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From the Reaching Behavior at 5 Months of Age to Hand Preference at Preschool Age

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Abstract

The aim of the study was to examine the reaching behavior at the age of 5 months, and to determine whether and to what extent there is a relationship between hand use at this age and manual laterality at preschool age. 20 participants (13 girls and 7 boys) were investigated on two occasions: At the age of 5 months we assessed the hand use for reaching for four different objects placed at the infant's body midline or in their right or left hemispaces, respectively. At the age of 5 years and 7 months, we assessed the hand use for 22 motor tasks. The handedness status was calculated in order to reflect the sinistrality-dextrality continuum. All but one infant were unimanual reachers at 5 months of age. Preferential reaching was space dependent rather than object dependent at this stage. Children reaching for objects in the right hemisphere predominantly with their right hand showed a significantly greater right hand laterality at late preschool age than children who at the age of 5 months had shown inconsistent hand use ($p < .05$). Children who at the age of 5 months had reached for objects in the left hemisphere with their left hand proved to be less lateralized in their right hand use approximately 5 years later ($p < .05$).

Keywords

handedness quotient; hand preference; hemisphere; infant; laterality

INTRODUCTION

Visually directed reaching is one of the most striking developments during the first months of life, marking an important step toward the mastery of objects and tools. Infants with normal development start reaching for objects at 12–15 weeks post-term age (Hopkins & Prechtel, 1984; Von Hofsten, 1984). Kinematic analyses have provided evidence that this early reaching is less controlled and adapted to the properties of the target objects than some weeks later (Konczak & Dichgans, 1997).

Reaching for and subsequently grasping an object requires decoding the object's location, size and shape (Jeannerod, 1988). Infants aged no more than 3–4 months were reported to reach for objects more often when the objects were manageable than when they were too large, and they did so with both hands (Bruner & Klossowski, 1972). Aged 5 months,

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however, infants were less likely to try and reach for small objects (Siddiqui, 1995). Another month later, infants still used both hands for large objects, but they only used one hand (favoring neither the left hand nor the right) when reaching for small ones (Clifton, Rochat, Litovsky, & Perris, 1991; Gesell & Ames, 1947). Similar results have been obtained in infants aged 7–8 months, who appear to reach for large objects bimanually more often than for small ones (Fagard, 2000).

Another question that has been posed is to what extent infants are capable of reaching across the body midline. This requires the inhibition of a reach with the ipsilateral hand, followed by a categorical contralateral effort (Bishop, 1990). In adults, reaching across the midline is slower and less accurate than ipsilateral reaching (Carey, Hargreaves, & Goodale, 1996); additionally, it is determined primarily by information related to the proximity between the stimulus and the hand (Helbig & Gabbard, 2004). According to Bruner (1969), infants have difficulties accomplishing tasks that require reaching across the midline; he therefore proposed the term “midline barrier.” Provine and Westerman (1979) found that the ability to extend one arm across the midline to reach for laterally positioned objects emerged at approximately 18 weeks. All infants older than 20 weeks of age managed to reach for and touch single objects placed in the contralateral space (Provine & Westerman, 1979). Obviously, reaching across the body midline allows an infant to use both hands to grasp a laterally positioned object too large to grasp with one hand (Van Hof, van der Kamp, & Savelsbergh, 2002).

Adults use their preferred hand for approximately 30% of the attempts when reaching into the contralateral space (Leconte & Fagard, 2004). Interestingly, 6- to 11-year-old children use their preferred right hand in the left hemispace more consistently than adults, but also more consistently than 3- to 7-year olds (Pryde, Bryden, & Roy, 2000). Leconte and Fagard (2004, 2006) have differentiated between strongly lateralized children and inconsistent handers. In their assessments, strongly lateralized handers used their preferred hand more often when the object was presented to them contralaterally, and they did so to a greater extent during the more complex task (Leconte & Fagard, 2006). Inconsistent handers, however, appeared more likely to shift to using their nonpreferred hand when the object was presented on the same hand’s side (Leconte & Fagard, 2004). On the other hand, Bryden and Roy (2006) found that 3- to 10-year-old children used their preferred hand to grasp into the ipsilateral hemispace significantly more often than they did when the object was presented to them in the contralateral hemispace—regardless of age or task—which indicates that object proximity cues hand selection (Bryden & Roy, 2006). These results are based on cross-sectional studies; the children’s hand preference and their behavior regarding the crossing of the body midline were assessed at preschool or school age. Our longitudinal study provides the unique possibility to relate the hand use when crossing the midline at the age of 5 months to the hand use preference at late preschool age, more than 5 years later.

Based on previous findings, we posed the following questions:

- Do 5-month-old infants preferably reach for larger objects bimanually? Do smaller objects elicit unimanual reaching? And, do 5-month olds favor one particular hand for unimanual reaching?
- Is the crossing of the body midline uni- or bimanual in 5-month-old infants? To what extent does this depend on the target object?
- To what extent is hand use at 5 months of age related to hand preference at preschool age? Do children who at the age of 5 months used their right hand more often when reaching into the left hemispace have a high handedness status at preschool age? And do the children who as infants used their left hand more often

when reaching into the left hemispace have a lower handedness status at preschool age?

METHODS

Participants

Thirty-three children participated in this prospective longitudinal study focusing on various aspects of motor development. The children were recruited at the Department of Obstetrics and Gynecology of the Graz University Hospital, Austria, a few days after their birth in 1998. Inclusion criteria were as follows: singleton birth at term, appropriate birth weight, absence of pre- or perinatal complications, normal neonatal neurological findings (Einspieler & Prechtl, 2005; Prechtl, 1977), middle- or upper-class social background (defined by parental education and living conditions), and residing in or close to Graz. Until 2004, a slightly varying number of children participated in 17 assessments from birth to preschool age. The assessments were carried out and videoed at the Institute of Physiology, Medical University of Graz, with the written informed consent of the parents and in conformance with the standards of the Austrian Ethics Commission, which also approved the study.

The present study focuses on various aspects of the reaching behavior during the 5-month-assessment and on hand preference at preschool age. A considerable number of 5-month-old infants did not complete the entire assessment of reaching behavior. Their data were eliminated from the analysis due to following reasons: (a) 11 infants were unwilling to continue the assessment; and (b) 2 infants hardly ever had their hand at rest when the target object was presented to them. Hence, the assessment eventually comprised 20 children (7 boys and 13 girls; Tab. 1) who managed to reach for each object regardless of its placement (as described below). Fifteen participants, including one left-handed girl (case 17), had right-handed parents. The mother of the cases 1, 16, and 18, as well as the father of the cases 8 and 12 were left-handers.

Reaching Behavior at 5 Months of Age: Procedure and Data Analysis—The test material comprised the following objects: a yellow dumbbell rattle (length: 12 cm), a gray cup with a handle (the opening facing up; 8 cm × 6 cm × 8 cm), a red block (2.5 cm × 2.5 cm × 2.5 cm), and a red pearl (diameter: 2 cm; mounted on a string for reasons of safety).

The 5-month-old infant (± 1 week) was seated on the mother's lap at table level, facing forward, the upper limbs free to move and the trunk supported by the mother. The experimenter was seated on a chair at the table, directly opposite to the infant. The objects were placed on the table in random order: at the infant's body midline, at 45° from the midline to the right, and at 45° from the midline to the left. The distance between the hand and the object presented in the midline was approximately 75% of the infant's arm length. This radius was also used for objects placed into the right and left hemispace. The distance was the same for each object size. The dumbbell rattle was placed horizontally with its long axis left to right. The cup was presented with the opening face up and the handle toward the infant's body midline.

The aim was to achieve at least one valid trial under each condition. Trials were repeated if the infant did not reach for the object instantly, with a maximum of three presentations. If the infant did not reach within three presentations, the object was randomly placed in his/her left or right hand; the infant was allowed to handle it for a short time and develop interest. Once their interest was aroused, the item was presented to them again. In case of more than one reach per object presentation, only the first one was analyzed. Occasionally, a trial was allowed to continue after the infant had grasped the object to prevent them from getting

frustrated. We analyzed 12 trials per infant, that is, four objects presented under three different conditions.

The behavior of the infant was videotaped. Video cameras were placed above the infant and to their right in such a way that the full range of their arm movement was captured. Observational data were obtained from the video recordings by means of the Observer program (Version 4.0, Noldus Information Technology, Wageningen, The Netherlands). Two independent observers scored 12 trials per infant.

The reaching behavior (reaching for the object, reaching for and touching the object, reaching for and grasping/handling the object) was registered as one-handed (left or right) or two-handed. A two-handed reach was defined as both hands approaching the object simultaneously, before one hand or both of them contacted the object. At each trial, the interscorer agreement (Cohen's Kappa) was higher than .96.

Hand Preference at Preschool Age—Commonly, Austrian children enter kindergarten at the age of 3 years, elementary school at 6 years of age. Hence, we refer to 5 years and 7 months (± 2 weeks) as the “late preschool age.” We observed the following 19 motor tasks (adapted from Oldfield, 1971; Passian, Suchenwirth, & Ferner, 1969; Subirana, 1969; Suchenwirth, 1969): brushing the teeth, combing, crumpling a piece of paper, cutting a piece of paper, drawing, drinking, eating a cookie, finger counting, grasping the doorknob, opening a box, pointing, racing a toy car, removing an object from a box, stringing pearls, throwing a ball, using a hammer and a screwdriver, using a spoon, and writing. During video playbacks, hand use was scored by two observers (interscorer agreement, Cohen's Kappa .98). The handedness status was calculated by dividing the frequency of right hand use by the total number of tasks (e.g., Michel, Tyler, Ferre, & Sheu, 2006).

Statistics: We applied the Chi-square test for the nominal data describing the reaching behavior. The Mann–Whitney *U*-test was applied to relate the reaching behavior to the handedness status at preschool age. The statistical package SPSS 14.0 was used and a two-tailed *p*-value less than .05 was considered significant.

RESULTS

Reaching Behavior at the Age of 5 Months For each infant it was determined whether they predominantly (at least 7 out of 12 presentations) used both hands (bimanual reachers) or one hand (unimanual reachers). Data were collapsed across objects and positions.

With the exception of one participant (Tab. 1, case 15), all infants were “unimanual reachers.”

Effect of Objects on Reaching—Uni- and bimanual reaching was determined for each infant and each object (at least two out of three presentations). Data were collapsed across the object position.

The rattle (20/20), the cup (20/20), and the block (18/ 20) elicited unimanual reaching. Only the pearl elicited “predominant bimanual reaching” in 6 out of 20 infants (Chi-square = 3.2, n.s.).

Hand Use Preference During Unimanual Reaching at 5 Months of Age

For each infant and each presentation it was determined whether the object was predominantly (at least three out of four objects) approached with the left hand or with the right. Five infants (marked with ^a in Tab. 1) used predominantly both hands (at least three

out of four objects) when the object was presented at the infant's body midline. One of these infants (case 15) also used both hands for at least three out of four objects when the object was presented in the left hemispace. The distribution of bimanual reaching according to the object presentation was not significantly different (Chi-square 3.1, n.s.). These five infants were excluded from further calculations of unimanual reaching. Data were collapsed across objects.

Object presentation at the infant's body midline resulted as follows: 4 infants showed a right hand use preference; 1 infant used the left hand predominantly, and the remaining 10 infants were inconsistent in their hand use (Chi-square = 8.4, $p < .05$; Tab. 1, Fig. 1).

Object presentation in the left hemispace resulted as follows: again, the majority of the infants (14 infants) were inconsistent in their hand use. Three infants predominantly used the left hand, two infants the right (Chi-square = 14.8, $p < .001$; Tab. 1, Fig. 1).

Object presentation in the right hemispace resulted as follows: Only four infants were inconsistent in their hand use. Sixteen infants showed a right hand use preference (Chi-square = 5.4, $p < .05$; Tab. 1, Fig. 1).

Hence, when we considered only the unimanual reaching in respect to the object placement, the frequency of right hand versus left hand reaching shows that reaching is clearly ipsilateral when the object is presented to the right, relatively more right-than left handed when presented at the midline, and more inconsistent when presented to the left ($p < .05$; Fig. 1).

Crossing the Body Midline at 5 Months of Age

In order to examine the midline-crossing-behavior, only reaching into the left or into the right hemispace was scored. For each infant it was determined whether they had crossed the body midline on at least half of the attempts. Each infant was accordingly categorized as "midline crosser" or "midline noncrosser," with the data being collapsed across object and lateral position. Only five infants (Cases 2, 5, 6, 10, 20, Tab. 1) proved to be midline crossers.

In order to gain further insight into the relation between evoked reaching (uni- or bimanually) and the crossing of the midline, it was determined for all reaches crossing the midline whether the object had predominantly been approached with one hand (unimanual crossers) or with both hands (bimanual crossers). Out of the five "midline crossers," four were "unimanual crossers."

Effect of Objects on Crossing the Midline—Regarding all reaches that crossed the body midline, it was determined for each infant and for each object whether the object had predominantly been approached with one hand or with both hands. Data were collapsed across the position of the object.

The cup and the block did not elicit crossing the midline when presented in either hemispace. Out of 20 infants, 2 (Cases 10, 20; Tab. 1) were "midline-crossers" when the rattle was presented to them, and 4 (Cases 2, 5, 6, 10; Tab. 1) were "midline crossers" when reaching for the pearl. Among the latter, three used both hands to reach for the pearl both into the right and into the left hemispace.

Handedness Status at Preschool Age

With the exception of case 17, all participants showed a right-hand-preference at late preschool age (Tab. 1). The handedness status revealed various degrees of right-handedness,

reaching from .58 to .95; median .89 (interquartile range, IQR, .84, .90). Case 17 was left-handed with a handedness status of .05 (Tab. 1).

Reaching Behavior at 5 Months of Age and Handedness Status at Preschool Age

Infants who had been classified as “unimanual reachers” in respect to the object presentation ($n = 15$, Tab. 1) tended to have a higher handedness status at preschool age (median, .89; IQR, .84, .95) than those classified as “bimanual reachers” ($n = 5$; median, .81; IQR, .76, .91), but the difference was not significant (Mann–Whitney U -test, n.s.).

“Midline crossers” ($n = 5$) tended to have a lower handedness status at preschool age (median, .84; IQR, .47, .92) than “noncrossers” ($n = 15$; median, .89; IQR, .79, .95), but again, the difference was not significant (Mann–Whitney U -test, n.s.).

Predominant right hand reachers into the right hemisphere ($n = 16$; Tab. 1) had a higher handedness status at preschool age (median, .89; IQR, .84, .95) than those children who as infants had shown inconsistent hand use when reaching into the right hemisphere ($n = 4$; median, .76; IQR .25, .84; Mann–Whitney U -test, $p < .05$).

Predominant left hand reachers into the left hemisphere ($n = 3$; Tab. 1) had a lower handedness status at preschool age (median, .68; IQR, .58, .79) than those children who as infants had shown inconsistent hand use when reaching into the left hemisphere ($n = 14$; median, .87; IQR .84, .95; Mann–Whitney U -test, $p < .05$).

Predominant right hand reachers for objects presented to them at the body midline ($n = 4$; Tab. 1) tended to have a higher handedness status at preschool age (median, .92; IQR, .85, .95) than those children who as infants had shown inconsistent hand use when reaching for objects presented to them at the body midline ($n = 10$; median, .86; IQR .77, .90), but the difference was not statistically significant (Mann–Whitney U -test, n.s.).

The one child with a left hand use preference at preschool age (case 17, Tab. 1) had shown an inconsistent hand use during the reaching-assessment at the age of 5 months.

DISCUSSION

When data were collapsed across objects and positions all but one infant were for the most part unimanual reachers at 5 months of age. This is partly due to the task constraints as two-thirds of the presentations were side presentations which might favor unimanual reaching. For the majority of infants, the size and the shape of the object did not affect the occurrence of uni- or bimanual reaching. This corresponds with previous studies (Corbetta & Thelen, 1996; Fagard, 2000; Newman, Atkinson, & Braddick, 2001). As to the presentation of the cup, we did not vary between presenting the opening facing up and facing down. Newell, McDonald, and Baillargeon (1993) had found that infants used one hand when the cup was presented to them with the opening facing up, two hands when the opening was facing down. We only presented the cup with the opening facing up; all infants reached for it unimanually.

The consistency of the preference of a particular hand during the first months of reaching and grasping is object of debate. Some consider that handedness is relatively stable (Carlson & Harris, 1985; Michel & Harkins, 1986), others that variability and fluctuations are characteristic of this age period (Fagard, 2006). Our findings of inconsistent hand use described when an object was placed at the infant's body midline are in agreement with previous findings in 6-month olds (Rönqvist & Domellöf, 2006). Inconsistent hand use also holds true for objects placed in the left hemisphere. However, presentation of the various

objects in the right hemisphere evoked a predominant right hand reaching in 16 out of 20 infants. When performing actions ipsilaterally it is believed that there is a lesser need for inter-hemispheric communication, resulting in a gain of movement efficiency (Carson, Goodman, & Elliott, 1992). In his hemispheric bias hypothesis Carnahan (1998) postulated a bias toward using each hand in its respective hemisphere, as the hands perform both faster and more accurately in the ipsilateral space. Recently, Bryden and Roy (2006) stated that hand selection in reaching tasks may be determined by hand preference initially. In addition, information concerning the location of the object may be important. In their kinesthetic hypothesis, Gabbard and Rabb (2000) have argued that several processes might be at work in determining limb selection for reaching: limb dominance as associated with handedness, and attentional or spatial information related to the particular task demands.

Although we expected the majority of the 5-month-old infants to be “midline crossers” (Provine & Westerman, 1979) this was not the case. Only five infants predominantly reached into the contralateral hemisphere, four of them predominantly with one hand. The longitudinal study by Van Hof et al. (2002) on 20 infants assessed from 12 to 26 weeks of age demonstrated that the majority of midline crossings were bimanual. In addition, they found that a large object evoked midline crossing more often than a small object. These results suggested that crossing the body midline predominantly emerges in connection with bimanual reaching (Van Hof et al., 2002). In our study, the smallest object evoked more midline crossings than the other objects, but the difference was not significant. In most cases we found no object dependence for crossing the midline, even though Van Hof et al. (2002) stressed that environmental constraints such as object size did have an influence on the occurrence of midline crossing. In our study, the number of children being predominant “midline crossers” turned out to be small.

Among the children of 5 years and 7 months of age we found 19 children with a more or less strong right hand use preference. The remaining child showed a left hand use preference; during the 5-month-reaching-assessment her hand use had been inconsistent and had not indicated her later hand preference.

Michel, Sheu, and Brumley (2002) stated that the infant’s hand use preferences for apprehending objects are likely developmental precursors of adult handedness. Although in our assessment the number of participants was small, we managed to demonstrate that children who had reached for an object into the right hemisphere predominantly with their right hand were more right hand lateralized at late preschool age than children who had shown inconsistent hand use at 5 months of age (Tab. 1). This finding was independent of object and size. Furthermore, children who had reached into the left hemisphere with their left hand were less lateralized in their right hand use some 5 years later. In this respect, our longitudinal findings are in accordance with previous cross-sectional studies on handedness and concurrent reaching into hemispheres carried out in preschool and school children (Bryden & Roy, 2006; Bryden, Pryde, & Roy, 2000; Leconte & Fagard, 2004, 2006). Especially inconsistent right handers proved more likely to shift to using their nonpreferred hand when the object was presented to them on the respective side (Leconte & Fagard, 2004). Reaching toward the midline and toward positions in the ipsilateral hemisphere resulted in significantly more preferred-hand-use than reaching into the contralateral hemisphere (Bryden & Roy, 2006). These results indicate that object proximity cues hand selection (Bryden & Roy, 2006) and that handedness is a dynamic process in which motor preferences interact with task demands, probably also depending on task-related attention (Leconte & Fagard, 2004). Correspondingly, 5-year-old children reached into their contralateral hemisphere more frequently with their nonpreferred hand (Gabbard, Rabb, & Gentry, 1998; Hill & Bishop, 1998). Gabbard, Helbig, and Gentry (2001) reported that right-handed children aged 5–7 years used their dominant hand more frequently for reaching

toward the body midline position and toward their ipsilateral hemispace. Again, in the contralateral hemispace they switched to their nondominant hand. Our own study has revealed similar results—but already in infants as young as 5 months of age.

The present study shows that preferential reaching at 5 months of age is space dependent rather than object dependent. The same participants were assessed for their manipulative movements from 14 to 25 months of age. At this age, hand use preference was more consistent when grasping for, manipulating and inserting a peg than when the same action was carried out with a block, hence, it was clearly object depending (Geerts, Einspieler, Dibiasi, Garzarolli, & Bos, 2003). In addition, hand use preference was related to the complexity of the task: It fluctuated more when blocks were used for building a tower than when they were inserted (Marschik, Einspieler, Strohmeier, Garzarolli, & Prechtel, 2007).

Our main conclusion concerns the relationship between the reaching behavior at 5 months of age and later hand preference: Right-handed preschool children in the upper range of the continuum used their right hand more frequently in their own ipsilateral hemispace as early as aged 5 months; in the contralateral hemispace, their hand use was inconsistent.

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FIGURE 1.

Frequency of a predominant (i.e., at least three out of four objects) right or left hand use as well as inconsistent hand use during unimanual reaching ($n = 15$) in respect to the object placement assessed at 5 months of age.

Table 1

Gender (f, Female; m, Male), Hand Use During Unimanual Reaching in Respect to the Object Placement Assessed at 5 Months of Age, and Handedness Status (0/Left to 1/Right) Assessed at 5 Years and 7 Months of Age ($n = 20$)

Case	Preferred Hand Use (At Least 3/4 Objects) During Unimanual Reaching at 5 Months of Age			Handedness Status at Preschool Age
	At Body Midline	At 45° to the Left	At 45° to the Right	
17 f	Inconsistent	Inconsistent	Inconsistent	.05
12 m	Inconsistent	Left	Right	.58
1 f	<i>a</i>	Left	Inconsistent	.68
16 m	<i>a</i>	Left	Right	.79
13 f	Left	Inconsistent	Right	.79
2 f	Inconsistent	Inconsistent	Right	.84
4 m	Inconsistent	Inconsistent	Right	.84
5 f	<i>a</i>	Inconsistent	Right	.84
3 f	Inconsistent	Inconsistent	Inconsistent	.84
9 m	Right	Inconsistent	Inconsistent	.84
15 m	<i>a</i>	<i>a</i>	Right	.89
6 f	Inconsistent	Inconsistent	Right	.89
19 f	Inconsistent	Inconsistent	Right	.89
10 f	Right	Right	Right	.89
20 m	Inconsistent	Right	Right	.89
8 f	Inconsistent	Inconsistent	Right	.95
11 f	<i>a</i>	Inconsistent	Right	.95
14 f	Right	Inconsistent	Right	.95
7 f	Inconsistent	Inconsistent	Right	.95
18 m	Right	Inconsistent	Right	.95

^aPredominant bimanual reaching.