Hand preference status and reach kinematics in infants

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Abstract

Infants show age-related improvements in reach straightness and smoothness over the first years of life as well as a decrease in average movement speed. This period of changing kinematics overlaps the emergence of handedness. We examined whether infant hand preference status is related to the development of motor control in 53 infants ranging from 11 to 14 months old. Hand preference status was assessed from reaching to a set of 5 objects presented individually at the infant’s midline; infants were classified into ‘right preference’ or ‘no preference’ groups. Three-dimensional (3-D) recordings were made of each arm for reaches under two distinct conditions: pick up a ball and fit it into the opening of a toy (grasp-to-place task) or pick up a Cheerio® and consume it (grasp-to-eat task). Contrary to expectations, there was no effect of hand preference status on reach smoothness or straightness for either task. On the grasp-to-eat task only, average speed of the left hand differed as a function of hand preference status. Infants in the no preference group exhibited higher left hand average speeds than infants in the right preference group. Our results suggest that while behavioral differences in the use of the two hands may be present in some infants, these differences do not appear to be systematically linked to biases in motor control of the arms early in development.

1. Introduction

Reaching in adults is characterized by two major movement patterns (Jeannerod, 1988). First, adult reaches are very straight. The straightness of the reach refers to the ratio of the path traveled by the hand over the distance between the hand and its target, with values closer to 1 indicating straighter movements. Second, adult reaches are very smooth. The smoothness of the reach refers to the number of peaks in the hand-speed profile, and similar to straightness, values closer to 1 indicate smoother movements. Adult reaches consist of a single acceleration and deceleration in hand speed, what von Hofsten (1979) termed a single ‘movement unit’. Visually, a movement unit has a speed profile resembling a bell curve with a single rise and fall.

By contrast, infant reaches are typically comprised of a sequence of movement units, or multiple accelerations and decelerations in the hand speed profile. The hand path is also less straight. This pattern has largely been attributed to the protracted postnatal development of the cerebellum and corticospinal system, and to a lesser extent, the mechanical properties of the arm (for a discussion, see Berthier, 2011). Despite individual differences observed in infants studied longitudinally, many...
investigators who have quantified reaching using two-dimensional (2-D) and three-dimensional (3-D) motion analysis systems in infants have reported age-related improvements in reach straightness and smoothness over the first years of life as well as a decrease in average speed (Berthier & Keen, 2006; Corbetta & Thelen, 1996, 1999; Konczak & Dichgans, 1997; Konczak, Borutta, Topka, & Dichgans, 1995; Mathew & Cook, 1990; Rönnqvist & Domellöf, 2006; von Hofsten, 1979 but see Fetters & Todd, 1987).

In an effort to understand the origins of handedness, research has begun to explore left-right side differences in the kinematics of these infant arm movements, particularly for reach straightness and smoothness. Prior to and immediately following the onset of successful reaching at around 16 weeks of age, there are no detectable kinematic differences between the two arms (Lynch, Lee, Bhat, & Galloway, 2008; Souza, de Azevedo Neto, Tudella, & Teixeira, 2012). Kinematic arm differences seem to emerge once the infant has acquired some reaching experience. In a study that examined infants every two weeks from 20 to 32 weeks of age using 2-D recordings, the path of the right arm was straighter and had a shorter movement time compared to the path of the left arm (Morange-Majoux, Peze, & Bloch, 2000). In a study of 6-month-olds using 3-D recordings, Hopkins and Rönnqvist (2002) found that the right arm was smoother than the left arm. Rönnqvist and Domellöf (2006) reported that the right arm was smoother than the left arm in children assessed longitudinally at 6, 9, 12, and 36 months of age. The right hand also had a straighter hand path than the left hand at 9 and 12 months, but not at 36 months of age. At this last timepoint of 36 months, hand preference was assessed separately from reach kinematics and all children exhibited a right hand preference for throwing, drawing and hammering. These findings are of particular interest because the direction of asymmetry (favoring the right side) matches the group-level right hand preference observed in both adults (e.g., Annett, 1985, 2002) and infants (e.g., Fagard, 1998; Ferre, Babik, & Michel, 2010; Hinojosa, Sheu, & Michel, 2003; Jacobsohn, Rodrigues, Vasconcelos, Corbetta, & Barreiros, 2014; Ramsay, 1980).

A limitation of prior work is that infants’ hand use preference has not consistently been measured separately from kinematic recordings. If developing hand preference and developing arm control are related, the classic kinematic approach may miss hand-by-hand-preference interactions. With respect to arm control in infants, motor development follows a proximodistal pattern such that control of the upper (proximal) arm develops before control of the (distal) hand (Berthier, Clifton, McCall, & Robin, 1999). Furthermore, the development of the corticospinal tract, which is responsible for reaching and grasping, is dependent on activity and experience (Martin, 2005). The development of hand preference could therefore be conceptualized in terms of experience as an accumulation of skill with one hand (preferred) over the other hand. In this view, the proposed developmental link between hand preference and motor control acquisition in infants is experience. Thus, infants with a hand preference should exhibit greater control of the preferred hand because the infant has more experience using that hand. Likewise, the hands should not differ in motor control for infants with no hand preference, who have presumably equal usage of both hands.

We measured hand preference in 11- to 14-month-old infants for reaching to 5 objects presented individually at the midline, and collected 3-D recordings from both arms on two separate reaching tasks. Following the naming convention of Flindall and Gonzalez (2013), infants reached to and picked up a ball to fit into the opening in a toy (grasp-to-place task) and reached to a cup and picked up a Cheerio® to consume it (grasp-to-eat task) on different trials. The testing range was chosen based on Touwen’s (1976) observation that the pincer grasp develops between 11 and 14 months of age, and our own observations that the tasks were too difficult to be used reliably with younger infants. We hypothesized that the hands would differ systematically in infants exhibiting a hand preference at the time of testing, and that any differences would favor the preferred hand. We were particularly interested in the effect of hand preference on the reach properties of straightness and smoothness, for which left-right side differences have been previously reported in infants (Hopkins & Rönnqvist, 2002; Morange-Majoux et al., 2000; Rönnqvist & Domellöf, 2006). In addition, we examined biases in average speed with the hypothesis that lower average speeds would indicate more advanced motor control, given the developmental pattern for average speed (e.g., Berthier, 2011). Conversely, we predicted that the hands would not differ systematically for infants characterized as having no hand preference at the time of testing.

2. Method

2.1. Participants

53 healthy, full-term 11-month-old (15 males, 13 females, \(M = 336 \pm 6.4\) days) and 14-month-old infants (10 males, 8 females, \(M = 419 \pm 8.3\) days) participated in this study. Seven infants did not contribute useable kinematic data either due to fussiness or equipment error. Of the remaining 46, four infants were excluded on the basis of left hand preference status and therefore insufficient group size for analyses. By task type, data from 26 infants were analyzed for the grasp-to-place task and from 42 infants for the grasp-to-eat task. Infant names were acquired through public birth records or a commercial source. Parents first received a letter in the mail describing the study, and were later contacted by phone. A lab visit was scheduled within two weeks of the child’s target monthly birthdate. All infants received a small gift as a token of our appreciation. The University of Massachusetts Amherst Institutional Review Board approved the following procedure.
Table 1
Number of infants* who provided kinematic data for analyses by hand preference status, gender, and task.

<table>
<thead>
<tr>
<th>Task</th>
<th>Males (N=24)</th>
<th>Females (N=18)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grasp-to-place and Grasp-to-eat</td>
<td>No pref. = 10</td>
<td>No pref. = 9</td>
<td>26</td>
</tr>
<tr>
<td>Grasp-to-eat only</td>
<td>Right = 5</td>
<td>Right = 2</td>
<td></td>
</tr>
<tr>
<td>Grasp-to-eat only</td>
<td>No pref. = 6</td>
<td>No pref. = 6</td>
<td>16</td>
</tr>
<tr>
<td>Grasp-to-eat only</td>
<td>Right = 3</td>
<td>Right = 1</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>Right = 16</td>
<td>Right = 15</td>
<td>42</td>
</tr>
</tbody>
</table>

No pref. = no hand preference. See text for calculation of hand preference status groups.

* 4 additional infants were classified as having a left hand preference, but were excluded from analyses due to sample size (1 male and 1 female had data from both tasks, 1 male had data from the grasp-to-place task only, and 1 female had data from the grasp-to-eat task only).

2.2. Procedure

The primary investigator reviewed the informed consent form with the parents, described the three tasks, and explained the motion capture equipment prior to beginning data collection. Parents were instructed not to assist their child in any way. Infants were seated on a parent’s lap at waist height at a table across from the experimenter. All infants completed the tasks in the same order, beginning with the hand preference assessment followed by the grasp-to-place and then the grasp-to-eat tasks. Infants wore Velcro® wristbands containing 5 mm infrared-emitting markers for kinematic recordings during the two reaching-grasping tasks only. The wristbands were affixed after the hand preference status assessment. All of the experimental tasks were video recorded with a Sony Handycam® digital camcorder positioned behind the experimenter.

2.2.1. Hand preference status groups

Hand preference was assessed from reaching to 5 objects presented individually at the infant’s midline (see Sacco, Moutard, & Fagard, 2006 for a similar approach). The objects consisted of a block, a toy hammer, a toy mobile phone, plastic stacking rings, and a pop-up toy. All objects were obtained from a local store. The initial reach to each object was coded from videotape as left hand, right hand, or bimanual (infant contacted object with both hands simultaneously). Inter-rater reliability using percent agreement between two observers for approximately 10% of observations was 100% for the hand(s) used to contact the objects. After contacting the toy, infants were allowed to play with each object on their own for 90 s. The extended playtime helped to establish comfort between the infant and the lab environment.

To determine hand preference status, a Handedness Index (HI) was calculated for each infant using the formula, \( \frac{(R - L)}{(R + L + B)} \), where \( R \) represents the number of right hand contacts, \( L \) represents the number of left hand contacts, and \( B \) represents the number of bimanual contacts. The HI varies continuously from –1.0 to 1.0 with negative values indicating a left preference and positive value indicating a right preference. Using HI values, infants were classified into three hand preference groups (Potier, Meguerditchian, & Fagard, 2013): left preference (HI < –0.5), right preference (HI > 0.5), or no preference (–0.5 > HI < 0.5). Because infants were assessed only once, this classification represents their hand preference status at the time of testing. Roughly 9% of the sample, or 4 infants, were identified as having a left hand preference status. These data were excluded from further analysis due to insufficient sample size. The majority of infants (67%) were identified as having no hand preference, while 24% were identified as having a right hand preference. We were unable to examine gender effects in the sample due to the distribution of males and females across hand preference status groups (Table 1). Initial analysis revealed that infants did not differ systematically by age, and infants were subsequently pooled according to hand preference status for all analyses. The final sample used in analyses was 42 (no hand preference = 31; right hand preference = 11).

2.2.2. Reaching tasks

Infants reached for a ball (grasp-to-place, Fig. 1A) or a Cheerio® (grasp-to-eat, Fig. 1B) during two experimental tasks following the hand preference status assessment. The grasp-to-place task required the infant to reach to a round “bee” (i.e., ball) and place (i.e., fit) it into the top of a toy beehive. The diameter of the beehive was 5 cm, which allowed just enough space for the ball to pass through. The height of the beehive was 17 cm and it was attached by industrial strength Velcro® to a painted wooden platform measuring 45.7 cm × 26.7 cm. Two circular wells were made on the platform 18.5 cm from the center of the beehive, and these wells served to hold the ball in place at the start of each trial. The experimenter demonstrated the task for each infant by reaching to and fitting the ball into the beehive twice with each hand. A song played when the ball fell through the opening of the beehive, which served as a reinforcer. The starting location of the ball (left or right) was randomized across trials and counterbalanced across participants. The platform with the stimuli was pushed forward to the edge of the table closest to the infant to facilitate reaching and to keep the infant seated on the parent’s lap during testing. Infants were given 12 trials and expected to use the hand ipsilateral to the ball. Additional trials were given in an attempt to collect sufficient data from each hand (e.g., the contralateral hand was used, or the ball was thrown or mouthed instead of the intended placing action).

The grasp-to-eat task required the infant to reach to a small cup and retrieve a Cheerio® that had been placed inside. The cup was a 118 ml storage container made of clear plastic and attached by Velcro® to the reverse side of the wooden platform from the grasp-to-place task. The cup measured 5.5 cm tall and had an opening of 7 cm. It was affixed to either the far left or
the far right side of the platform to induce ipsilateral hand use. The experimenter placed a single Cheerio\textsuperscript{®} (1 cm in diameter) in the cup and allowed the infant to retrieve it. After baiting the cup, the testing platform was pushed forward for infants, as in the grasp-to-place task. The starting location of the cup was randomized across trials and counterbalanced across participants. Infants were given 12 trials and expected to use the hand ipsilateral to the cup. Additional trials were given as needed to obtain sufficient data from each infant. Infants ate the Cheerio\textsuperscript{®} between trials. Infant hand starting location was not controlled in either reaching task.

2.2.2.1. Video analysis of reaching tasks. Videotape of the reaching tasks was reviewed frame-by-frame using MPEG Streamclip (Squared S) to determine the onset and offset of reaches on trials where the intended action (i.e., pick up the ball and place it into the beehive, or reach to the cup and eat the Cheerio\textsuperscript{®}) was completed successfully with the ipsilateral hand. For the grasp-to-place task, the onset of the reach was defined as the first frame of directed movement toward the ball and the offset of the reach was defined as the first frame where the hand contacted the ball. Grip time was defined as the first frame where the infant contacted the ball to the first frame where the infant lifted the ball off the platform. To control for differences in the ultimate outcome of reaches to the ball, trials where the ball was picked up and manipulated in some manner before being placed into the beehive, the ball was transferred to the opposite hand, or the ball was not placed successfully (e.g., overshoot the opening of the beehive) were not scored. The primary observer scored 100\% of the data and a second observer scored approximately 10\% of the data. Inter-rater reliability using a percent agreement score that allowed for a difference of 5 frames between observers was 89\% for reach onset, 98\% for reach offset, and 100\% for ball lift for the grasp-to-place task.

For the grasp-to-eat task, the onset of the reach was defined as the first frame of directed movement toward the cup and the offset of the reach was defined as the first frame where the infant’s hand entered the cup. Grip time was defined as the first frame where the infant’s hand entered the cup to the first frame where the infant’s hand was entirely removed from the cup. Any trials where the hand opposite to the cup was used or the infant changed hands before retrieving the food were excluded from analyses. If more than one attempt was made to get the Cheerio\textsuperscript{®}, only the final successful reach was analyzed. The primary observer scored 100\% of the data and a second observer scored approximately 10\% of the data. Inter-rater reliability using percent agreement as in the previous task was 93\% for reach onset, 98\% for reach offset, and 99\% for cup exit for the grasp-to-eat task.

2.2.2.2. Kinematic analysis of reaching tasks. Kinematic data were captured continuously throughout each reaching task at a rate of 100 Hz using a Visualeyez\textsuperscript{TM} three-dimensional real-time motion capture system (VZ4000, Phoenix Technologies Incorporated, Burnaby, B.C., Canada) and were synchronized with behavioral data from the digital camcorder during data processing. Kinematic data were extracted and processed with Matlab (The MathWorks, Inc., Natick, MA) using custom programs. Data were processed from a single marker with valid data from the wristband array. Data were low-pass filtered at 4 Hz with a 4th order dual-pass Butterworth filter (Corbetta & Thelen, 1999; Spencer & Thelen, 2000; Thelen et al., 1993; Thelen, Corbetta, & Spencer, 1996). A loss of up to 30 kinematic frames (approximately 10 video frames) or 1/3 of a second was interpolated with cubic spline interpolation. The onset of the reach was further refined by an algorithm that searched for the minimal velocity in a 30 kinematic frame window prior to the behaviorally coded start of the reach (see Corbetta & Thelen, 1996 for a similar approach). A three-point differentiation technique was used to calculate speed (mm/s\textsuperscript{2}). The average speed was the mean speed of the hand during the reach.

Reach duration, straight-line distance, path length, and reach smoothness were calculated. Reach duration was the time in milliseconds between the onset and offset of the reach, and was used as a covariate in statistical models.
Table 2
Means and standard error for movement parameters as a function of hand preference group and hand for the grasp-to-place task.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>N</th>
<th>Group</th>
<th>Hand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No pref.</td>
<td>Right</td>
</tr>
<tr>
<td>Average speed (mm/s)</td>
<td>101</td>
<td>153 ± 10.3</td>
<td>182 ± 24.7</td>
</tr>
<tr>
<td>Smoothness&lt;sup&gt;a&lt;/sup&gt;</td>
<td>97</td>
<td>2.38 ± 0.154</td>
<td>2.25 ± 0.397</td>
</tr>
<tr>
<td>Straightness&lt;sup&gt;b&lt;/sup&gt;</td>
<td>85</td>
<td>1.88 ± 0.124</td>
<td>1.74 ± 0.188</td>
</tr>
<tr>
<td>Grip time (ms)</td>
<td>100</td>
<td>1152 ± 52.0</td>
<td>1147 ± 102.8</td>
</tr>
</tbody>
</table>

<sup>a</sup> Measured by number of movement units. Values closer to 1 indicate smoother reaches.

<sup>b</sup> Measured by the ratio of hand path length to straight-line distance. Values closer to 1 indicate straighter reaches. N = number of reaches analyzed.

Group = hand preference status (see text for calculation of groups). No pref. = no hand preference.

distance was a calculation of the estimated straight line between the starting position of the hand marker and the ending position of the hand marker. Path length corresponded to the length of the actual path of the hand marker. Straightness was computed by the ratio of path length to straight-line distance and values near 1 indicated straighter reaches (Churchill, Hopkins, Rönnqvist, & Vogt, 2000). Smoothness was characterized using movement units with an algorithm derived from von Hofsten (1991). A movement unit was composed of a significant acceleration (defined as having a difference from the peak to the preceding valley of 200 mm/s²) and of having an average acceleration of 500 mm/s² during the rise from the preceding valley to the peak) followed by a similarly sized deceleration. Visually, a movement unit consisted of a peak and the subsequent valley in the hand-speed profile.

2.2.3. Statistical analysis

Dependent variables included average speed (mm/s), smoothness (number of movement units), straightness (ratio of path length to straight-line distance), and grip time (ms) for the grasp-to-place and grasp-to-eat tasks. Linear mixed-effects models (Bates, Maechler, & Bolker, 2012) were used to examine the effects of hand (left or right), hand preference status (right preference or no preference), and hand-by-hand-preference status interactions for each dependent variable using the statistical program R (R Core Team, 2012). The mixed effects procedure is robust with unbalanced data (for details and comparisons to repeated measures ANOVA, see Baayen, 2008, 2011; Gueorguieva & Krystal, 2004; Krueger & Tian, 2004). Duration and straight-line distance were used as covariates to control for differences in hand starting location. Outliers were defined as values three times the interquartile range and were excluded from analyses. p-Values were estimated from Markov chain Monte Carlo simulations given the difficulty in calculating the degrees-of-freedom for error terms in mixed-effects models (Baayen, 2011; Baayen, Davidson, & Bates, 2008). Estimates of the model regression coefficients (b), 95% confidence intervals (CI) of those coefficients, and estimated p values are given.

3. Results

3.1. Grasp-to-place task

194 trials were video coded for the grasp-to-place task. Of these, 101 had valid marker data representing 26 infants. The average number of reaches ± standard deviation) per infant to the ball was 3.9 ± 2.4. The number of usable reaches varied to due individual infant performance in completing the target action (i.e., placing the ball) and marker visibility throughout the reach. There were 49 left hand reaches and 52 right hand reaches. By hand preference status, no preference infants contributed 77 reaches and right preference infants contributed 24 reaches to analyses. Means and standard errors are given for each reach parameter as a function of hand preference status group (no preference or right preference) and hand (left hand or right hand) in Table 2. There were no main effects of hand or hand preference status and no significant hand-by-hand-preference interactions on average speed, smoothness, straightness, or grip time for the grasp-to-place task (all ps > .05, Table 3).

Table 3
Estimates of the model regression coefficients (b), 95% confidence intervals (CI) of those coefficients, and estimated p values for the grasp-to-place task.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>b</th>
<th>95% CI</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average speed</td>
<td>Hand effect</td>
<td>0.18</td>
<td>[−11.56, 11.92]</td>
</tr>
<tr>
<td></td>
<td>Preference effect</td>
<td>−3.46</td>
<td>[−15.04, 8.12]</td>
</tr>
<tr>
<td></td>
<td>Interaction effect</td>
<td>−2.72</td>
<td>[−14.31, 8.87]</td>
</tr>
<tr>
<td>Smoothness</td>
<td>Hand effect</td>
<td>0.03</td>
<td>[−0.19, 0.25]</td>
</tr>
<tr>
<td></td>
<td>Preference effect</td>
<td>−0.20</td>
<td>[−0.54, 0.15]</td>
</tr>
<tr>
<td></td>
<td>Interaction effect</td>
<td>0.13</td>
<td>[−0.08, 0.34]</td>
</tr>
<tr>
<td>Straightness</td>
<td>Hand effect</td>
<td>−0.15</td>
<td>[−0.39, 0.09]</td>
</tr>
<tr>
<td></td>
<td>Preference effect</td>
<td>0.07</td>
<td>[−0.17, 0.31]</td>
</tr>
<tr>
<td></td>
<td>Interaction effect</td>
<td>−0.03</td>
<td>[−0.27, 0.21]</td>
</tr>
<tr>
<td>Grip time</td>
<td>Hand effect</td>
<td>32.86</td>
<td>[−68.57, 134.29]</td>
</tr>
<tr>
<td></td>
<td>Preference effect</td>
<td>10.77</td>
<td>[−121.84, 143.38]</td>
</tr>
<tr>
<td></td>
<td>Interaction effect</td>
<td>36.38</td>
<td>[−65.05, 137.81]</td>
</tr>
</tbody>
</table>
Table 4
Means and standard error for movement parameters as a function of hand preference group and hand for the grasp-to-eat task.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>N</th>
<th>Group</th>
<th></th>
<th>Hand</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No Pref.</td>
<td>Right</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>Average speed (mm/s)</td>
<td>243</td>
<td>202 ± 6.53</td>
<td>185 ± 12.23</td>
<td>200 ± 7.58</td>
<td>193 ± 9.00</td>
</tr>
<tr>
<td>Smoothness(^a)</td>
<td>236</td>
<td>2.52 ± 0.10</td>
<td>2.56 ± 0.17</td>
<td>2.53 ± 0.11</td>
<td>2.53 ± 0.13</td>
</tr>
<tr>
<td>Straightness(^b)</td>
<td>221</td>
<td>1.98 ± 0.10</td>
<td>2.16 ± 0.16</td>
<td>2.05 ± 0.12</td>
<td>1.99 ± 0.11</td>
</tr>
<tr>
<td>Grip time (ms)</td>
<td>247</td>
<td>3361 ± 123.8</td>
<td>3423 ± 224.9</td>
<td>3289 ± 140.9</td>
<td>3482 ± 170.1</td>
</tr>
</tbody>
</table>

\(^a\) Measured by number of movement units. Values closer to 1 indicate smoother reaches.
\(^b\) Measured by the ratio of hand path length to straight-line distance. Values closer to 1 indicate straighter reaches. N= number of reaches analyzed. Group = hand preference status (see text for calculation of groups). No pref. = no hand preference.

Table 5
Estimates of the model regression coefficients (b), 95% confidence intervals (CI) of those coefficients, and estimated \( p \) values for the grasp-to-eat task.

<table>
<thead>
<tr>
<th>Parameters</th>
<th></th>
<th>95% CI</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average speed</td>
<td>Hand effect</td>
<td>−2.89</td>
<td>[−10.81, 5.03]</td>
</tr>
<tr>
<td></td>
<td>Preference effect</td>
<td>1.07</td>
<td>[−9.61, 11.69]</td>
</tr>
<tr>
<td></td>
<td>Interaction effect</td>
<td>8.41</td>
<td>[0.45, 16.37]</td>
</tr>
<tr>
<td>Smoothness</td>
<td>Hand effect</td>
<td>−0.09</td>
<td>[−0.20, 0.02]</td>
</tr>
<tr>
<td></td>
<td>Preference effect</td>
<td>0.03</td>
<td>[−0.10, 0.16]</td>
</tr>
<tr>
<td></td>
<td>Interaction effect</td>
<td>0.10</td>
<td>[−0.01, 0.21]</td>
</tr>
<tr>
<td>Straightness</td>
<td>Hand effect</td>
<td>−0.02</td>
<td>[−0.19, 0.15]</td>
</tr>
<tr>
<td></td>
<td>Preference effect</td>
<td>−0.05</td>
<td>[−0.28, 0.18]</td>
</tr>
<tr>
<td></td>
<td>Interaction effect</td>
<td>0.04</td>
<td>[−0.14, 0.22]</td>
</tr>
<tr>
<td>Grip time</td>
<td>Hand effect</td>
<td>−106.35</td>
<td>[−344.08, 131.38]</td>
</tr>
<tr>
<td></td>
<td>Preference effect</td>
<td>−27.76</td>
<td>[−265.49, 209.97]</td>
</tr>
<tr>
<td></td>
<td>Interaction effect</td>
<td>25.45</td>
<td>[−212.28, 263.18]</td>
</tr>
</tbody>
</table>

The significance of bold in column \( p \) for all effects is the only value less than .05.

3.2. Grasp-to-eat task

364 trials were video coded for the grasp-to-eat task. Of these, 247 had valid marker data representing 42 infants. The average number of reaches (± standard deviation) per infant to the Cheerio\(^a\) was 5.9 ± 3.2. There were 133 left hand reaches and 114 right hand reaches. By hand preference status, no preference infants contributed 176 reaches and right preference infants contributed 71 reaches to analyses. Means and standard errors are given for each reach parameter as a function of hand preference status group (no preference or right preference) and hand (left hand or right hand) in Table 4. There were no main effects of hand or hand preference status on average speed, smoothness, straightness, or grip time for the grasp-to-eat task (all \( p s > .05 \), Table 5). There was a significant hand-by-hand-preference status interaction on average speed (Fig. 2). The left hand differed between the two hand preference status groups: the left hand had a higher average speed in no preference infants compared to right preference infants. By comparison, the average speed of the right hand did not differ between the two hand preference status groups. Although not significant, the right hand preference group showed a trend toward lower average hand speeds compared to the no hand preference group overall. There were no hand-by-hand-preference status interactions on smoothness, straightness, or grip time (all \( p s > .05 \), Table 5).

4. Discussion

The primary goal of this study was to examine the relationship between developing arm control and developing hand preference in infants. Infants were divided into groups for analyses based on hand use for reaching to a set of 5 objects – those exhibiting a right hand preference were compared to those exhibiting no hand preference. 3-D recordings were made
of each arm on two reaching tasks independent of the hand preference status assessment; these tasks differed in the end goal of the reaching action. In the grasp-to-place task, infants reached for a ball and subsequently placed it into the opening of a toy. In the grasp-to-eat task, infants reached for a cup with a Cheerio® inside, which they ate after each trial. We had hypothesized that we would observe side differences favoring the right in infants with a right hand preference, and that the arms would not differ systematically in infants with no hand preference. Specifically, we had predicted that the right arm would be both smoother and straighter, and have a lower average speed as compared to the left arm in infants with a right hand preference. Contrary to these predictions, there was no clear and robust effect of hand preference status on infant reach kinematics. There were no main effects of hand or hand preference status on either task, and no significant interactions for the grasp-to-place task. On the grasp-to-eat task, there was a significant interaction for the variable of average reach speed, but not for smoothness or straightness.

Examining average reach speed on the grasp-to-eat task in more detail, an interesting difference emerged between the two hand preference status groups for the left hand. The average left hand speed was higher for no preference infants compared to right preference infants, although there was no difference between groups for right hand average speed. This pattern may suggest that infants who exhibited laterialized hand use behavior had greater control of both hands, not just the preferred hand. Average hand speed did not differ between the left and right hands in the right preference group. This finding is in agreement with adult data from right-handers for a grasp-to-eat task (Flindall & Gonzalez, 2013; note: there was a right hand advantage on maximum grip aperture, a variable that was not measured in this study). Similarly, there was no effect of hand on average speed in right-handed adults on a grasp-to-place task, although there was an advantage for the preferred hand on tests of fine motor skill such as drawing and moving pegs (Grosskopf & Kught-Buschbeck, 2006). These adult studies illustrate how it would be possible for an infant to exhibit a bias at the behavioral level in his or her hand use without a corresponding bias at the level of motor control. Presumably, the majority of infants in the no preference group will be right-handed as adults (i.e., Michel, Babik, Sheu & Campbell, 2014), which could explain the trend for the right hand to have a lower average speed than the left hand in that group. Although the idea that kinematics and hand preference would be connected during development when both of these aspects of motor control are being refined is appealing, it appears that our preliminary infant data do not support early kinematic differences. Future work will examine adult performance specifically on the infant grasp-to-place and grasp-to-eat tasks from this study to determine whether handedness effects occur under these particular task constraints in a population with greater handedness experience where lateralization may be more established.

The lack of a general right hand bias on the variables of smoothness and straightness contrasts with prior findings from other investigators who have measured reach kinematics in both arms in infants with reaching experience, irrespective of hand preference (Hopkins & Rönnqvist, 2002; Morange-Majoux et al., 2000; Rönnqvist & Domellöf, 2006). However, none of those prior studies specifically measured the age range of 11–14 months that was tested in this study. In the closest age sampled, Rönnqvist and Domellöf (2006) reported that the right hand was smoother and had a straighter hand path than the left hand at 12 months. Strikingly, the majority of their sample was male (14 of 17 infants). Although we were unable to statistically analyze gender, 8 of 11 of the right preference infants in our sample were male. We are unaware of any studies that have described a gender difference in infant reach kinematics. Such a bias, if it exists, would be contrary to the gender bias observed in adult handedness that favors a greater incidence of left-handedness in males (for a meta-analysis, see Papadatou-Pastou, Martin, Munafó, & Jones, 2008) and also contrary to the lack of a gender bias observed in infant handedness (for a large-scale study of 328 infants, see Michel et al., 2014). These issues surrounding gender would need to be addressed in future work.

Future work should also consider the type of task used to measure both hand preference and reach kinematics. The prior studies examining laterality differences in infant reach kinematics presented objects (e.g., small cube or toy) for the infant to grasp and manipulate, often at the midline. The general pattern in these studies was that differences favoring the right arm (i.e., straighter, smoother) appeared to emerge after the onset of reaching (Hopkins & Rönnqvist, 2002; Lynch et al., 2008; Morange-Majoux et al., 2000; Rönnqvist & Domellöf, 2006; Souza et al., 2012). By contrast, infants in the present study were required to execute a specific action with the object after grasping it, and objects were presented in line with each hand. Studies employing kinematic measures in infants, older children, and adults have shown that reaches are influenced by the outcome of the action (e.g., Armbrüster & Spijkers, 2006; Claxton, Keen, & McCarty, 2003; Wilmot, Byrne, & Barnett, 2013). It would be informative to compare kinematics across all three types (grasp only, grasp-to-place, grasp-to-eat), as well as other conditions where the end goal of the action may differ (i.e., grasp-to-throw) and the starting placement of the target object may differ (i.e., midline, left, or right). Recent work has also suggested that hand preference for grasp-to-eat may be separate from hand preference for grasp-to-place (or more generally, manipulating objects), and that a hand preference for eating may precede a hand preference for manipulation (Sacrey, Arnold, Whishaw, & Gonzalez, 2013). These data suggest that investigators should incorporate multiple measures of hand preference and link different action types to kinematic measures. Further characterizing no preference infants would likely have the greatest impact on understanding the potential role of laterality in developing motor control, as there is no equivalent group of adults to test without some bias toward the left or right hand, if not a strong preference for one hand over the other.

In summary, infants’ arm movements undergo significant transformation during the first years of life. Broadly, reaches increase in straightness and smoothness and decrease in speed (Berthier & Keen, 2006; Corbetta & Thelen, 1996, 1999; Konczak et al., 1995; Konczak & Dichgans, 1997; Mathew & Cook, 1990; Rönnqvist & Domellöf, 2006; von Hofsten, 1979 but see Fetters & Todd, 1987). At the same time, handedness begins to emerge, although the timing and patterning of
handedness varies (Atun-Einy, Berger, Ducz & Sher, 2014; Cochet, 2012; Michel et al., 2014; Michel, Nelson, Babik, Campbell, & Matcinowski, 2013; Michel, Sheu, & Brumley, 2002; Nelson, Campbell, & Michel, 2013). Our initial findings suggest that while behavioral differences in the use of the two hands may be present in some infants, these differences do not seem to be systematically linked to biases in motor control of the arms when infants are 11–14 months of age. We caution that these data are merely a first step in exploring issues of how the development of manual preferences may be linked to the development of motor control. We encourage investigators working with infants to consider recordings of both arms in conjunction with behavioral measures of hand preference, particularly in samples where a longitudinal design can be implemented to reconcile differences observed in cross-sectional studies.

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