-handers and predominant right-handers (Bishop, Ross, Daniels, & Bright, 1996; Doyen & Carlier, 2002), and exclusive left- and predominant left-handers (Calvert & Bishop, 1998). It also discriminates typically developing children and children with language impairment or a developmental co-ordination disorder (Bishop, 2001, 2005; Hill & Bishop, 1998), and, to a certain extent, two groups of disabled persons with one of two genetic diseases (Trisomy 21 and Williams–Beuren syndrome) compared to typically developing individuals (Carlier et al., 2006).

Laterality questionnaires and laterality tasks measure different aspects of manual laterality and there are several advantages in using a behavioral measurement for assessing hand preference, especially in children. Inventories (or questionnaires) vary in the number of items and in item point scales, and contain items associated with social pressure and different meanings for left- and right-handers (Doyen, Duquenne, Nuques, & Carlier, 2002).
as well as items where the participant’s familiarity in handling them may be age-related. It has been established that the prevalence of left-handedness differs not only according to the items used in the questionnaire, but also to the laterality index chosen; see, for example (Fagard, 2004 for a review; Medland, Perelle, De Monte, & Ehrman, 2004; Peters, 1992). For populations of children, preference responses have to be observed directly while the actions are being performed (questionnaires therefore cannot be valid). Any researcher wishing to collect information on handedness by using an inventory, can easily (as is recommended) add a manual task to the experimental protocol.

In previous research studying 260 French adults (Doyen & Carlier, 2002), we showed that Bishop’s card-reaching task has good metric qualities (high homogeneity, and test–retest reliability), confirming results obtained by Bishop and her team testing English samples. However, to the best of our knowledge, no data can be found in the literature on the developmental trend of the hand preference as assessed by the card-reaching task. As Bishop (2005) argues that her task is a measure of developmental maturity, it would be useful to have more data on the developmental curve in the performance of this task. The more sensitive the task is to developmental processes, the easier it will be to observe differences between atypical groups and typically developing children.

### Table 1
Characteristics of the samples as a function of age

<table>
<thead>
<tr>
<th>Age</th>
<th>Number of children</th>
<th>Boys</th>
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<th>Right-handers</th>
<th>Left-handers</th>
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</table>

### Descriptive statistics for the TOT CROS variable

<table>
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<th>SD</th>
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<td>6.20</td>
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### Partial comparisons for the TOT CROS variable (levels of significance)

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<tr>
<td>9</td>
<td>0.500</td>
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</tbody>
</table>

Descriptive statistics for the total number of midline crossings variable (TOT CROS). SD, standard deviation. Planned comparisons across ages. Statistical differences (p values) after comparisons using the LSD method. p values < .05 are in italics.

* Due to experimental error, the sex of the participant was not recorded for 1 child in the 7-year-old age group, 15 children in the 8-year-old age group and 1 child in the 9-year-old age group.
no classification could be made using these two items, the toothbrush, scissors and the number of “Right” answers were used. There were 110 left-handed and 322 right-handed children; 217 boys (52.3%), and 198 girls (47.7%)—see Table 1. The high number of left-handers was obviously due to the selection of the families in the familial study. Children were also classified as strong right-handers (at least 10 right-hand uses for the 11 items), strong left-handers (no more than 2 uses of the right-hand), and mixed (others); this was done for the purpose of comparing our data with previously published data on children assessed with a very similar task (Gabbard & Helbig, 2004; Gabbard, Helbig, & Gentry, 2001; Gabbard, Rabb, & Gentry, 1998).

2.2. Assessment of body midline crossing

In the English adult version of Bishop’s card-reaching task a cardboard template placed on a table in front of the participant is used to mark seven numbered positions, each at a distance of 40 cm from the mid-point of a baseline, at successive 30° intervals. Position 4 is the midline. Positions 1, 2, and 3 are situated on the left hand side of the semicircle, positions 5, 6, and 7 on the right hand side of the semicircle. Three playing cards are placed at each numbered spatial position (from 1 on the left to 7 on the right, and 4 in the middle)—see Fig. 1. The participant is asked to pick up the playing cards on each of the numbered locations and place them in a central box. There are no time limits and the task is easy to perform provided the participants can read numbers and have no serious motor impairment. In previous research studying adults, we changed the original procedure slightly: the number of cards to be reached at each spatial position was doubled (i.e., 6 per position) and an additional card was placed at each spatial position so that participants did not realize that the last card had been taken when they had to reach for the sixth position (as for the task with numbers, an additional card was placed at each spatial position to avoid any orientation strategy for the last reach). In a previous experiment (Carlier and Lamard, unpublished) observing 46 typically developing children (6–8 years old), we found a high correlation with the laterality index, calculated using the larger cardboard template plus cards with numbers, and the smaller cardboard template plus cards with pictures ($r(44) = 0.83, p < .01$).

Children able to read were assessed using the larger set and numbers. To compare the performances of reading and non-reading children, only the results of the first three cards were considered (as in Bishop’s original procedure).

2.3. Procedure and statistics

The children were tested individually in a single 15–20 min test session, first doing Annett’s questionnaire (by being asked to perform each action), and secondly the card-reaching task. In the card-reaching test two indexes were calculated: the first was the proportion of right-hand reaches $-0.50$; this records a continuous score ranging from $+0.50$ for any participant reaching with the right hand only and down to $-0.50$ for those reaching with the left hand only (Calvert & Bishop, 1998). This index (referred to here as LATB, i.e., Laterality/Bishop) gives the direction and degree of manual laterality, and was used to classify the participants as left- or right-handers. The second index assessed the reaches as a function of the hemispace (Bishop et al., 1996; Calvert & Bishop, 1998): when the right hand was used to reach a card in positions 1, 2, and 3, the participant crossed the body midline, reaching into the contralateral hemispace, position 1 being the farthest point left and position 3 being the nearest to the midline—see Fig. 1. When the left hand was used to reach a card at positions 5, 6, or 7, the participant crossed the midline, in this case, position 7 being the farthest from and position 5 the nearest to the midline. The total number of midline crossings was counted for each child (referred to here as TOT CROS). It should be emphasized that TOT CROS is an indication of degree of laterality independent of the direction and the score shows a high correlation with the absolute value of LATB: individuals who frequently cross the midline are obviously more strongly right- or left-handed (in our sample the value of the correlation between $|LATB|$ and the total number of crossings was 0.90, after partialling out the age effect). Then, going further than Bishop, we calculated the number of reaches crossing the midline as a function of the distance from the midline, regardless of the hand used. One reach with
the right hand to position 1 (left hemispace) was therefore equivalent to and added to one reach with the left hand to position 7 (right hemispace), and so on, respectively, for positions 2 and 6, and positions 3 and 5. With this original procedure (i.e., using right or left hands) all the participants could be included in the same analysis so as to focus solely on the distance from the midline when a crossing occurred. This increased the power of the statistical tests and gave an opportunity for computing statistical analyses without classifying participants into categories of left- and right-handers, avoiding the problem of certain participants who are always difficult to classify as right or left-handers (see Section 1).

We used the SPSS 11.5 package for all the analyses. Participants were classified as left- or right-handers on the basis of their performance of Annett’s questionnaire (see above) and also of the card-reaching task. They were considered right-handed when their LATB score was >0, and left-handed when their LATB score was <0. This classification produced a larger number of left-handers: (131 instead of 110). Contradictory left/right-hander classifications using the Bishop and Annett criteria mostly concerned younger children (see Table 1). For the TOT CROS variable, differences across the eight age groups were tested with analysis of variance (ANOVA). As ANOVA does not recognize age groups forming a linear series, regression analysis on age was added. ANOVAs with repeated measures (three positions) were used to test differences in midline crossing according to the position of the card across the eight age groups. We could not test the three factors of sex, laterality, and age in the same analysis because of the eight age groups. We could not test the three factors of sex, laterality, and age in the same analysis because of the eight age groups. The mean values of TOT CROS increased from age 3 to 10—see Table 1. Planned comparisons showed that younger children (aged 3 and 4) crossed the midline less frequently than children over the age of 7. The differences between these contrasted groups explained 7.2% of the variance. Regression analysis of age on TOT CROS gave a similar picture. The linear tendency was the best fit (F(430) = 18.89, p < .000, \( R^2 = 0.04 \)), although quadratic and cubic tendencies were also significant: the number of midline crossings increased with age, the rejection of the null hypothesis can be accepted with a very low risk although the percentage of variance explained by the linear tendency was medium (4%).

We then considered the number of midline crossings as a function of the spatial position of the cards and observed a position effect (F(2,848) = 41.69, p < .000, \( \eta^2_p = 0.09 \)) with a significant linear tendency (F(1,424) = 72.44, p < .000, \( \eta^2_p = 0.146 \)). The number of midline crossings was higher near the body midline than in the mid-way and farthest positions with a medium effect size. The interaction between the spatial position and age factors was not significant. Fig. 2 shows that the numbers of crossings increase with age, reaching a plateau around 8 years. In every age group, the number of crossings was higher for cards positioned near the body midline. ANOVA with age and laterality (assessed with the questionnaire) as independent factors, and position as repeated measures showed no difference related to the direction of laterality either as an independent factor (F(1,416) = 0.033, p = .86) or as an interaction with age (F(7,416) = 0.771, p = .61) or an interaction with position (F(2,832) = 0.151, p = .86). Independently of age, the means of the number of crossings by right- and left-handers were similar (right-handers: 1.48 ± 0.08, 1.68 ± 0.08, and 1.88 ± 0.08, respectively, for positions Far, Middle, and Near; left-handers: 1.44 ± 0.14, 1.53 ± 0.14, and 1.89 ± 0.13 for the Far, Middle, and Near positions, respectively). When participants were classified as right- or left-handers on the basis of their LATB score, a laterality effect emerged as an interaction with the position factor (F(2,832) = 4.246, p = .015, \( \eta^2_p = 0.01 \)). The mean number of crossings was higher for right-handers compared to left-handers, and the differences were greater for the Far and Middle positions (right-handers: 1.57 ± 0.08, 1.66 ± 0.8, and 1.88 ± 0.08 for positions Far, Middle, and Near respectively; left-handers: 1.29 ± 0.11, 1.46 ± 1.10, and 1.87 ± 0.11 for positions Far, Middle, and Near, respectively). Partial comparisons showed that the differences between right and left-handers were significant only for the Far position (F(1,431) = 4.43, p = .036).

A developmental trend was observed in the two groups of strongly lateralized children as classified by the question-
naire: older children crossed the body midline more frequently (see Fig. 3). To avoid very small numbers, certain age groups were pooled: 3–4, 5–7, and 8–10. For strong right-handers, there was a significant age–position interaction \( F(6,918) = 2.88, p = .001, \eta^2_p = 0.04 \). The curve shows that the between-group variance was mainly due to the crossings of the midline (left hemispace). Partial comparison showed that the youngest group differed from the oldest (group 1 vs. 3, \( p = .015 \)). A similar trend was observed with the strong left-handers. As the number of strong left-handers was too small in the youngest group (2), the analysis was done on the other two groups where the age–position interaction was significant \( F(6,294) = 4.27, p = .000, \eta^2_p = 0.08 \), with younger children crossing the midline less frequently (i.e., performing more right-hand reaches into the right hemispace).

4. Discussion

A regular developmental trend was observed for the total number of crossings and for crossings as a function of the spatial position: when reaching, older children tended to cross the body midline more frequently than younger children. The effect was independent of the sex of the participants and was observed with both strong left- and right-handers. These findings confirmed results published many years ago (Cermak et al., 1980; Stilwell, 1987), but do they tally with more recent data? Gabbard et al. (1998, 2001), Gabbard and Helbig (2004) had very similar experimental conditions, observing both children and adults, and showed that most hand movements were in ipsilateral space. This was also observed in our sample. However, the design used by Gabbard et al. was an incomplete...
developmental design: they compared, without statistical analyses, 5–7-year-old or 6–8-year-old children to adults and found that children and adults presented a similar pattern of behavior. However visual comparison of figures published by Gabbard and Rabb (2000) and Gabbard et al. (2001) shown that the children crossed the midline more frequently than adults. Moreover they did not compare the children in the different age groups, so could not test for a developmental trend. What’s more, they studied only strong left- and right-handers, and excluded within participant variability in their analyses. These conditions make it impossible to assess some of the individual differences in laterality (as participants who were not strongly lateralized were excluded) and some of the within variability (as participants are not always consistent in their behavior). More recently Pryde, Bryden, and Roy (2000) observed that 6 and 10 years children used more frequently their preferred hand to carry out different actions in left-hemispace than younger children or adults. However there participants were all right-handed.

In our study, midline crossing followed a developmental trend from age 3 to age 8, and differences across age groups explained about 5% of the variance, i.e. medium effect size. This developmental trend could follow the development of motor dominance. Sensitivity for detecting significant age-related differences was not very great as differences appeared only when contrasting groups were compared (3–4 years old compared to children older than 8). However, in general in studies of this kind, it is unusual to find differences between adjacent age groups. The absence of any sizeable differences between certain age groups may be because of the minimal motor demands and minimal complexity in the card-reaching task (Leconte & Fagard, 2004) and also because the time required to perform the actions was not recorded. Eason and Surburg (1993) and Screw and Eason (1998) suggested that important information may be gained through time measurements and the added pressure which comes with a timed protocol. However, we believe that time pressure would radically change the significance of the task, particularly when assessing mentally disabled individuals: one advantage of the card-reaching task is the absence of any time pressure, which means that children with developmental disorders readily agree to do it (Carlier et al., 2006).

5. Conclusion

We confirmed the developmental trend in crossing the body midline using the card-reaching task as developed by Bishop and her team, although age-related differences were not very great. Once again our observations raise the long-standing debate on the development of handedness. How does handedness develop? Which laterality trait is stable from infancy to adulthood? Which trait follows a developmental curve and at what age is handedness fully developed? Published data have shown that the age where a plateau is observed in the developmental trend in laterality and the form of the curve depend on the task, on the index chosen to assess manual handedness in a single task and probably on the samples being studied (Annett, 2002; Bryden & Roy, 2005; Carlier, Duyne, Capron, Dumont, & Perez-Diaz, 1993; De Agostini, Paré, Goudot, & Delatallas, 1992; Delatolas & De Agostini, 2004, among others). What will be observed in the card-reaching task with future studies of adolescent and adult samples? According to Gabbard et al. and Pryde et al. data, a decreasing number of midline crossings should be observed as adults make more efficient use of spatial information to program their movements. This expectation will be tested in an ongoing research program.

Acknowledgments

This research project was supported by the CNRS (UPR 9074, Orléans), the University of Provence (EA3273), the University Institute of France, and the Fondation Jérôme Lejeune. We wish to thank Audrey Perez who collected some of the data, the school teachers, families and, of course, the children who agreed to take part in the study.

References


