Handedness for bimanual coordinated actions in infants as a function of grip morphology

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We investigated the emergence of bimanual handedness in tasks involving complementary roles for the two hands, one hand holding a base object and the other hand removing several pieces from the base object. Infants aged 12, 16, and 20 months were tested on bimanual tasks differing mainly in the precision of the movement required to remove the pieces. The results show that the right hand was more often used than the left hand not only to grasp the base object but also to remove the pieces, often after transferring the base object from the right to the left hand. As of 12 months of age, right hand preference for the active part of the bimanual task was stronger in the precision grip than in the whole-hand grip tasks. These results indicate that even though infants often do not anticipate that they will need their preferred hand to remove the pieces, they show clear handedness in such coordinated repeated bimanual actions, and do so to a greater degree on tasks requiring precision grip than on ones requiring whole-hand grip. These results agree with the notion that handedness develops very early and is related to the precision required from the active hand.

Keywords: Handedness; Bimanual; Repeated actions; Grip; Development.

Handedness is generally evaluated by observing the hand used for unimanual actions, and more seldom with bimanual actions, particularly in infants. However, most daily activities require the use of both hands, with one hand assuming the postural role of holding the object and the other hand being more active and often performing repeated actions on the object. Examples...
of this kind of bimanual activities are peeling a fruit or, for infants, holding a
toy in one hand and hitting it repeatedly with the other hand. The goal of the
study presented here was to evaluate the emergence of handedness for these
types of cyclic repeated bimanual actions using either precision or whole-
hand grip.

Infants’ handedness is an early feature, seen in utero in thumb sucking
(Hepper, Wells, & Lynch, 2005). As soon as grasping emerges there are clear
signs of hand preference (Cornwell, Harris, & Fitzgerald, 1991; Fagard &
Lockman, 2005; Hawn & Harris, 1983; Lewkowicz & Turkewitz, 1982;
McCormick & Maurer, 1988; Michel, Ovrut, & Harkins, 1985; Morange &
Bloch, 1996; Ramsay, 1980). This hand preference does not lead to a
population ratio of right-handers as high as the one found in adults for
writing, and many infants show no preference. The percentage of non-
lateralised infants varies between studies, and depends on the number and
kind of items used to observe handedness, as well as on the criteria used to
categorise the infants as right- or left handed. One finding common to most
studies, however, is that from the beginning there are substantially more
right-handers than left-handers.

In complement to the results of these cross-sectional studies, longitudinal
studies on infants’ handedness often lead to two conclusions: first,
handedness fluctuates during the first months of prehension, and infants
may alternately use their left hand, right hand, or both hands depending on
the session, although the overall percentage shows always a clear tendency
towards using the right hand in the majority of infants. Fluctuations may
arise from change in other domains of development (Corbetta & Thelen,
2002). Second, handedness in the first sessions predicts handedness in later
sessions rather well (Corbetta & Thelen, 1999; Coryell & Michel, 1978;
Ferre, Babik, & Michel, 2010; Flament, 1975; Gesell & Ames, 1947; Ramsay,
1985), and handedness increases only slightly over the first 2 years of life

As mentioned above, most of the items used for evaluating infants’
handedness involve simple whole-hand grasping and are unimanual. The
choice of tasks to test handedness is important since hand preference is
sensitive to the constraints of the task. Some studies have underlined the role
of the type of grip morphology when reaching (e.g., hand full grip versus
precision grip) in the expression and strength of right handedness in infants
(Fagard & Lockman, 2005) and in nonhuman primates such as chimpanzees
(Hopkins, Cantalupo, Wesley, Hostetter, & Pilcher, 2002; Hopkins, Russell,
Hostetter, Pilcher, & Dahl, 2005). More generally, task demands have an
effect on the patterns of hand preference and its strength at both the
individual and population levels, as shown by a large set of data in humans
(e.g., Flowers, 1975; Steenhuis & Bryden 1989; Perelle & Ehrman 1994;
Marchant, McGrew, & Eibl-Eibesfeldt, 1995) but also in nonhuman primates (for a review, see Hopkins, 2007).

In many of these studies the distinction between unimanual and bimanual behaviours turned out to be critical in determining the effect of task complexity on individual hand preferences and in revealing population-level handedness. For instance, unimanual behaviours elicited a lower degree of predominance of right handedness in comparison to bimanual behaviours (and unlike the latter, sometimes no such predominance) within the same samples of human infant participants (Fagard & Marks, 2000) as well as captive chimpanzees (Hopkins & Rabinowitz 1997; Wesley et al. 2002; Llorente, Mosquera, & Fabre, 2009), captive and wild gorillas (Byrne & Byrne 1991; Meguerditchian, Calcutt, Lonsdorf, Ross, & Hopkins, 2010), and captive baboons (Vauclair, Meguerditchian, & Hopkins, 2005; see also, in capuchin monkeys: Spinozzi, Castornina, & Truppa, 1998). Most bimanual activities impose a different level of constraints on the two hands, one hand’s role being clearly more active than the other’s. Studies in adults show that the right hands of right-handers performing these bimanual actions take on the active role and the left hand the postural role (Guiard, 1987).

Infants become capable of such bimanual coordination, with the two hands taking on complementary roles, around the end of the first year (Bruner, 1970; Fagard, 1998; Kimmerle, Mick, & Michel, 1995; Michel et al., 1985). Thus bimanual handedness is likely to emerge later than unimanual handedness, since unimanual reaching emerges before bimanual coordination. For instance, comparing handedness for reaching and for bimanual coordination in infants from 6 to 13 months of age, Michel et al. found that right handedness for reaching can be observed before there is enough bimanual action to rate bimanual handedness (Michel et al., 1985). In addition, hand preference is not observed in bimanual coordination of complementary actions as soon as they appear but slightly later, around the beginning of the second year of life (Cochet et al., 2011; Kimmerle, Ferre, Kotwica, & Michel, 2010; Ramsay, Campos, & Fenson, 1979; Vauclair & Imbault, 2009).

Early expression of handedness for bimanual coordination depends on the extent of hand-role differentiation for the task: one study on 18- to 36-month-old infants found that bimanual handedness is stronger than unimanual handedness on tasks where the two hands have different and complementary roles (e.g., holding a container to get a tube out of it), but not on bimanual tasks with less role differentiation (e.g., turning a cube upside-down with one hand to catch a small piece inside with the other hand) (Fagard & Marks, 2000). In the first case, as holding requires relatively little control, the active hand is clearly the hand used to extract the tube.
In the second case the fact that turning a cube upside down is not very easy for a small child means that both hands’ actions require visual monitoring. All of these bimanual tasks on which infants’ hand preference has been studied require the more active hand to perform a discrete action. As mentioned above, most everyday bimanual activities require repeated actions with one hand on an object held in the other hand. When only one action is anticipated, the strength of bimanual handedness found in infants may be limited by the tendency to grasp the object with the preferred hand. One question is: When the active part of the task involves repeated actions, will this induce infants to grasp the object with the non-preferred hand so as to free the preferred hand for the active part? Or will this induce transfer of the object between hands, so that the preferred hand can first grasp the object and then act on it? In other words, when will infants start to anticipate the sequence of actions according to their hand preference? Another question is related to the potential effect of the type of grip morphology of the active hand on hand preference when bimanually manipulating an object. As mentioned above, precision grip with index–thumb opposition has been shown to elicit more hand preference than whole-hand grip (Fagard & Lockman, 2005). To our knowledge, the effect of the type of grip has only been investigated for unimanual behaviours, and not for bimanual actions. Does the use of a precision grip with the active hand in bimanual manipulation induce a stronger degree of handedness than the use of a whole-hand grip?

To investigate these questions we tested infants on repeated bimanual coordinated actions involving asymmetric roles for the two hands. The tasks consisted in holding a base object in one hand and removing several small pieces from the base object with the other hand. The tasks were inspired by non-human primate studies (Meguerditchian et al., 2010) in which the asymmetric coordination of the two hands for handling food has been shown to be critical for the expression of predominance of right handedness and also for brain lateralisation (e.g., Hopkins & Cantalupo, 2004). We used bimanual coordinated tasks requiring a variable degree of grip precision to remove the pieces in order to test whether grip morphology might affect patterns of hand preference. We started with 12-month-olds since the majority of infants at this age successfully perform bimanual tasks. We also included two older age groups, 16- and 20-month-olds, to check whether bimanual handedness increases with bimanual skill or whether it is already well established at the end of the first year and does not change during the second year.

We hypothesised that bimanual hand preference on a cyclic task would be observed as of 12 months; that it would be greater when infants had to remove the small pieces with a precision grasp (bimanual precision
condition) than when infants had to remove the small pieces with the whole hand (bimanual whole-hand condition).

METHOD

Participants

The participants included 41 infants, twelve 12-month-olds (11m 30d to 12m 31d, mean age: 12.4; eight girls), sixteen 16-month-olds (15m 21d to 16m 9d, mean age 16.0; eight girls), thirteen 20-month-olds (19m 25d to 22m 2d, mean age: 21.3; ten girls). A total of 58 infants were tested but there were missing data for 17 infants, either because they were fussy and did not finish the test or because they did not remove the pieces from the base object for one object. Prior parental consent was granted before observing the infants, and the experiment was conducted in accordance with the ethical standards specified in the 1964 Declaration of Helsinki.

Tasks

Infants were first tested on a unimanual baby handedness test to establish hand preference for grasping simple objects (Sacco, Moutard, & Fagard, 2006). On this test infants were presented with five small objects placed along their mid-sagittal plane, one at a time. Objects were small baby toys: two Playmobil small figures, one hand-shake toy (maracas), one tooth-ring, and a thin tube inserted in a small flask.

To evaluate bimanual handedness all infants performed seven bimanual tasks, corresponding to six different objects, one of the objects being used twice in two different presentations. All tasks involved a main object and several smaller pieces attached to it that the infant could remove. The tasks were grouped into three categories (see Figure 1).

The first category (whole-hand grasping) corresponds to the four objects on which the small pieces could be removed using the whole hand: five balls pasted with Velcro at the end of a wooden stem (objects 1 and 2); five paper puppets inserted at the end of straws (object 3); nine paper flowers and leaves attached to the end of fake branches with Velcro (object 4). The objects were presented in the infants’ reaching space, in the midline and at shoulder height, except for the second presentation of the ball/stem object, where it was placed on the table.

The second category (precise grasping) corresponds to two objects whose small pieces required a precision grip to be removed from the base object: five small stickers placed on the edge of a cup, with the concave side up (object 5), and five small stickers placed on top and on the sides of a plastic
cup, with the convex side up (object 6). Both cups were presented on the
table in the midline.

The third category (bimanual symmetrical) included only one object: four
small fabric animal figures inserted at both ends of plastic stems (two on
each side) (object 7). This object was presented in the infants’ reaching space,
on the table horizontally in front of the infant. We added this object to check
whether a symmetrical presentation of the pieces to be removed would
eliminate the expression of handedness in infants. For two infants data are
missing for this condition.

For the bimanual tasks there was one presentation per object, seven
presentations in all per participant. We will refer to the objects to be removed
as the attached “pieces” and to the stems, straws, or cups as the “base
object”. The stems and the straws were attached together with a rubber band
so that the infant could hold all of them in one hand.

Procedure
The infant was seated on the parent’s lap. Parents were asked not to interfere
with the infant’s activity. After a few minutes to get the infant accustomed to
the new environment, the session started. The unimanual test was always
given first, so that bimanual use of the two hands would not influence
spontaneous unimanual handedness. The bimanual tasks were presented in the same order for all infants so that whole-hand grasping and precision grasping would be mixed (objects 1, 3, 5, 4, 7, 6, 2). In most cases the infants spontaneously started to remove the attached pieces from the base object. When they did not do so spontaneously, the experimenter demonstrated how to remove the attached pieces, once using the right hand to grasp the base object and the left to remove the pieces, and once with the reverse configuration, in random order.

Data recording and analyses

Each session was videotaped using a video camera. The videos were analysed frame by frame and the following events were coded: hand grasping the object (unimanual test) or the base object (bimanual tests); transfer of the base object to the non-grasping hand (when it occurred) and hand removing the pieces (bimanual tests). Inter-rater agreement, based on two independent observers coding three infants per age group, was 95.8% for grasping and 98% for removing the pieces and for transfer.

Hand preference was evaluated using two different methods. First, on the basis of the number of times each hand was used for a given manual task—i.e., unimanual task (grasping) and bimanual tasks (removal of the pieces)—a handedness index (HI) was calculated for each participant in order to quantify the degree of individual hand preference using the formula \( \frac{R-L}{R+L+B} \), where \( R \) and \( L \) represent the number of right- and left hand responses, respectively, and \( R+L+B \) represents the total responses, including bimanual (B). For removal of the pieces the HI score was calculated on the basis of the active hand (note that there were no bimanual responses for removal). HI values could vary on a continuum from -1.0 to 1.0, with the sign indicating the direction of hand preference: positive = right hand preference; negative = left hand preference. Based on the HI value obtained on the unimanual test, we categorised infants as being right handed (HI > .5), left handed (HI < - .5) or non-lateralised (- .5 > HI < .5) (Resch et al., 1997). Absolute values reflect the strength of hand preference. We also used the percentage of right hand (RH), left hand (LH), and bimanual (BH) strategies, in particular when there were not enough data to calculate a HI, as for grasping the base object in the bimanual tasks.

In addition, for the bimanual tasks, occurrences of object transfer between the two hands were also quantified. We then calculated the percentage of right–left versus left–right transfer (versus no transfer) among all infants.

Because the data did not follow normality we used non-parametric ANOVAs: Kruskal-Wallis ANOVA for group comparison (age effect), and Friedman ANOVA for comparison between conditions.
RESULTS

Unimanual handedness

The mean handedness index for unimanual objects was greater than zero for all age groups (HI = .5, .45, and .72 at 12, 16, and 20 months respectively). This indicates that, as a group, infants of each age group more often used the right hand than the left. A $t$-test comparing the percentage of right hand grasps against the value of 50% showed that the right hand was used significantly more than chance, $t(40) = 5.7, p < .00001$. The percentage of right-handers obtained from this HI tended to increase with age (see Figure 2) but a Kruskal-Wallis ANOVA on HI as a function of age indicated that the age difference was not significant. The handedness of the three groups of infants in this study was representative of the population (Cornwell et al., 1991; Fagard, 2004; Michel et al., 1985).

Bimanual handedness

*Grasping the base object.* Results on the hand used to grasp the base object in the three categories of bimanual tasks were compared with those from the unimanual task. The dependent variable is the percentage of right- versus left- and both-hand grasps.

In all categories except bimanual symmetrical, the percentage of right hand grasps exceeded 50% (see Figure 3). For whole-hand grasping a $t$-test comparing the percentage of right hand grasps (65.9%) against the value of 50% showed that the right hand was used significantly more than chance, $t(40) = 2.71, p < .01$. For precision grasping too a $t$-test comparing the percentage of right hand grasps (62.2%) against the value of 50% showed

![Figure 2](image_url)

*Figure 2.* Percentage of right-handed, left-handed, and non-lateralised infants based on the handedness index (HI) from the unimanual baby test of handedness as a function of age.
that the right hand was used significantly more than chance, $t(41) = 2, p < .05$. For the symmetrical category there were fewer than 50% grasps with the right hand (33.3%).

We performed a Kruskal-Wallis ANOVA on the percentage of right hand grasps as a function of age ($\times 3$: 12, 16, and 20 months) for the three bimanual categories. There was no significant age effect ($p = .88$). We then used a Friedman ANOVA to compare the four categories (unimanual, bimanual whole-hand, bimanual precision, and bimanual symmetrical) on this variable. We found a main effect of category, $\chi^2(3, 39) = 14.6, p < .01$. Two by two comparisons indicated that the symmetrical category was significantly different from the three other categories *unimanual: $\chi^2(1, 39) = 8.7, p < .01$; whole-hand grasp: $\chi^2(1, 39) = 6.7, p < .01$; precision grasp: $\chi^2(1, 39) = 8.5, p < .01$. None of the other comparisons proved significant.

**Removing small pieces.** In all categories except bimanual symmetrical the percentage of right hand removals exceeded 50%. For whole-hand grasping a $t$-test comparing the percentage of right hand removals (55.8%) against the value of 50% showed that the right hand was not used significantly more than chance ($p = .35$). In contrast, for precision grasping a $t$-test comparing the percentage of right hand removals (69.3%) against the value of 50% showed that the right hand was used significantly more than chance, $t(40) = 4.8, p < .0001$. For the symmetrical category there were fewer than 49.8% grasps, not significantly different from 50% ($p = .98$).

Here we were able to use the HI as dependent variable, since even for symmetrical presentation there were several pieces to remove. We performed a Kruskal-Wallis ANOVA on HI as a function of age ($\times 3$: 12, 16, and 20 months).
months). There was no significant age effect ($p = .10$). We then used a Friedman ANOVA to compare the three categories (bimanual whole-hand, bimanual precision, and bimanual symmetrical) on this variable. We found no significant effect of category (see Figure 4).

Transfer from one hand to the other. For transfer the dependent variable was the percentage of right hand versus left hand transfer for all categories. Not all infants transferred the base object after grasping. Checking the behaviours occurring at least once, we observed that, for the whole-hand tasks, 18 infants transferred the base object after grasping, whereas 33 infants transferred in the case of the precision tasks. Only 11 infants transferred in the symmetrical task. Some infants grasped the base object with both hands and then let go with one hand in order to remove the small pieces. Most often these bimanual grasps were followed by use of the right hand to remove the pieces: 14 infants grasped bimanually in at least one of the tasks and let go of the right hand to retrieve the pieces with it, whereas only 6 infants grasped bimanually and let go of the left hand to retrieve the pieces with it. We performed a Kruskal-Wallis ANOVA on the percentage of transfers as a function of age ($\times 3$: 12, 16, and 20 months). There was no significant age effect ($p = .40$). We then used a Friedman ANOVA to compare the three categories (bimanual whole-hand, bimanual precision, and bimanual symmetrical) on this variable. We found an effect of category,
Two by two comparisons indicate that the precision category is significantly different from the two other categories—whole-hand grasp: \( \chi^2(1, 41) = 22.5, p < .001 \); symmetrical: \( \chi^2(1, 39) = 8.3, p < .01 \). Infants transferred more often in the precision category than in the other two categories. In contrast, there was no significant difference between whole-hand and symmetrical categories (see Table 1).

We then analysed whether infants who transferred did so more often from the right hand to the left hand than the reverse. Since infants more often grasped the base object with the right than with the left hand, the occurrence of transferring from right to left was greater than the occurrence of transferring from left to right. For this reason we compared the percentage of transfer from right to left out of all right hand grasps with the percentage of transfer from left to right out of all left hand grasps, doing so for each category separately (see Figure 5).

A binomial test was calculated separately for each category to compare the percentage of R-L and L-R transfers, with all age groups considered together. The percentage of R-L transfers (following right hand grasps: 31.5% for whole-hand grasping; 75.8% for precision grasping) was different from the percentage of L-R transfers (following left hand grasps: 0% for whole-hand grasp; 37.5% for precision grasp). This difference between the percentage of R-L and L-R transfers was significant for whole-hand \( p < .000001 \) and precision \( p < .01 \) grasping, with a 95% confidence interval \([0; .08]\). For the symmetrical category there was no significant difference between the 30.8% of R-L and 38.9% of L-R transfers.

Thus, in the two asymmetrical categories, infants who grasped the base object with their right hand were more likely to transfer it to their left hand than infants who grasped the base object with their left hand were to transfer it to the right hand.

Comparison of unimanual and bimanual handedness. So far we have compared unimanual and bimanual handedness in the population as a whole. But do unimanual left-handers behave differently from right-handers? To answer this question we first calculated the Pearson correlations between the HI for the unimanual and bimanual tasks (removing small pieces) separately for the whole-hand and precision categories. The correlation

<table>
<thead>
<tr>
<th>Bimanual task</th>
<th>12 mo</th>
<th>16 mo</th>
<th>20 mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole-hand grasp</td>
<td>14.6 (7.2)</td>
<td>14.1 (5.6)</td>
<td>32.7 (10.0)</td>
</tr>
<tr>
<td>Precision grasp</td>
<td>41.7 (10.4)</td>
<td>56.3 (10.1)</td>
<td>65.4 (6.7)</td>
</tr>
<tr>
<td>Symmetrical</td>
<td>40.0 (16.3)</td>
<td>31.3 (12.0)</td>
<td>15.4 (10.4)</td>
</tr>
</tbody>
</table>
between unimanual grasping and removal in bimanual whole-hand category was negative ($r = -0.27$), whereas the correlation between unimanual grasping and removal in bimanual precision category was positive ($r = 0.27$). However, none of these two correlations was significant. Although bimanual handedness is usually defined by the active hand (in our case, the hand removing the small pieces), it is worth noting that the correlation between the HI for the unimanual grasping and grasping the base object (bimanual tasks) was positive and significant ($r = 0.55$; whole-grasp and precision categories tasks were considered together since there were not enough data to calculate a HI on the precision task alone in the case of grasping the base object).

We then conducted a finer, mostly qualitative analysis of the percentage of right and left responses of the 3 infants categorised as left-handers on the unimanual test, compared with the 29 infants categorised as right-handers. It showed that the left-handers differ from the right-handers on the bimanual tasks in grasping the base object more often with their left hand, significantly for the whole-hand grasp category, $F(1, 30) = 13.7$, $p < .001$, and not significantly for the bimanual precision category ($p = .07$). Interestingly, for removal there was a reversed tendency: left-handers tended to remove the small pieces with their left hand more than the right-handers in the bimanual precision category but not in the bimanual whole-hand
category for which the left-handers removed the pieces with their right hand most of the time (see Table 2). This means that left-handers did not transfer the base object after grasping in the whole-hand category.

### DISCUSSION

The goal of this study was to evaluate handedness for sequences of repeated bimanual complementary actions in infants at the age when they begin to demonstrate such skills. In addition we investigated whether handedness varies as a function of the kind of grip required in the bimanual tasks as it is known to vary in the unimanual tasks.

We first checked that our population of infants was representative of the known frequency of right-handed, left-handed, and non-lateralised children using a classical baby handedness test involving simple unimanual grasping not requiring bimanual coordination (Sacco et al., 2006). Our results agree with previous results, showing that although many infants in this age range are not yet lateralised, the percentage of right-handers greatly surpasses that of left-handers, and that the mean laterality index is clearly greater than 0 (towards the right side) (Corbetta & Thelen, 2002; Fagard & Lockman, 2005; Fagard & Marks, 2000; Ferre et al., 2010; Michel et al., 1985; Michel, Tyler, Ferre, & Sheu, 2006). In addition we did not observe a significant increase in right handedness over the age period studied, which also agrees with the results of previous studies (Jacquet et al., 2012). Although these results are based on a relatively small number of items, due to the fact that we did not want to extend an already relatively long testing session, they correlate rather well with results obtained with the same items presented twice (Sacco et al., 2006).

We then evaluated handedness for bimanual coordinated actions through three different variables: grasping the base object, removing the attached

| TABLE 2 |
| Percentage of right, left, and bimanual hand use at the bimanual whole-hand and precision tasks in right-handed and left-handed infants (based on the handedness index from the unimanual baby test of handedness) |

<table>
<thead>
<tr>
<th>Bimanual task</th>
<th>Left-handers (N = 3)</th>
<th>Right-handers (N = 29)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L hand</td>
<td>Bim</td>
</tr>
<tr>
<td><strong>Grasping the base object</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole-hand tasks</td>
<td>83.3%</td>
<td>0%</td>
</tr>
<tr>
<td>Precision tasks</td>
<td>50%</td>
<td>16.7%</td>
</tr>
<tr>
<td><strong>Removing the pieces</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole-hand tasks</td>
<td>6.9%</td>
<td>1.1%</td>
</tr>
<tr>
<td>Precision tasks</td>
<td>38.2%</td>
<td>0%</td>
</tr>
</tbody>
</table>
pieces and, when it occurred, transferring the base object to the non-grasping hand to free the grasping hand for removal of the attached pieces. We hypothesised that infants might use the two hands in a complementary fashion, with the left hand (in most infants) holding the base object and the right hand removing the pieces using one of two different strategies: they could either grasp the base object directly with the non-preferred hand, anticipating the need for the preferred hand to be free to remove the pieces, or grasp the base object with the preferred hand but then transfer it to the non-preferred hand.

Results showed that, at the age tested, the second type of behaviour is more frequent than the first. For the two categories of asymmetrical bimanual coordination tasks the infants grasped the base object with the right hand more often than with the left, but they also removed the small pieces more often with the right than with the left hand, significantly for the bimanual precision category. They did so by transferring the base object from the right hand to the left, which they did more frequently than the reverse on both asymmetrical tasks. This result is important: it shows that even though infants tend to grasp the base object with their preferred hand, probably because at these ages they do not yet plan the action in anticipation (McCarty, Clifton, & Collard, 1999), their hand preference is strong enough to induce them to switch the hand that holds the base object. To our knowledge, transfer of the grasped object to the other hand is a variable that has never before been used in comparable studies. It turns out to be an interesting variable to study bimanual handedness. On the symmetrical bimanual task no such asymmetries were found.

The type of grip had a strong effect on the degree of hand preference that the infants displayed. In both asymmetrical categories infants tended to remove the attached pieces with the right hand, but this was observed significantly in the precision grasp tasks and not significantly in the whole-hand grasp tasks. Similarly, in both asymmetrical categories the infants transferred the base object significantly more frequently from the right hand to the left than the reverse, but performed such transfers significantly more often on the precision grasp tasks than on the whole-hand grasp tasks. These results show that the predominance of right handedness for bimanual coordinated action is greater when a precision grip is required than when the task can be performed using a whole-hand grip. Thus the grip morphology of the active hand within bimanual coordinated behaviours is an important factor in the expression of the predominance of right handedness in infants. This fits with previous results from unimanual tasks showing that hand preference is stronger on tasks requiring greater precision in both human infants (Fagard & Lockman, 2005), adults (Flowers, 1975; Marchant et al. 1995; Perelle & Ehrman 1994; Steenhuis & Bryden 1989), and nonhuman primates such as chimpanzees (Hopkins et al., 2002, 2005).
Another important finding is that there was no significant age effect, either for unimanual handedness or for any of the bimanual indices of handedness. This is in accordance with previous unimanual results showing only a weak and non-significant tendency for handedness to increase during the second year of life (Cochet et al., 2011; Jacquet et al., 2012). We wondered whether we would observe an increase in the frequency of anticipatory strategies (grasping with the non-preferred hand and removing with the preferred hand) with age here, but that was not the case.

The relation between handedness, based on the handedness index from the unimanual baby test, and bimanual handedness is not simple to analyse. We found a positive and significant correlation between unimanual grasping and bimanual grasping of the base object in the two asymmetrical categories. However, bimanual handedness is usually defined by the hand performing the active part of the task, and the correlation between unimanual grasping and the hand used for removing the small pieces was not significant and tended to be negative for the whole-hand category but positive for the precision category. This means that, most of the time, infants did not anticipate that they would need their preferred hand to remove the pieces, but that when the task required precision they shifted the hand holding the base object so as to retrieve the small pieces with their preferred hand. This result is important in terms of assessment of hand preference in infants. It means that the choice of hand depends on several factors: hand preference but also task constraints and anticipation of the action following grasping the (base) object. Thus observing infants’ handedness requires analysing not only how they grasp and manipulate objects, but also other behaviours such as transferring the object after grasping.

Finally, the three left-handers, as defined at the unimanual handedness test, grasped the base object with their left hand more than the right-handers, and tended to remove the small pieces with their right hand more often than the right-handers for the whole-hand category, but not for the precision category. No strong conclusion can be drawn, given the small number of left-handers in this study. However, the fact that left-handers transferred less than right-handers in order to perform the active part of the task with their left hand, at least when no strong precision was required by the task, fits with the observation in adults that left-handers are often less strongly laterised and more flexible than right-handers (Borod, Caron, & Koff, 1984; McManus, 2002).

In conclusion, these results show that handedness can be observed with skills requiring the two hands to play asymmetrical complementary roles in repeated sequences of action as early as 12 months of age when several variables are taken into account. Such bimanual handedness has been shown before but, in infants, only with single-step actions (Cochet et al., 2011; Fagard & Marks, 2000). The interest of using repeated-action tasks is that it
offers an opportunity to test infants’ handedness beyond the first tendency to grasp the base object with the preferred hand. The results also stress the role of the type of grip in eliciting hand preference, with precision grip inducing a greater use of the preferred hand for the active part of the bimanual coordinated action than whole-hand grip.

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