Infant Behavior & Development 32 (2009) 137–146

Contents lists available at ScienceDirect

Infant Behavior and Development

Reaching and grasping a moving object in 6-, 8-, and 10-month-old infants: Laterality and performance

Jacqueline Fagard [a,*], Elizabeth Spelke [b], Claes von Hofsten [c]

[a] Laboratoire Psychologie de la Perception, Université Paris-Descartes, 45 rue des Saints-Pères, 75006, Paris CNRS, France
[b] Department of Psychology, Harvard University, Cambridge, MA 02138, USA
[c] Department of Psychology, Uppsala University, 75142 Uppsala, Sweden

ARTICLE INFO

Article history:
Received 3 January 2008
Received in revised form 28 October 2008
Accepted 13 December 2008

Keywords:
Reaching
Grasping
Moving objects
Infants
Handedness
Visual field

ABSTRACT

The goal of this study was to investigate some of the visuo-motor factors underlying an infant's developing ability to grasp a laterally-moving object. In particular, hand preference, midline crossing, and visual-field asymmetry were investigated by comparing performance as a function of the object's direction of motion. We presented 6-, 8-, and 10-month-old infants with a graspable object, moving in a circular trajectory in the horizontal plane. Six-month-old infants reached for the object with the ipsilateral hand and grasped it with the contralateral hand. Eight-month-old infants showed a strong right-hand bias for both reaching and grasping. Ten-month-old infants showed a greater diversity of strategy use including bimanual and successful ipsilateral grasping following ipsilateral reaching in both directions of motion. Thus, motor constraints due to spatial compatibility, hand preference and bimanual coordination (but not midline crossing) must be taken into account to understand age differences in grasping a moving object.

1. Introduction

Several studies have shown that, as early as 18 weeks, infants are able to perform predictive actions in the direction of a moving object in order to grasp it (von Hofsten, 1980, 1983; von Hofsten & Lindhagen, 1979; von Hofsten, Vishton, Spelke, Feng, & Rosander, 1998). Indeed, infants reach for a moving object by initiating arm and hand movement before the object is within reach. The reaching is predictive in that it is geared towards a future position of the moving object rather than towards the object's initial position at the beginning of the reaching movement. Although infants make reaching attempts as early as 15 weeks of age, these reaches lead to touching rather than to grasping of an object (von Hofsten & Lindhagen, 1979). Grasping a moving object becomes increasingly successful over the following weeks. When the object is moving laterally (right to left or left to right) several factors related to handedness and bimanual coordination may influence the rate of successful grasping. The goal of the present study was to explore age-related differences in hand preference, crossing the midline, switching of hands, planning for contralateral hand grasping, and the use of both hands together, to assess relative contributions to progress in grasping a laterally-moving object. Thus, the effect of the object's direction of motion (right-to-left versus left-to-right) on infants' performance was analysed.

Since *handedness* changes during the second half of the first year of life, this in particular might influence the strategies used to grasp a laterally-moving object. Infants show some degree of hand preference as soon as voluntary grasping emerges,

* Corresponding author. Tel.: +33 1 42864316.
E-mail address: jacqueline.fagard@parisdescartes.fr (J. Fagard).

0163-6383/$ – see front matter © 2008 Elsevier Inc. All rights reserved.
doi:10.1016/j.infbeh.2008.12.002

as indicated by both cross-sectional (Cornwell, Harris, & Fitzgerald, 1991; Fagard, 1998; Gesell & Ames, 1947; Hawn & Harris, 1983; Michel, Ovrut, & Harkins, 1985; Morange & Bloch, 1996; Peters, 1983), and longitudinal studies (Carlson & Harris, 1985; Coryell & Michel, 1978; McCormick & Maurer, 1988; Michel & Harkins, 1986; Ramsay, 1985; Ramsay, Campos, & Fenson, 1979; see Michel, 1984 and Provins, 1992, for reviews). However, during the course of the first year, hand preference, when tested on simple grasping, is not very strong, fluctuating between right-handedness, left-handedness, and no hand preference, even though right-handedness is more frequent than left-handedness from the outset (Carlson & Harris, 1985; Corbetta & Thelen, 1996; Gesell & Ames, 1947; Fagard, 1998; Flament, 1975; McCormick & Maurer, 1988; Thelen, Corbetta, & Spencer, 1996). Handedness is more easily observed in particularly challenging tasks, such as bimanual manipulation (Fagard & Marks, 2000), or grasping a small object inserted into another (Fagard & Lockman, 2005). We hypothesized that grasping a moving object would be challenging enough to call hand preference into play, and that we would observe globally more right-hand than left-hand use, leading to differential performance depending on the direction of motion (from right to left versus left to right). We expected hand preference to increase with age in line with the findings of Fagard (1998), but only up until a certain point, following which hand preference becomes less marked as the task becomes less challenging (for the older infants).

However, the intrinsic preference for one hand or another is not the only variable to influence hand choice in reaching: infants, to a greater extent than older children and adults, tend to *use their ipsilateral hand* to reach for a laterally-presented object (Fagard, 1998; Morange & Bloch, 1996; Sacco, Moutard, & Fagard, 2006). Hand differences in reaching kinematics and spatio-temporal organization (Corbetta & Thelen, 1999; Morange Majoux, Peze, & Bloch, 2000) may modulate the level of difficulty associated with reaching for moving objects depending on whether the ipsilateral hand is the preferred hand or not. If the reaching movement performed by the ipsilateral hand is not fast enough to capture an object in the ipsilateral hemifield, then the infant may need either to cross the midline or to switch to the contralateral hand.

Crossing the body midline can be observed from the age infants begin to reach for objects (Provine & Westerman, 1979). It has sometimes been considered a milestone in infant development (Bruner, 1970). Later research has been more inclined to approach the concept of midline crossing from a functional point of view. van Hof, van der Kamp, and Savelsbergh (2002) presented young infants with different-sized objects and found that spontaneous midline crossing was primarily expressed within the context of bimanual grasping of large objects where two hands were needed. Crossing the midline is also more frequent with the preferred than with the non-preferred hand (Fagard, 1998). We thus hypothesized that infants would be more likely to cross the midline with the right hand in the right-left direction than with the left hand in the left-right direction. More generally, we wanted to investigate whether crossing the midline to pursue on object after having failed to grasp it with the ipsilateral hand would change over the age period studied.

After failing to grasp an object with the ipsilateral reaching hand, infants can also *switch to the contralateral hand.* Contralateral grasping appears to be a common strategy which increases with the speed of the object (von Hofsten, 1980, 1983; von Hofsten & Lindhagen, 1979; Hof, van der Kamp, Caljou, & Savelsbergh, 2005). In addition to switching hands after an ipsilateral reaching, using the contralateral hand to grasp a moving object can be the result of a contralateral reaching from the start. One point investigated here was whether improvement in grasping a moving object would be associated with an increase in contralateral grasping frequency, and, if this is the case, whether it would be associated with an increased capacity to switch hands or planning the use of the contralateral hand from the onset of object motion. Hand switching during object manipulation belongs to an infant's early motor repertoire (Fagard & Lockman, 2005). But this strategy requires some kind of intermanual coordination, which, like complementary bimanual coordination, might not necessarily be fully developed until some time during the last half of the first year of life (Fagard, 1994). Reaching with the contralateral hand from the onset of object motion enables the infant to meet the object instead of chase it and provides extra time for planning the grasp, allowing him/her to simply wait for the object to move forward before grasping it. We expected this tendency to be larger if the preferred hand, rather than the non-preferred hand, was on the contralateral side relative to the departure point of the motion.

Our experimental set-up therefore involved 6-, 8-, and 10-month-old infants being presented with an object that moved laterally within reaching distance either from left to right or vice versa. Grasping performance was compared between the two directions of motion, and its relation to right-hand versus left-hand use, ipsilateral versus contralateral hand use, midline-crossing and hand-switching frequencies was analysed.

2. Methods

2.1. Participants

Eight 6-month-olds (mean age: 6 months 2d), six 8-month-olds (mean age: 8 months 1d), and seven 10-month-olds (mean age: 10 months 5d) took part in the experiment: 11 girls and 10 boys, evenly distributed across age groups. All infants were full-term, with no known or suspected abnormalities, and were from middle-class families, recruited from a list of local families who expressed interest in being part of infant development studies. Infants were tested at the laboratory and prior parental consent was granted before observation. The experiment was conducted in accordance with the ethical standards specified in the 1964 Declaration of Helsinki.

Fig. 1. Apparatus and experimental set-up.

2.2. Design and material

To present the infant with a moving object, we used a motion-producing apparatus similar to the one described in von Hofsten and Lindhagen (1979) (see Fig. 1). An object was attached to the end of a 55-cm-long horizontal glass–fibre rod, fastened via a felt coupling to the perpendicular shaft of an electric motor with variable speed and direction. Speed was set to 30 cm/s. The objects moved along a horizontal circular path approximately 115 cm in diameter at the infant's nose height: this was ensured by moving the rod up or down as a function of the infant's height. Objects were small plastic or furry and brightly-coloured figures (1–3 cm).

2.3. Procedure

The infants sat in a baby chair, in front of the apparatus, with the parent(s) standing behind them. Testing began once the infant was accustomed to the surroundings. The experimenter presented the object to the infant without letting him or her grasp it, then fastened it to the rod before starting the motion. Motion direction alternated between right to left (R–L) and left to right (L–R). The direction of the first trial was counterbalanced within age groups. When the infants succeeded in grasping the object, they were allowed to play with it for a few seconds. Subsequently, the same or another object was presented in the reversed direction. When an infant failed to grasp the object, the same object was put in motion in the reversed direction. The infants received between 10 and 15 trials in each condition. Two 25 Hz digital video cameras recorded the whole session, one above and one in front of the infant. Using the videotape recordings, two observers first coded independently when the reaching movement started, whether the infants touched or grasped the object, and with which hand, until at least a 98% inter-rater agreement was reached. Onset of reaching was defined as the first frame in which the hand is seen moving towards the object.

2.4. Variables

We analyzed the frequency of successful touching (i.e. reaching) and of full success (i.e. grasping). "Hand used" for reaching was scored as bimanual only if the two hands started synchronously or with a delay of less than 80 ms. Grasping was considered unimanual as long as the second hand did not touch the object before it was detached from the rod. Reach-grasp strategies leading to success were categorized according to which hand was used for reaching and grasping in the same trial: [RH (right hand) initiation – RH grasp/RH initiation – LH (left-hand) grasp/RH initiation – Bim (bimanual) grasp; LH initiation – RH grasp/LH initiation – LH grasp/LH initiation – Bim grasp; Bim initiation – RH grasp/Bim initiation – LH grasp/Bim initiation – Bim grasp)]. Trials in which the infants did not try to touch or grasp the object were discarded.

2.5. Statistical analyses

ANOVAs with age and direction of motion (repeated measures) as independent variables were calculated for the following dependent variables: percentage of success in touching and grasping the object, percentage of unimanual strategies used (left, right, and right–left difference), percentage of bimanual strategies used, percentage of reach-grasp strategies leading to success used (such as described in the previous paragraph), and position of the object at the onset of reaching. *T*-tests for matched samples were added for within age-group comparisons between the two directions of motion when the effect for direction was close to significant (p between .05 and .10). In such cases, we also calculated the effect size (Corroyer & Rouanet, 1994), using Cohen's "*d*" statistic (Cohen, 1977).

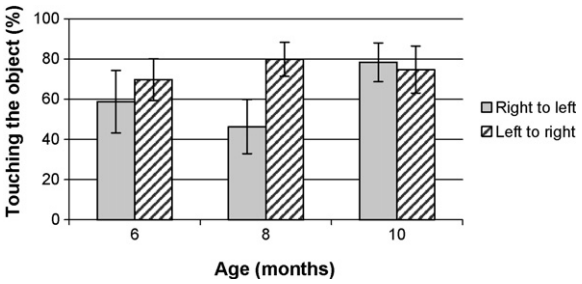

Fig. 2. Touching the object as a function of direction at 6, 8, and 10 months (with or without grasping).

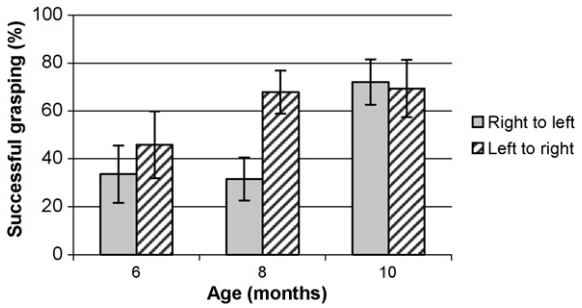

Fig. 3. Grasping the object as a function of direction at 6, 8, and 10 months.

3. Results

3.1. Touching and grasping an object moving from right to left versus left to right

The majority of infants managed at least to touch the moving object (61.7%, S.D.: 28.6 and 74.4%, S.D.: 20.2, for RL and LR, respectively). An ANOVA for age and direction of motion (repeated measures) calculated with the percentage of trials in which the object was touched (with or without grasping) showed no significant main effect for age and direction, and no significant age × direction interaction. However, the effect for direction, although non significant, was large ($F(1,18) = 3.5$, $p < .05$; $d = .88$). This effect is mostly due to the 8-month-olds who touched the object more often when it was moving from left to right than when it was moving from right to left (see Fig. 2). A *t*-test for matched samples showed that this difference was significant at 8 months ($t(5) = -.275$; $p < .04$).

Touching the object was followed by successful grasping in many trials but not all. An ANOVA for age and direction of motion (repeated measures) calculated with the percentage of full success (object grasped) showed significant effects for age ($F(2,18) = 6.28$, $p < .01$), and for direction ($F(1,18) = 5.5$, $p < .05$), but no significant age × direction interaction. Grasping improved with age. An LSD post-hoc test indicated that the age effect was due to the difference between the two younger groups and the 10-month-olds. The direction effect was due to the two youngest age groups who grasped the object more often when it was moving from left to right than when it was moving from right to left, especially the 8-month-olds (see Fig. 3). A *t*-test for matched samples showed that this difference was significant at 8 months ($t(5) = -4.22$; $p < .01$).

We also calculated the percentage of successful grasping relative to successful touching and found that it increased with age (see Table 1). An ANOVA for age and direction of motion (repeated measures) calculated with this percentage showed a significant effect for age ($F(2,17) = 4.87$, $p < .05$), but no significant effect for direction and no significant age × direction interaction. A LSD post-hoc analysis indicated that there was no significant difference between 6- and 8-month-olds and between 8- and 10-month-olds. In contrast, the difference was significant between the 6- and 10-month-olds ($p < .01$).

Table 1
Percentage of successful grasping relative to successful touching as a function of age and direction of motion (S.D.).

Age group	Right to left	Left to right
6	59.6 (23.3)	74.8 (23.5)
8	68 (36.7)	86.2 (19.5)
10	97.9 (5.4)	95.3 (9.4)

Table 2
Frequency (% of all trials) of bimanual reaching and grasping as a function of age and direction of motion (S.D.).

	Reaching		Grasping	
	Right to left	Left to right	Right to left	Left to right
6	4.5 (12.8)	4.4 (9)	10.4 (17.5)	15.7 (21.5)
8	4.4 (7.2)	6.1 (7.1)	9.2 (12.1)	8.5 (9.8)
10	28.7 (34)	5.1 (7.5)	26.7 (28.6)	11.7 (15.3)

3.2. Strategies for reaching and grasping

3.2.1. Unimanual versus bimanual reaching

Most reaching movements were unimanual. An ANOVA for age and direction (repeated measures) calculated using the percentage of bimanual reaching showed no significant main effect but an age × direction interaction ($F(2,18) = 4.31$, $p < .05$). An LSD post-hoc test indicated that the effect was due to the difference in the right-to-left direction between the two younger groups and the 10-month-olds, the latter executing about a quarter of their reaches bimanually for an object moving in this direction (see Table 2).

3.2.2. Hand used for unimanual reaching

All conditions and age groups considered, there was slightly more right-hand (49.13%) than left-hand reaching (42%). An ANOVA for age and direction of motion (repeated measures) was calculated using the difference in frequency between right- and left-hand reaching: a significant effect for age was found ($F(2,18) = 3.4$, $p < .05$), a significant direction effect ($F(1,18) = 16.9$, $p < .001$), but no significant age × direction interaction. The age effect was due to the difference between the 8-month-olds and the two other groups. When all age groups were considered, most reaches were right-handed when the object started its motion from the right (RH: 65.6%; LH: 21.8%), and left-handed when it started from the left (RH: 32.6%; LH: 62.2%). However, as opposed to the 6- and 10-month-olds who tended to reach with the ipsilateral hand, the 8-month-olds reached more often with their right hand in both conditions of direction (see Fig. 4).

3.2.3. Unimanual versus bimanual grasping

Although grasping was slightly more often bimanual than was reaching, it was mostly unimanual in both directions of motion (see Table 2). An ANOVA for age and direction (repeated measures) calculated using the percentage of bimanual grasping showed no significant main effect and no age × direction interaction.

3.2.4. Hand used for unimanual grasping

All conditions and age groups considered, there was more right-hand (22.04%) than left-hand grasping (16.9%). An ANOVA for age and direction of motion (repeated measures) was calculated using the difference in frequency between right- and left-hand grasping, and it was found that there was no effect for age, a significant direction effect ($F(1,18) = 34.05$, $p < .0001$), and no significant age × direction interaction. When all age groups were considered, most grasps were left-handed when the object started from the right (RH: 6.8%; LH: 23.04%), and right-handed when the object started from the left (RH: 37.31%; LH: 10.87%). The 6-month-olds tended to grasp with the hand contralateral to the side of object departure, whereas the 8-month-olds grasped globally more often with their right than with their left hand, and more so when the right hand was contralateral to the side of object departure (see Fig. 5).

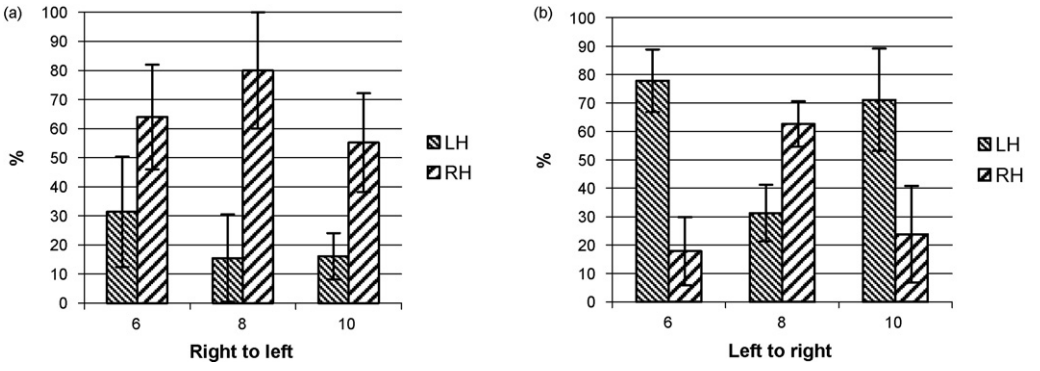

Fig. 4. Frequency of right-hand and left hand unimanual reaching at 6, 8, and 10 months in the right-to-left (4a) and left-to-right (4b) direction of motion.

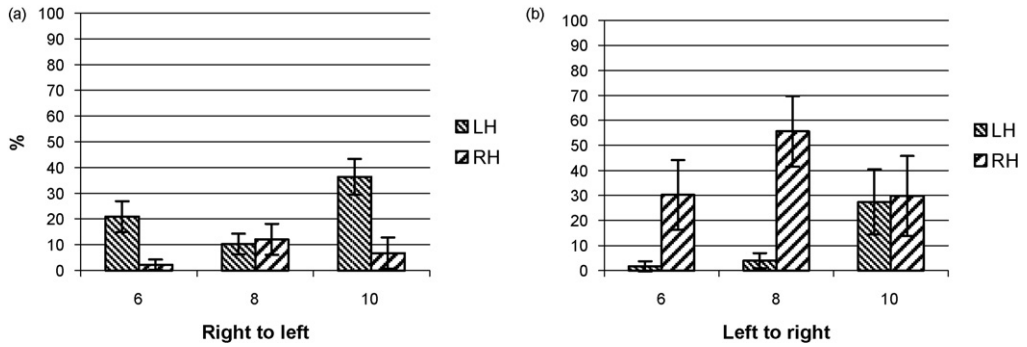

Fig. 5. Frequency of right-hand and left hand unimanual grasping at 6, 8, and 10 months in the right-to-left (5a) and left-to-right (5b) direction of motion.

3.2.5. Crossing the midline

Crossing the midline may be unimanual (one hand alone crosses the midline) or bimanual (one hand joins the other hand across the midline). Unimanual crossing of the midline occurred when infants started unimanually with the ipsilateral hand, could not grasp the object in time before it moved to the other hemifield, and then pursued it to grasp or try to grasp it (there was almost no instance of the contralateral hand crossing the midline to grasp the object unimanually). The frequency of unimanual crossing of the midline decreases with age (see Table 3). An ANOVA for age and direction of motion (repeated measures) calculated using the frequency of unimanual crossing showed a significant effect for age ($F(2,18) = 6.9$, $p < .02$), no effect for direction of motion and no significant interaction. A post-hoc LSD test indicated that the age effect was due to the difference between the 6- and the 10-month-olds. Unimanual midline crossing was almost never followed by successful grasping. Note that 8-month-olds tended to cross the midline with the right hand in the right-left direction more than with the left hand in the left-right direction. However, the difference was not significant.

Bimanual crossing occurred when infants crossed the midline with one hand joining the other hand for a bimanual grasp (or tentative grasp) of the object. This could have been the hand contralateral to the side of the object's departure joining the ipsilateral hand before the object crossed the midline, or the ipsilateral hand crossing the midline being then helped by the contralateral hand to grasp the object. An ANOVA for age and direction of motion (repeated measures) calculated using the frequency of bimanual crossing showed no significant effect for age and direction, and no age × direction interaction. Note that bimanual grasping occurred often at the midline, especially in 10-month-old infants, yet these occurrences were not considered as bimanual crossing of the midline.

3.2.6. Manual strategies leading to successful grasping: analysis of whole reach-to-grasp strategies used

To check to what extent progress in grasping a moving object was associated with change in unimanual skill or in cooperation between hands, whether by switching hands or by using both hands together, we coded the different strategies leading to successful grasping, and we compared the relative frequencies of each strategy:

- RH (right hand) initiation-RH grasp (1)/RH initiation – LH (left-hand) grasp (2)/RH initiation – Bim (bimanual) grasp (3);
- LH initiation – RH grasp (4)/LH initiation – LH grasp (5)/LH initiation – Bim grasp (6);
- Bim initiation – RH grasp (7)/Bim initiation – LH grasp(8)/Bim initiation – Bim grasp (9).

Table 4 shows the frequency of each strategy as a function of age in the R–L (4a) and L–R (4b) directions of motion. At 6 months, when infants tended to start reaching with their ipsilateral hand and to grasp with their contralateral hand, most successful instances of grasping occurred after hand switching. However, as can be seen in Table 4a and b, the 6-month-olds were more likely to activate their right hand after having started with their left hand when the object was moving from left to right, than to activate their left hand after having started with their right hand when the object was moving from right to left. This is valid if one considers sequential activation (one hand, then the other), or the second hand joining the first one (one hand, then bimanual). Some successful grasping also occurred in infants of this age when the contralateral hand reached for and unimanually grasped the object. The 8-month-olds' main strategy consisted in using their right hand, for both reaching and grasping, alone in the left-right direction, or in coordination with the left hand (sequentially or in conjunction) in the

Table 3
Percentage of unimanual and bimanual crossing of the midline as a function of age and direction of motion (S.D.).

	Unimanual crossing		Bimanual crossing	
	Right to left	Left to right	Right to left	Left to right
6	16.5 (16)	23.2 (24)	10 (17)	9.4 (14.)
8	16.2 (12)	9.4 (20)	10.2 (14)	5.8 (6.6)
10	1.3 (3.4)	6.6 (6.2)	14.8 (18)	8.6 (9.4)

Table 4
Frequency of the different reach-grasp strategies leading to success as a function of age (% of all trials).

Reach	RH	RH	RH	LH	LH	LH	BH	BH	BH
Grasp	RH	LH	BH	LH	RH	BH	RH	LH	BH
a: Object moving from right to left									
6	1, 1	7, 3	6, 6	13, 6	0, 0	0, 0	0, 0	0, 0	3, 4
8	10, 6	5, 8	6, 4	2, 8	0, 0	2, 8	0, 0	1, 7	0, 0
10	7, 6	12, 0	17, 0	8, 9	0, 0	0, 0	1, 3	12, 6	12, 5
b: Object moving from left to right									
6	9, 6	0, 0	0, 0	2, 9	17, 0	13, 4	3, 1	0, 0	0, 0
8	48, 2	0, 0	1, 2	3, 9	1, 2	5, 7	6, 1	0, 0	0, 0
10	14, 7	0, 0	0, 0	27, 4	11, 4	11, 7	4, 2	0, 0	0, 0

right-left direction. There were several different strategies used which lead to successful grasping at 10 months of age. In the right-left direction of motion, grasping was found to be, in order of frequency from highest to lowest, bimanual following a right-hand or a bimanual initiation, left-handed following a bimanual or a unimanual (right- or left-hand) initiation, or right-handed following a right-hand initiation. In the left-right direction of motion, the strategies tended to be less variable across infants, as ipsilateral (left-handed) reaching often lead to successful grasping with the same hand. However, there were other successful strategies employed such as right-handed reaching followed by right-handed grasping, or left-handed reaching followed by right-handed or bimanual grasping.

We then grouped grasping strategies into three categories: unimanual without hand switching (1, 5, 7, and 8), unimanual with hand switching (2 and 4), and bimanual (3, 6, and 9). Fig. 6 shows that the increase in successful grasping corresponds mainly to an increase in unimanual strategy without switching hands. An ANOVA for age and direction of motion (repeated measures) calculated using the percentage of trials involving successful unimanual grasping without switching hand (out of all trials) revealed a significant effect for age ($F(2,18) = 4.4$, $p < .05$), a significant effect for direction ($F(1,18) = 14.6$, $p < .01$), and a significant age x direction interaction ($F(2,18) = 5.4$, $p < .02$). A post-hoc LSD test indicated that the age effect was due to the difference between 6-month-olds and the two older groups of infants.

3.3. Spatial field-related differences in the onset of reaching

Finally, we examined the position of the object in the visual field when infants started reaching (with the ipsilateral or the contralateral hand) to check whether we would find a visual-field asymmetry, as in Lange Kuttner and Crichton's study (1999). Lange-Kuttner and Crichton found perceptual asymmetries in infants that were different for visual tracking and reaching: a right spatial field bias for tracking in 16–18-week-old infants, but a left spatial bias for reaching in 18–20-week-old infants. In order to compare with Lange-Kuttner and Crichton's results, the present study involved pooling positions in such a way as to distinguish distal locations (20° to 40° and −20° to −40° for R–L and L–R, respectively) and proximal locations of the object (1° to 19° and −1° to −19° for R–L and L-R respectively). As can be seen in Fig. 7, starting onsets were mostly symmetrical. The only difference lay in the greater number of movement initiations when the object was in a distal location in the R–L as compared with the L–R direction of movement found at 8 months of age. A student t-test revealed the difference to be significant ($t(55) = 2.8$, $p < .05$). This difference was due to a high percentage of right-handed reaching movements at 8 months. When the infants started with their right hand, they started earlier when the object came from the right than when it came from the left side

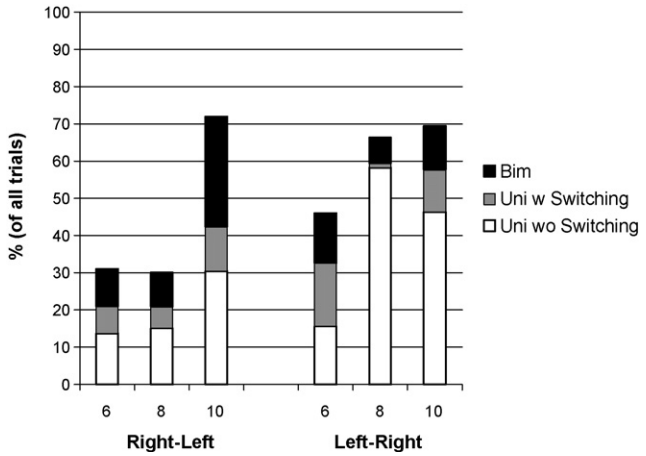

Fig. 6. Frequency of the three main strategies (unimanual with or without hand switching, bimanual) as a function of age and direction of motion.

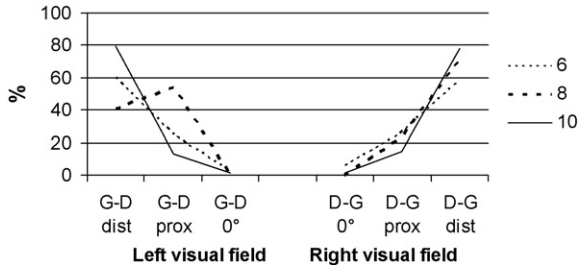

Fig. 7. Frequency of reaching onset when the object was at proximal versus distal location as a function of age and direction of motion.

of space. When the infants started mostly with the ipsilateral hand (at 6 and 10 months), there was no asymmetry found.

4. Discussion

Grasping a moving object can be a challenging task for 6- to 10-month-old infants, and even more so for younger than for older infants. Furthermore, handedness, which emerges over this age period (see e.g. Fagard, 1998), is more likely to show up on difficult tasks (Fagard & Marks, 2000). Applying these principles to the present study, it was expected that differences in hand use in reaching, grasping, crossing the midline and switching would influence success in grasping a laterally-moving object and would influence it differentially when the object moved from right to left or left to right. We also expected the manifestation of handedness to increase from 6 to 8 months of age in this task, and then decrease as the task became less challenging. The results confirmed these basic expectations. Grasping performance improved with age and differed between the two directions of motion, being more efficient when the right hand was the contralateral hand in the two younger groups, but not any better for the 10-month-olds. In addition, it was found that while neither the 6-month-olds nor the 10-month-olds expressed a clear hand preference, the 8-month-olds showed a significant right hand preference.

In general, reaching actions towards a moving object consist of two parts, an initial approach and a final grasp. The strategies used for reaching and grasping were found to differ significantly between the three age groups. At 6 months, the initial approach was most often performed by the ipsilateral hand and the final grasp most often by the contralateral hand. This tendency to begin reaching for the object with the ipsilateral hand is in line with other findings (Fagard, 1998; Morange & Bloch, 1996; Sacco et al., 2006). For the 6-month-olds, where reaches ended up in successful grasping of the object, the left hand was involved most often when the object came from the right, and the right hand was involved most often when the object came from the left. This tendency to grasp the object with the contralateral hand also replicates earlier findings (von Hofsten, 1980, 1983). Grasping the object with the contralateral hand enables the child to meet the object instead of chase it and concurrently provides more time for planning the capture of the object.

At 8 months, laterality interacts with the tendency to make an initial approach with the ipsilateral hand and to grasp with the contralateral hand. Eight-month-olds initially approached the object with the right hand more often than with the left hand in both directions of motion, although to a greater extent when the right hand was the ipislateral hand than when it was the contralateral hand. Thus, at 8 months, handedness was a more powerful factor than ipsilaterality. Similarly, 8-month-olds tended to grasp the object with their right hand, almost exclusively when the right hand was the hand contralateral to the origin of the motion and to a lesser extent when it was ipsilateral to it.

The 10-month-olds showed a greater diversity of strategies used for executing the whole movement, including frequent bimanual strategies and successful ipsilateral grasping following ipsilateral reaching. The fact that manual strategies when grasping a moving object change in a non-linear way during the first year of life is in line with other findings (van Hof et al., 2005).

Crossing the midline with the ipsilateral hand when trying to grasp an object is a less useful grasping strategy than using the hand contralateral to the object. If the reach is properly planned with the contralateral hand, the object should arrive straight in front of the hand they want to capture it with at the completion of the reach. If the child has a tendency to plan reaches with their preferred hand there will be a greater chance that the child uses the right hand even when it would be more rational to use the left. Thus, we expected more frequent midline crossings with the right hand in the right–left direction than with the left hand in the left–right direction. This expectation was not confirmed, except as a tendency at 8 months. The maturational hypothesis stating that midline crossing will increase with age (see e.g. Bruner, 1970) was clearly not validated in this study. On the contrary, it was found that the frequency of midline crossings decreased with age. There are several possible explanations for this age-related decrease in crossing the midline in a unimanual context: first of all, the 6-month-olds, who started reaching most often with the ipsilateral hand, were less skilful that the older infants in grasping the moving object, and thus were more likely to have the opportunity to follow the object in the contralateral hemifield. Eight-month-old infants, on the other hand, began more often their reach with their contralateral hand than the 6-month-olds, especially in the left-right direction, allowing them to intercept the object with the contralateral hand. And the 10-month-olds, who, like the 6-month-olds, often started with the ipsilateral hand, were more skilful in grasping the object

before it crossed the midline, with one or two hands, including with the left hand. These results might reflect an increased involvement of advanced cognitive strategies with age in reaching for moving objects (Fagard, 1998; Schaffer, Greenwood, & Parry, 1972; Schaffer & Parry, 1970). One indication of such cognitive strategies is suggested by the 8-month-olds' tendency to wait, before starting the reaching movement with the right hand, for a rightward moving object to enter the proximal field. The results presented here do not fit with the visual-field asymmetries found for reaching in younger infants (Lange Kuettner & Crichton, 1999). Finally, whereas no hand difference was found for crossing the midline, the 6-month-olds, who frequently began reaching with their ipsilateral hand without being able to grasp the object before it reached the midline, switched more often to their right hand after a left-hand start than the reverse.

In terms of handedness, these results clearly show that laterality is not something that emerges independently of the task. Some expression of right-hand preference was already present at 6 months, although other tendencies such as ipsilateral activation were more powerful. Consistent choice of using the right hand was most apparent for the 8-month-olds, but even then, hand preference was very much modified by the task. Finally, the 10-month-olds were successful at grasping an object even when using their left hand. The decline in right-hand use in favor of left-hand and bimanual actions for the 10-month-olds might indicate that the task had become less of a challenge at this age, leading to weaker manifestation of handedness, or that increasing bimanual coordination (Fagard, 1994) allowed a diversity of the strategies. It is also possible that laterality fluctuates as a function of age. This has been noted by other investigators (Corbetta & Thelen, 1996; Fagard, 1997; Goldfield & Michel, 1986). Since there was no independent assessment of handedness for these infants in a simple grasping task, which was decided upon in order to have the maximum number of trials with the moving object at an age when infants easily become tired, the possibility that individual differences in terms of handedness make up some of the age differences cannot be eliminated.

In conclusion, these results show that reaching for moving objects becomes more efficient with age, first in the rightward direction (at 8 months), reflecting an increased frequency of reaching movement with the contralateral right hand, and then in the leftward direction (at 10 months), reflecting an increased ability to grasp an object with the hand ipsilateral to the side of its departure before it crosses the midline, even when it was the left hand, either by itself or with the help of the contralateral hand. This progress may reflect improved cognitive strategies with age, for example for determining when and how the moving object should be approached. But in addition to the need for predicting the path of a moving object, motor constraints due to spatial compatibility, hand preference and bimanual coordination must be taken into account in order to understand age differences in grasping a moving object.

References

Bruner, J. S. (1970). The growth and structure of skills. In K. J. Connolly (Ed.), *Motor skills in infancy* (pp. 63–94). New York: Academic Press.

Carlson, D. F., & Harris, L. J. (1985). Development of the infant's hand preference for visually direct reaching. *Infant Mental Health Journal*, *6*, 158–172.

Cohen, J. (1977). *Statistical power analysis for the behavioral sciences* (rev. ed.). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Corbetta, D., & Thelen, E. (1996). The developmental origins of bimanual coordination: a dynamic perspective. *Journal of Experimental Psychology. Human Perception and Performance*, *22*(2), 502–522.

Corbetta, D., & Thelen, E. (1999). Lateral biases and fluctuations in infants' spontaneous arm movements and reaching. *Developmental Psychobiology*, *34*(4), 237–255.

Cornwell, K. S., Harris, L. J., & Fitzgerald, H. E. (1991). Task effects in the development of hand preference in 9-, 13-, and 20- month-old infant girls. *Developmental Neuropsychology*, *7*(1), 19–34.

Corroyer, D., & Rouanet, H. (1994). Sur l'importance des effets et ses indicateurs dans l'analyse statistique des donnees. On the importance of effect size and indicators of effect size in the statistical analysis of data. *Année Psychologique*, *94*(4), 607–623.

Coryell, J. F., & Michel, G. F. (1978). How supine postural preferences of infants can contribute toward the development of handedness. *Infant Behavior and Development*, *1*, 245–257.

Fagard, J. (1997). Motricité réactive versus motricité prédictive: changements dans le geste d'atteinte de l'objet au cours de la première année. In J. Lorenceau, A. Streri, B. Victorri, & Y. M. Vissetti (Eds.), *Le mouvement: des boucles sensori-motrices aux représentations cognitives et langagières*. Bonas: Actes de la sixième école d'été de l'Association pour la Recherche Cognitive.

Fagard, J. (1998). Changes in grasping skills and the emergence of bimanual coordination during the first year of life. In K. J. Connolly (Ed.), *The Psychobiology of the hand, Clinics in Developmental Medicine* (pp. 123–143). Londres: Mac Keith Press.

Fagard, J. (1994). Manual strategies and interlimb coordination during reaching, grasping, and manipulating throughout the first year of life. In S. P. Swinnen, H. Heuer, J. Massion, & P. Casaer (Eds.), *Interlimb coordination: neural, dynamical, and cognitive constraints* (pp. 439–460). New York: Academic Press.

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

Fagard, J., & Marks, A. (2000). Unimanual and bimanual tasks and the assessment of handedness in toddlers. *Developmental Science*, *3*(2), 137–147.

Flament, F. (1975). *Coordination et prévalence manuelle chez le nourisson*. Paris: Editions du Centre National de la Recherche Scientifique.

Gesell, A., & Ames, L. B. (1947). The development of handedness. *Journal of Genetic Psychology*, *70*, 155–175.

Goldfield, E. C., & Michel, G. F. (1986). The ontogeny of infant bimanual reaching during the first year. *Infant Behavior and Development*, *9*, 87–95.

Hawn, P. R., & Harris, L. J. (1983). Hand differences in grasp duration and reaching in two- and five-month-old infants. In G. Young, S. J. Segalowitz, C. M. Corter, & S. E. Trehub (Eds.), *Manual specialization and the developing brain* (pp. 331–348). New York: Academic Press.

von Hofsten, C. (1980). Predictive reaching for moving objects by human infants. *Journal of Experimental Child Psychology*, *30*, 369–382.

von Hofsten, C. (1983). Catching skills in infancy. *Journal of Experimental Psychology. Human Perception and Performance*, *9*(1), 75–85.

von Hofsten, C., & Lindhagen, K. (1979). Observations on the development of reaching for moving objects. *Journal of Experimental Psychology*, *28*, 158–173.

von Hofsten, C., Vishton, P., Spelke, E. S., Feng, Q., & Rosander, K. (1998). Predictive action in infancy: Tracking and reaching for moving objects. *Cognition*, *67*(3), 255–285.

Lange Kuettner, C., & Crichton, M. T. (1999). Change of spatial field effects in 16- to 20-week-old infants. *Brain and Cognition*, *39*(2), 75–92.

McCormick, C. M., & Maurer, D. M. (1988). Unimanual hand preferences in 6-month-olds: consistency and relation to familial handedness. *Infant Behavior and Development*, *11*, 21–29.

Michel, G. F. (1984). Development of hand-use preference during infancy. In G. Young, S. J. Segalowitz, C. M. Corter, & S. E. Trehub (Eds.), *Manual specialization and the developing brain* (pp. 33–70). New York: Academic Press.

Michel, G. F., & Harkins, D. A. (1986). Postural and lateral asymmetries in the ontogeny of handedness during infancy. *Developmental Psychobiology*, *2*, 29–38.

Michel, G. F., Ovrut, M. R., & Harkins, D. A. (1985). Hand-use preference for reaching and object manipulation in 6- through 13-month-old infants. *Genetic, Social and General Psychology Monographs*, *111*(4), 409–427.
Morange, F., & Bloch, H. (1996). Lateralization of the approach movement and the prehension movement in infants from 4 to 7 months. *Early Development and Parenting*, *5*(*2*), 81–92.
Morange Majoux, F., Peze, A., & Bloch, H. (2000). Organisation of left and right hand movement in a prehension task: A longitudinal study from 20 to 32 weeks. *Laterality*, *5*(4), 351–362.
Peters, M. (1983). Lateral bias in reaching and holding at six and twelve months. In G. Young, S. J. Segalowitz, C. M. Corter, & S. E. Trehub (Eds.), *Manual specialization and the developing brain* (pp. 367–374). New York: Academic Press.
Provine, R. R., & Westerman, J. A. (1979). Crossing the midline: limits of early eye-hand behavior. *Child Development*, *50*, 437–441.
Provins, K. A. (1992). Early infant asymmetries and handedness: A critical evaluation of the evidence. *Developmental Neuropsychology*, *8*(4), 325–365.
Ramsay, D. S. (1985). Fluctuations in unimanual hand preference in infants following the onset of duplicated syllable babbling. *Developmental Psychology*, *21*, 318–324.
Ramsay, D. S., Campos, J. J., & Fenson, L. (1979). Onset of bimanual handedness. *Infant Behavior and Development*, *2*, 69–76.
Sacco, S., Moutard, M. L., & Fagard, J. (2006). Agenesis of the corpus callosum and the establishment of handedness. *Dev Psychobiol*, *48*(6), 472–481.
Schaffer, H. R., Greenwood, A., & Parry, M. H. (1972). The onset of wariness. *Child Development*, *43*, 165–176.
Schaffer, M., & Parry, M. H. (1970). The effects of short-term familiarization on infants' perceptual-motor co-ordination in a simultaneous discrimination situation. *British Journal of Psychology*, *61*, 559–569.
Thelen, E., Corbetta, D., & Spencer, J.-P. (1996). Development of reaching during the first year: Role of movement speed. *Journal of Experimental Psychology: Human Perception and Performance*, *22*(5), 1059–1076.
van Hof, P., van der Kamp, J., Caljouw, S. R., & Savelsbergh, G. J. (2005). The confluence of intrinsic and extrinsic constraints on 3- to 9-month-old infants' catching behavior. *Infant Behavior and Development*, *28*, 179–193.
van Hof, R., van der Kamp, J., & Savelsbergh, G. J. (2002). The relation of unimanual and bimanual reaching to crossing the midline. *Child Development*, *73*(5), 1353–1362.