Strength of Infants’ Bimanual Reaching Patterns is Related to the Onset of Upright Locomotion

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Infants typically exhibit a shift from unimanual to bimanual reaching toward the end of their first year, which has been linked to walking onset. Until now, however, it has been unclear whether it was the onset of walking per se that influenced reaching patterns or whether a more general shift to an upright posture might have prompted the reorganization of the motor system. To address this question, the current study longitudinally chronicled...
the uni- and bimanual reaching preferences of 25 infants every 3 weeks starting at 7 months, prior to the onset of pulling-to-stand and through the onset of cruising. Experimenters recorded infants’ reaching behavior via a semi-structured reaching procedure and documented their motor development. There was no relationship between the shift from uni- to bimanual reaching and the onset of pulling-to-stand. However, the onset of cruising was related to a shift in reaching pattern preference, suggesting that the increase in infants’ bimanual reaching was prompted by a reorganization of the motor system in which the arms are recruited for use in new ways to support locomotion. We also discuss individual differences in the trajectory of reaching activity in terms of the pitfalls of using age as an explanatory variable.

In the past 30 years or so, research on the development of reaching in infancy has described its protracted development as stemming from its inextricable link to infants’ postural control (e.g., van der Fits, Otten, Klip, van Eykern, & Hadders-Algra, 1999; Hopkins & Rönnqvist, 2002; Rochat & Goubet, 1995; Rochat, Goubet, & Senders, 1999; Shumway-Cook & Woollacott, 2001; Thelen & Spencer, 1998). Infants first begin to develop the motor skills that serve as the foundation for reaching at around 4–5 months of age. These early reaching attempts are characterized by a lack of control in the form of flailing and corrective movements, are often performed with both hands, and are limited to supine or supported sitting postures because infants cannot yet reach while sitting independently (Corbetta & Snapp-Childs, 2009; von Hofsten, 1991; Thelen et al., 1993; White, Castle, & Held, 1964). New sitters support their weight with their arms, causing them to topple over if they let go to reach for an object (Rochat & Goubet, 1995). In a supine or otherwise supported position, 5-month-olds increase their chances of making contact with an object using a bimanual reach where they approach the object with both hands from either side (Rochat, 1992), but with supplementary postural support to the pelvic girdle and upper legs or trunk, nonsitters can be induced to carry out more mature reaches, moving just one hand to the object (Hopkins & Rönnqvist, 2002; Marschik et al., 2008). Unimanual reaching increases around 5–6 months of age (Fagard, 1998).

Between 6 and 7 months, infants demonstrate two aspects of bimanual role differentiation (e.g., Fagard, Spelke, & von Hofsten, 2009; Kimmerle, Mick, & Michel, 1995). One aspect is related to the characteristics of the target of the reach. For example, infants begin to differentiate between large target objects that require both hands to grasp and small ones that they can obtain with one hand. The second aspect of bimanual role differentiation is related to the functional roles of the two hands. Infants’ reaching and their ability to manipulate objects mature as they use their hands
in complementary roles, such as supporting an object with one hand while manipulating it with the other (Bojczyk & Corbetta, 2004; Fagard, 1998, 2000; Karniol, 1989; Kimmerle et al., 1995; Ramsay & Weber, 1986). At 7 months, infants begin to display stabilized, relatively nonvariable reaching patterns, and show signs of modifying their reaching according to the context (Clearfield & Thelen, 2001).

Aside from the direct relationship between the motor control required for infants to stabilize their bodies without support and having their arms free to reach (c.f., Bertenthal & von Hofsten, 1998; Spencer, Vereijken, Diedrich, & Thelen, 2000), other work has demonstrated a relationship between reaching behavior and change in posture that demonstrate an interconnectedness of the motor system (c.f., Babik, 2010; Berger, Friedman, & Polis, 2011; Corbetta & Bojczyk, 2002; Goldfield, 1989; Thurman, Corbetta, & Bril, 2012). For example, being able to sit independently and the emergence of hands-and-knees crawling coincide with increases in more mature unimanual reaching, whereas infants who have not yet begun to crawl or who do not use an alternating limb pattern when they do crawl are more likely to still be reaching bimanually (Babik, 2010; Corbetta, Williams, & Snapp-Childs, 2006; Goldfield, 1993; Rochat, 1992). By 7 months, most infants finally have sufficient postural control to reach while sitting independently.

Given infants’ success at adopting context appropriate reaching responses by the end of the first year, it has been a longstanding puzzle as to why infants typically experience an increased rate of less adaptive two-handed reaching patterns at the start of their second year (e.g., Babik, 2010; Corbetta & Thelen, 1996; Fagard & Pezé, 1997; Goldfield & Michel, 1986; Ramsay, 1985). Corbetta and Bojczyk (2002) were the first to suggest that infants’ tendency to return to two-handed reaching around the end of the first year was associated with changes in postural control upon the emergence of walking. By tracking nine infants weekly over the course of their transition to upright locomotion, including documenting arm position during walking and reaching patterns, Corbetta and Bojczyk (2002) demonstrated that infants who displayed competent and adaptive reaching responses prior to walking, such as reaching primarily with one hand for small objects, typically began to reach more often with two hands for small objects after walking onset. As infants’ balance control improved, the two-handed reaching pattern declined, suggesting that something unique about the motor constraints associated with the onset of walking played an important role in the developmental reorganization of reaching (Corbetta & Bojczyk, 2002).

Walking is the culmination of a whole sequence of upright postures, making it difficult to fully interpret the mechanism underlying the
relationship between its onset and infants’ return to bimanual reaching. In particular, we do not yet know whether there was something unique about walking or whether it was the general postural shift to an upright position that reorganized the motor system. It could be that the onset of the high guard posture used for balance control prompted the reorganization of infants’ reaching patterns. However, it is also possible that it was the more general switch to being upright that prompted the reorganization. In that case, we may see a relationship between the development of bimanual reaching and other upright postures like pulling-to-stand or cruising (moving sideways holding onto furniture with one or both hands for support). In fact, some recent preliminary work suggests that the onset of independent standing may be related to infants’ reaching patterns and that subsequent walking strategies shape the trajectory of changes in reaching preferences (Thurman et al., 2012). Thus, our first aim was to expand our understanding of the relationship between the development of bimanual reaching and postural control by examining manual pattern preferences relative to motor milestones other than walking in the first year. Our second aim was to examine individual differences in the developmental trajectory of infants’ reaching preferences. Studies of early walking and cruising onset have shown variability in whether infants used a high guard posture when they began walking (Kubo & Ulrich, 2006), as well as in movement patterns used during the acquisition of cruising (Haehl, Vardaxis, & Ulrich, 2000). Exploring individual differences in the relationship between motor milestone onset and reaching preference may serve to explain the variability observed in the original study of the relationship between the onset of walking and infants’ return to bimanual reaching specifically (Corbetta & Bojczyk, 2002), as well as contribute more generally to an accurate picture of the range of normal development.

**METHOD**

**Design**

This project was part of a larger longitudinal study of 27 infants examining a host of factors influencing the timing and trajectory of infants’ motor development over the first year of life. Home visits occurred every 3 weeks starting when infants were 7 months old. We excluded one participant from these analyses because he did not contribute reaching data and one participant because she served as a microgenetic case study whose data were beyond the scope of this article.
We chose to start the study when infants were 7 months of age because we wanted to capture the development of skilled reaching ability and its relationship to the onsets of other motor milestones, which typically occur around and after this time (Capute, Shapiro, Palmer, Ross, & Wachtel, 1985; von Hofsten, 1983; Piper & Darrah, 1994). We also tried to be consistent with previous studies of infant reaching in which 7 months was a starting time point of investigation (e.g., Hinojosa, Sheu, & Michel, 2003; Michel, Sheu, & Brumley, 2002; Michel, Tyler, Ferre, & Sheu, 2006; Tronick, Fetters, Olson, & Chen, 2004).

Each infant contributed data from at least seven sessions. For most infants ($n = 18$), seven sessions were enough to capture the onset of cruising, as well as two postcruising sessions, but the remaining seven infants still had not begun cruising by the fifth session. For those infants, additional sessions were held until the criterion of two postcruising sessions was met. No systematic demographic differences were found between infants who had begun cruising by session 5 and the infants who cruised later. Unfortunately, we had to end the study before all of the infants had begun to walk independently. Many parents expressed an unwillingness or inability to participate for longer than 5 months, so we chose a time frame that sacrificed being able to capture walking, but still allowed us to capture pulling-to-stand and cruising. The number of home visits per participant ranged from 7 to 11 ($M = 8; SD = 0.89$).

Participants
Twenty-five full-term infants (16 male; nine female) participated in this study starting when they were 7 months old. On average, infants were 12.5 months old at the conclusion of the study, but depending on how many sessions they contributed, infants ranged in age from 11.5 to 14 months when the study ended. All infants were born at full term and were in good health. All families but one were urban and of middle to upper-middle socio-economic status. Both mothers and fathers had on average 17 years of education. Mothers’ average age at the start of the study was 33 years; fathers’ average age was 35 years.

Families were recruited to participate in the study by posting fliers about the research around the university where the research was conducted and by leaving fliers at healthcare centers. Participants were also recruited via “snowball” technique where participants mentioned the research via word-of-mouth to friends or contacts. Families received disks with the movies from each observation session and a children’s book as thank you gifts.
Procedures

Structured reaching

Based on prior studies of hand and reaching preference in infancy, we used a semi-structured reaching procedure at each session to test one- or two-handed reaching preference (e.g., Corbetta & Bojczyk, 2002; Corbetta & Thelen, 1999; Corbetta et al., 2006; Fagard & Lemoine, 2006; Hinojosa et al., 2003; Michel, Ovrut, & Harkins, 1985; Michel et al., 2002, 2006; Morange-Majoux, Pezé, & Bloch, 2000; Rönnqvist & Domellöf, 2006). The items used in the reaching task were a Fisher Price® two-part car and doll (7.5 cm long × 3.5 cm wide × 7 cm high), a plastic toy block with ribbons on top (5 cm long × 5 cm wide × 5 cm high), a plastic rattle (14 cm long × 14 cm circumference at the widest part × 3 cm wide at the handle), and a cup with a plastic egg inside (5.5 cm long × 5.5 cm wide × 6.5 cm high; see Figure 1). Because there is evidence that large objects provoke bimanual task performance in comparison with smaller objects, we chose objects that could feasibly be grasped with one hand to assess changes in reaching preference (see Greaves, Imms, Krumlinde-Sundholm, Dodd, & Eliasson, 2012 for a review).

Infants sat in a baby chair with a plastic tray. Before each presentation, we performed a check to ensure symmetrical body alignment of the trunk and hands to prevent any biases in reaching and acquisition of the toys (e.g., slightly turned to one side, one hand beneath the tray, etc.). The experimenter sat out of camera range to the side of the baby chair facing...
the infant. The camera was placed on a tripod, opposite the infant, at a distance of approximately 2 m. An experimenter presented each toy five times, for a total of 20 presentations per session (Tronick et al., 2004). Using Michel et al.’s (1985) procedure, we presented the objects in two ways: (1) three of the four toys were presented at midline directly in line with the infant’s nose so that the objects were equally accessible to each hand (e.g., Corbetta & Bojczyk, 2002; Fagard & Lemoine, 2006; Michel et al., 1985; Rönnqvist & Domellöf, 2006), and (2) two identical copies of the plastic rattle were presented simultaneously at shoulder line to explore interactions with different locations in space (Hinojosa et al., 2003; Michel et al., 1985, 2002, 2006). After initial reaching, the infant was free to explore and manipulate the toys for several seconds before presenting the next item.

Data coding

Trained raters coded the videotapes and identified whether the infant used one or both hands to make initial contact with each object. A reach was classified as unimanual if the infant reached for the toy with only one arm while the other arm remained inactive or if the infant began to reach with the second arm only after the first arm had contacted the toy. A reach was classified as bimanual if the infant extended both arms within 0 ms (simultaneous onset) to 250 ms in the direction of the toy. Coders viewed all recordings in real time and then in slow motion to identify the moment when infants’ fingers closed around the toy in a grasp. Infants received credit for reaching only if they made contact with the target. During a dual toy presentation, reaches were classified as bimanual if the infant extended both arms in the direction of one toy or if each arm was extended to a different toy. A preference score was calculated for each reach using the formula \( \frac{B - U}{B + U} \) = initial reach score (\( B = \) bimanual, \( U = \) unimanual). These definitions and index are frequently used for calculating lateralization or uni- vs. bimanual preferences (e.g., Corbetta & Bojczyk, 2002; Corbetta & Thelen, 1996, 1999; Corbetta et al., 2006; Cornwall, Harris, & Fitzgerald, 1991; Fagard, 1998; McCormick & Maurer, 1988; Michel et al., 2002). A second coder coded 25% of the trials. Inter-rater reliability was 92%.

Gross motor checklist

Parents received an illustrated checklist of motor milestones based on Scher and Cohen’s (2005) motor diary. Parents kept the motor checklist for the duration of the study documenting the timing of motor milestones,
including, pulling-to-stand, cruising, and walking. Parents were instructed to pay special attention to infants’ behavior and to contact the researcher as soon as the child began to attempt the new milestone. Pulling-to-stand onset was defined as the day when infants first successfully used furniture or another object as support to pull themselves up and maintain an upright position without falling for 1 min. Cruising onset was when infants could support an upright posture by holding onto a surface of support with their hands and execute two full cycles of movement using hands and feet. Walking onset was when infants could take five consecutive steps without falling. To corroborate parent reports, infants were videotaped for 20–30 min in their homes in conjunction with the reaching sessions. Experimenters confirmed infants’ motor milestone acquisition via video coding. Except for one infant whose parents reported that he had pulled-to-stand, but who would not do so at his observation the following day, there were no discrepancies between parent reports and experimenter observation.

RESULTS

Motor milestone onset

Age of motor milestone onset was determined using parents’ checklist diaries and corroborated via video coding. Mean age of the onset of pulling-to-stand was 8.68 months (range = 7.20–11.89 months; SD = 1.17). Mean age of cruising onset was 9.79 months (range = 8.05–12.59 months; SD = 1.07). Six infants began to walk before the conclusion of the study, with one beginning to walk during the second postcruising session (range = 10.91–12.95 months; SD = 0.88). The average time frame between the onset of cruising and the onset of walking was 77.33 days (range = 49–99 days; SD = 16.49). Age ranges fell within the expected normal developmental range (Bayley, 1993; Piper & Darrah, 1994).

Unimanual and bimanual reaching patterns

To ensure that changes in infants’ reaching were associated with the onset of cruising and not another coincident upright motor milestone, all analyses were run twice, both including and excluding the infant whose walking onset coincided with the second postcruising session. There were no differences for any outcome measure whether data from this infant were included or excluded, so all reported analyses are inclusive. The mean number of reaching trials per infant in each session was 18.50 (range = 15–20). Infants averaged 180 total reaching trials across all
observation sessions (range = 108–188). Pooled data from all participants across all sessions yielded 3,969 total reaching episodes.

The majority of infants’ reaches were unimanual; only 25% ($n = 992$) were bimanual reaches. On average, infants reached bimanually on 24% of trials (range = 0–65%; $SD = 15.39$). For each infant, reaching pattern preference was calculated by averaging all reaching trials performed at each session, for a total of 7 pattern preference scores. A score close to (+1) indicates a very strong bimanual preference, while a score close to (−1) indicates a very strong unimanual preference. A score close to (0) represents no reaching preference. Index scores ranged from −1 (absolute unimanual) to 0.9 (strong bimanual). A 2 (gender) × 2 (trial type: midline vs. dual presentation) × 7 (session) repeated-measures ANOVA on reaching pattern preference revealed no main effects for trial type or gender. Therefore, trial type and gender will be collapsed across all subsequent analyses. Figure 2 illustrates a significant quadratic main effect for session, $F(1, 24) = 12.26, p < .01, \eta = 0.34$. The quadratic trend suggests, and a series of post hoc, least significant difference, pairwise comparisons confirms, a strengthening of unimanual reaching from sessions 2 to 3, a peak at session 3, followed by a weakening of unimanual reaching, especially in session 7.

**Figure 2** Mean pattern preference index scores at each of seven sessions. The closer the preference score to +1, the stronger the preference for bimanual reaching. The closer the preference score to −1, the stronger the preference for unimanual reaching. Scores around 0 indicate no preference. Error bars depict the standard deviation for each session. Mean ages for sessions 1–7 (in months), respectively: 7.03, 7.71, 8.41, 9.10, 9.79, 10.48, and 11.25.
Relationship between motor ability and reaching pattern

We normalized to each infant four sessions surrounding the key upright motor milestones of pulling-to-stand and cruising: the session marking the onset of the milestone, the session immediately prior, and the two sessions following (see Table 1 for mean ages at each session). We chose those particular time points based on standard practices in the literature for taking assessments of an outcome measure immediately prior to a target event, followed by subsequent repeated assessments post-target event (Metcalfe et al., 2004; Pemberton Roben et al., 2012). We did not have data for one infant’s second session postcruising. Repeated-measures ANOVAs comparing infants’ Pattern Preference Index scores at the four

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<th>Table 1</th>
<th>Infants’ Mean Age in Months (SD) for Each Session at Pulling-to-Stand and Cruising</th>
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<tbody>
<tr>
<td><strong>Session</strong></td>
<td><strong>Pulling-to-Stand</strong></td>
</tr>
<tr>
<td>Preonset</td>
<td>8.04 (1.05)</td>
</tr>
<tr>
<td>Onset</td>
<td>8.72 (1.11)</td>
</tr>
<tr>
<td>Postonset 1</td>
<td>9.38 (1.12)</td>
</tr>
<tr>
<td>Postonset 2</td>
<td>10.11 (1.10)</td>
</tr>
</tbody>
</table>

Pattern Preference Index Scores Relative to Motor Milestone Onsets

**Figure 3** Mean pattern preference index scores at each of four sessions normalized to (a) pulling-to-stand and (b) cruising onsets. −1 on the x-axis refers to the session immediately prior to onset, 0 is the session marking onset, and 1 and 2 are the two sessions immediately following onset. Error bars depict the standard error for each session. One infant had only one postcruising session, so was not included in the final analysis (n = 24 for cruising).
sessions revealed no main effect for session for pulling-to-stand, $F(3, 72) = 1.00$, NS, but did reveal a significant main effect for session for cruising, $F(3, 69) = 10.09$, $p = .01$, $\eta = .20$ (see Figure 3). Pairwise comparisons showed a significant difference between the session at cruising onset and both postcruising onset sessions, where infants showed a significant increase in bimanual reaching patterns after cruising onset, $p = .02$ and $p < .01$, respectively. There was also a significant difference between the session prior to cruising onset and the second postcruise onset session, $p = .01$.

**Individual differences**

A cluster analysis classified participants into groups based on reaching pattern preference strength based on the $z$-scores of:

1. The frequency of using two hands on total reaching trials per infant;
2. Individual standard deviation of the Pattern Preference Index over time. Within-subject variance averaged $0.35$ (range $= 0.00–0.61$; $SD = 0.13$); and
3. The percentage of the seven observations for each infant in which a bimanual and unimanual preference was documented (Index score $> 0.5$).

The analysis revealed three groups: **Strong unimanual** ($n = 6$); **Fluctuations in preference** ($n = 14$); **No preference** ($n = 5$; see Table 2 and Figure 4). Kruskal–Wallis tests comparing the three groups found no differences between the groups in age of pulling-to-stand onset, cruising onset, gender, or hand preference.

Infants with a **Strong** profile reached almost exclusively unimanually over the course of the study, as defined by over $90\%$ of their sessions with

<table>
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<tr>
<th>Reaching Patterns Comprising the Three Profiles Produced from the Cluster Analysis</th>
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<tbody>
<tr>
<td>Percent reaching with both hands of total reaching</td>
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<tr>
<td><strong>Strong unimanual preference</strong></td>
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<tr>
<td><strong>Fluctuations in preference</strong></td>
</tr>
<tr>
<td><strong>No preference</strong></td>
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a Pattern Preference score greater than −.50; infants with a Fluctuations profile were unstable in their preference for unimanual or bimanual reaching from session to session, averaging four fluctuations over the course of the study; and infants with No preference primarily hovered between −.5 and .5 on the Pattern Preference Index at each session, with at least three sessions with a Pattern Preference Index of 0 (equal number of reaches with one and both hands in the same session). Two infants reflected the extremes of these profiles, with one showing an exclusive unimanual preference over the entire study and another showing a consistent weak preference for bimanual reaching over the course of the study.

DISCUSSION

This study longitudinally examined the development of unimanual and bimanual pattern preferences over the course of the latter part of infants’ first year and the relationship between the trajectory of preference and the
onset of upright motor milestones. Our primary aim was to examine whether infants’ return to bimanual reaching at the end of their 1st year was related to unique postural constraints associated with walking as previously claimed or whether the increased bimanual pattern preference was related to the general postural shift to an upright position. Our findings fell somewhere in between those two possibilities. We extended Corbetta and Bojczyk’s (2002) finding about the relationship between infants’ return to bimanual reaching and the onset of walking by longitudinally tracking almost three times the number of children than in the original study, combined with tracking the onset of two motor milestones and reaching preferences. This expansion necessitated concluding the study before all infants had begun walking; however, we were able to demonstrate that infants’ preference for unimanual reaching decreased at the onset of cruising, but there was no relationship between the onset of pulling-to-stand and a decreased preference for unimanual reaching.

Pulling-to-stand is typically infants’ first posture where they are upright on two feet. Pulling-to-stand is a transitional, “discrete” behavior, which means that it has a clear starting and ending point (Schmidt & Wrisberg, 2008). Pulling-to-stand involves a relatively slow displacement of center of gravity, primarily in the vertical plane. In contrast, during walking, the displacement of the center of gravity involves forward propulsion and a medial-lateral weight shift. Whereas walking movements have bilateral periodicity, the base of support on two legs during pulling-to-stand does not change while performing the action. The most obvious difference, of course, is that pulling-to-stand is a stable, “closed” posture with significantly less variability in the environment and perceptual information over the course of executing the skill than cruising and walking, which move the body from one place to another (Atun-Einy, Berger, & Scher, 2011).

In contrast, both cruising and walking are “open” tasks, which require the actors to respond to ongoing, often unpredictable, changes in perceptual information and environment as they move through space (Schmidt & Wrisberg, 2008) and both involve symmetrical, continuous, and rhythmical movements. For both postures, what is most relevant for infant reaching is the role of the arms. At the very onset of walking, infants adopt a high guard position with their arms. Being in high guard does not directly support infants’ weight as the arms do in cruising, but new walkers hold their arms high for balance and begin to lower their arms about 10 weeks after they have begun walking as their balance control, coordination, and understanding of perceptual information improves (Ledebt, 2000). Corbetta and Bojczyk (2002) posited that infants’ temporary return to bimanual reaching at the onset of walking reflects specific postural
changes—upper arm postures become practiced and then become hard to relinquish even beyond the context of walking—as well as a more systematic reorganization of the neuromotor system-reaching is just one part of a larger interconnected postural system such that changes to one part of the system may prompt changes to another.

To understand why cruising may also effect change in infants’ reaching patterns, we must consider the central role of the upper extremities for manual control of balance and haptic exploration. Cruisers keep balance manually and prioritize manual information to such an extent that they often fail to pay attention to perceptual information from any source other than their arms. As long as cruising infants have a continuous handrail to hold on to they will blithely cruise along into a 3-foot drop off in the floor—even when a researcher points it out to them (Adolph, Berger & Leo, 2011). Cruising infants use their hands to obtain haptic information about their surface of support (S. E. Berger, G. L. Y. Chan, & K. E. Adolph, unpublished data). They rub, tap, squeeze, etc., the support surface in the same way that infants explore toys and other novel objects (Klatzky, Lederman, & Mankinen, 2005; Lederman, Summers, & Klatzky, 1996; Lobo & Galloway, 2008). Although the arms and legs move independently in cruising (Vereijken & Adolph, 1999), the arms’ new role in exploration, balance control, and locomotion is complementary suggesting that the onset of cruising prompts an increase in bimanual reaching. It is not until the arms are rigidly coupled in the high guard position at the onset of walking that infants’ reaching preferences are overwhelmingly bimanual.

At the systemic level, the interconnectedness of the neuromotor system means that changes in one area may prompt changes in another. For example, the onset of the transition from crawling to walking is associated with increased instability for lateralization preferences (Berger et al., 2011; Goldfield, 1993). Even more broadly, changes in motor skill have effects beyond the motor domain (Berger & Scher, 2011). For example, the onset of sitting precipitates a decrement in infants’ ability to process faces and the onset of walking elicits an increase in perseverative behaviors (Berger, 2010; Cashon, Ha, Allen, & Barna, 2013). Situated in this broader context, infants’ preference for unimanual reaching may decrease at the onset of cruising because infants may need to reallocate attentional resources as they focus on acquiring the new skills of cruising and walking (Berger, 2010). Infants return to less adaptive, but less demanding behaviors to compensate for the overload of processing complex, novel information (e.g., Cashon et al., 2013; Cohen & Cashon, 2006; Cohen, Chaput, & Cashon, 2002). Thus, in the current case, infants’ attention is newly directed toward manually gathering relevant information from the environment...
about sufficient postural support and maintaining balance while cruising prompting a return to a more familiar, better-practiced, and lower-level reaching strategy.

The field of motor development has a long tradition of documenting individual differences. Studies have documented between-subjects variability in supine kicking, manual and pedal lateralization, fluctuations between unimanual and bimanual reaching preferences, crawling strategies, strategies for the acquisition of pulling-to-stand, and many others (Adolph, Vereijken, & Denny, 1998; Atun-Einy et al., 2011; Berger et al., 2011; Corbetta & Bojczyk, 2002; Corbetta & Thelen, 1996; Gesell & Ames, 1947; Jacobsohn et al., 2012 Thelen, Ridley-Johnson, & Fisher, 1983). We continue in that tradition by describing three trajectory profiles of infants’ reaching preferences: Strong unimanual, Fluctuations in preference, and No preference. Most infants fit the overall and expected group pattern of fluctuations between unimanual and bimanual reaching preferences over the course of the study. However, as in previous studies of the developmental trajectory of reaching preference (Corbetta & Bojczyk, 2002), we also identified a subset of infants who did not fit the group average.

Historically, variability in a data set was seen as a nuisance that was deemed best to ignore. More recently, variability has been frequently conceptualized as a behavioral pattern that facilitates finding the most efficient and successful solution to the problem of acquiring new motor skills (Adolph et al., 1998; Oakes & Plumert, 2002; Piek, 2002; Snapp-Childs & Corbetta, 2009). However, because infants had previously solved the problem of manual differentiation, but then adopted a less adaptive solution, this study, along with others describing the individual variation in the expression of bi- and unimanual reaching (e.g., Thelen & Corbetta, 2002), seems to be describing a different phenomenon in the case of variability in the trajectory of infants’ return to bimanual reaching. Rather than reflecting individual problem-solving strategies, in this case, the examination of the individual developmental trajectories may serve as a direct and effective way to understand the processes that lead to overall population trends (Jacobsohn et al., 2012). For example, previous work has shown that when infants switch from a quadrupedal to a bipedal stance, they need to restrict their motor patterns until they have more fully mastered the new locomotor skill (Babik, 2010; Berger et al., 2011; Corbetta et al., 2006). Returning to a well-practiced bimanual reaching pattern in the context of the transition from manual to pedal balance control may serve a similar stabilizing function. This new finding illustrates a more general developmental trend where novices, such as infants during the transition to a new locomotor skill, limit joint movements or the repertoire of executed behavior when they first acquire new
skills that require coordination (e.g., Atun-Einy et al., 2011; Berger et al., 2011; Harbourne & Stergiou, 2003; Vereijken & Waardenburg, 1996). In the case of fluctuations between unimanual and bimanual reaching, some of the variability in individual trajectories may lie in the differences in timing of locomotor milestone onset.

Another possible source of between-subjects variability may be neuro-maturation related to motor performance (Gesell, 1946). For example, bimanual coordination is dependent on the development of the supplementary motor area of the left and right frontal cortices and their interconnection through the corpus callosum (Diamond, 1991; Muetzel et al., 2008). A recent examination of 1-year-old infants with agenesis of the corpus callosum revealed significantly limited or delayed bimanual activity compared with typically developing children (Sacco, Moutard, & Fagard, 2006). Moreover, overflow movements, or limb movements that are extraneous to the primary motor action, diminish as the corpus callosum matures (Soska, Galeon, & Adolph, 2012), suggesting more efficient interhemispheric processing relevant for bimanual coordination. Because of the numerous, varied neural pathways influencing cortical structures, little else is known about the full role the corpus callosum plays in bimanual activity, but a promising direction for this work would take into account the multiple influences on infants’ reaching pattern preferences to provide a systemic account of the developmental trajectory.

The discrepancy between the session-to-session developmental trajectory that was depicted when reaching preference was averaged over all participants vs. when it was examined individually is noteworthy. While most participants did show fluctuations between uni- and bimanual reaching preferences, the ANOVA alone did not accurately reflect what several of the 25 participants actually experienced. By examining the three preference profiles revealed by the cluster analysis and the individual reaching trajectories relative to changes in other motor skill, we were able to avoid the pitfalls of using age as an explanatory variable (Adolph & Berger, 2006). The design of the present study allowed us to depict between-subjects differences and at the same time capture fluctuations in within-subject developmental trajectories. In so doing, we managed to avoid the drawbacks of averaging across a group without also examining the variability and were able to investigate developmental processes within a more accurate developmental framework of theory and design (van Geert & van Dijk, 2002; Lampl, Johnson, & Frongillo, 2001; Siegler, 2006). Our primary predictor of reaching preference was experience with a new locomotor skill, which did a moderately good job of predicting the decrease in bimanual reaching preference at the individual level. Future studies should delve even deeper into individual differences in motor ability and capture proficiency, which
would be a better indicator of level of effort than experience alone. Moreover, a future investigation into variability in the trajectory of reaching development should also include the relationship between patterns of trajectory and the timing of upright postural milestones. With studies thus far linking various milestones to changes in infant reaching, it may be that a long-term investigation with independent standing, cruising, and walking all as target events is the best way to understand and predict fluctuation (Jacobsohn et al., 2012; Thurman et al., 2012). The results of the present study highlight that developmental milestones can be the markers for change, both improvements and periodic regressions in behavior, and thus have not only theoretical and methodological significance, but are also informative for clinicians and for parents.

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