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Short survey

Feet first: object exploration in young infants

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Abstract

In this study, infants reached for toys with their feet weeks before using their hands. These results suggest that, contrary to long-held beliefs, early leg movements can be precisely controlled, the development of skilled reaching need not involve lengthy practice, and that early motor behaviors need not develop in a strict cephalocaudal pattern. © 2004 Elsevier Inc. All rights reserved.

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Human infants acquire many basic motor skills gradually over the first year. New skills unfold in a distinctive, head-to-toe progression: head control by about 3 months, reaching by about 5 months, sitting by about 8 months, and walking at around a year. The classic view is that this cephalocaudal trend reflects increasing cortical control over spinal and brainstem circuits (McGraw, 1945). Thus, the kicking movements commonly seen in infants during the first few months are widely believed to be non-volitional expressions of spontaneously active central pattern generators (Forssberg, 1985; Lamb & Yang, 2000). However, other evidence suggests that infants gain voluntary control of their legs far earlier than the cephalocaudal rule would predict. Indeed, Piaget (1952) was the first to notice that his young infant son repeated a leg kick that happened to shake a toy attached to his bassinet. More recently, researchers have induced infants to change the natural patterns of their spontaneous kicking movements by rewarding specific coordination movements, for example, using both legs simultaneously (Thelen, 1994), or moving predominantly in a flexed or extended posture (Angulo-Kinzler, 2001; Angulo-Kinzler, Ulrich, & Thelen, 2002).

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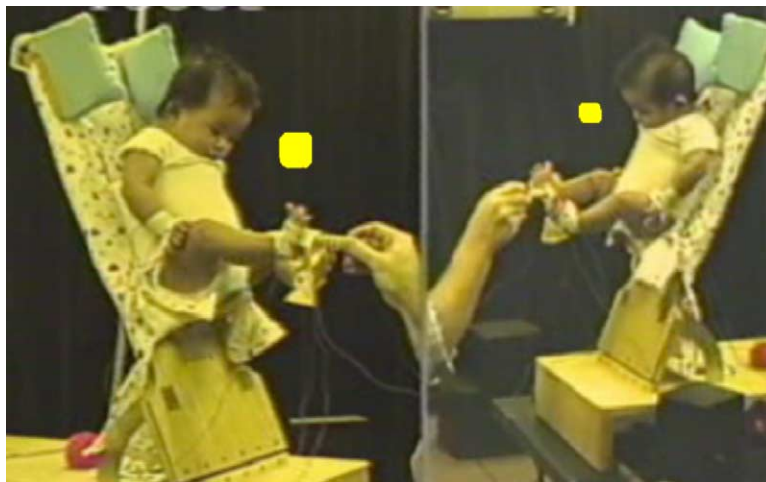


Fig. 1. Experimental setup, general toy positions at feet (toy) and hands (yellow circle), and infant displaying foot reaching. A split screen picture of a 12-week-old infant who made extended contact with a toy with the feet during a toy presentation. This was a ‘toy trial’ for the feet and ‘no toy trial’ for the hands. ‘Toy trials’ reflect movement of the limb relative to the actual toy, such as between feet and toy. ‘No toy trials’ reflect the movement of the alternate pair of limbs, here the hands, relative to the average position of the toy when it was presented at that alternate location (yellow circle). In experiment 2, toy locations varied with the limb’s position during each familiarization period. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Here we report an even more striking violation of the cephalocaudal rule: young infants visually aiming their feet to contact an object. In two experiments, we provided infants with equivalent opportunities to reach for toys with their hands and with their feet. ‘Feet-reaching’ preceded hand reaching by a month or more.

For both experiments, infants straddled a custom seat, which allowed their arms and legs to move freely (Fig. 1). In experiment 1, we observed 6 infants (3 male, 3 female; 2 Asian American, 4 Caucasian;) every week from the first week they were interested in toys (range 8–15 weeks-old) through the first week of consistent grasping. At each session, we offered sounding toys alternately at the hands and feet for ten 15-s trials. We placed the toys separately in midline at shoulder height and arm’s length, and at hip height and leg’s length. To contact the toys, infants needed to combine limb elevation with movement to the midline. Thus, simply raising the legs or arms in front of the body would not contact the toy. As an additional control against accidental contacts, we compared data when the toy was presented at the limb with data for the same limbs when the toy was presented at the alternate set of limbs. For instance, as shown in Fig. 1, toy offered at the feet generated ‘feet-toy’ data, and ‘hands-toy area’ data (hand relative to average toy position represented by yellow circle in Fig. 1). A six-camera (150 Hz) motion analysis system (Optotrak, Northern Digital, Inc.) recorded 3D hand and foot movement bilaterally, as well as toy position.

On average, infants first contacted the toy with their feet when they were 11.7 weeks-old and with their hands when they were 15.7 weeks-old ($P = 0.02$, paired t -test). The first week of extended toy contact (>15% of total time) was also earlier with the feet, occurring an average of 4 weeks before the hands ($P = 0.01$, paired t test). See Table 1 for individual data summary. Moreover, contact time with the feet exceeded that of the hands every week up to 2 to 3 weeks before the onset of consistent grasping

Table 1

Comparison of the first week of age that the feet and hands made initial and extended contact with the toy

Infant	First session (weeks of age)	Initial contact (weeks of age)		Contact differential (weeks)	Extended contact* (weeks of age)		Extended contact differential* (weeks)
		Feet	Hands	Hands–Feet	Feet	Hands	Hands–Feet
1	8	8	11	+3	8	11	+3
2	11	11	19	+8	11	19	+8
3	11	11	13	+2	11	13	+2
4	12	12	12	0	13	14	+1
5	13	13	18	+5	13	18	+5
6	15	15	21	+6	15	21	+6
Mean (S.D.)	11.7 (2.3)	11.7 (2.3)	15.7 (4.2)	+4.0 (2.9)	11.8 (2.4)	16 (3.9)	+4.2 (2.6)

Initial contact and extended contact columns show the week of age of first toy contact and the first week of extended toy contact with the feet and with the hands. Contact differential and extended contact differential columns show the difference between when the hands and feet made first contact and first extended contact, respectively (+, weeks reflects hands contacting toy at a later age).

* Extended contact: >15% of total movement time (>22.5 s of 150 s).

(compare solid black and solid gray lines in Fig. 2). Importantly, from the initial weeks on, infants spent longer times with their feet in contact with the toys than they spent moving their feet in the area where the toy would be (compare black solid and black dotted lines in Fig. 2, $P = 0.01$, paired t test). Thus, contact times for the feet were not simply a reflection of leg movements accidentally hitting the toy. Infants increased their contact time with the feet from 20% of total time 9 weeks before grasp onset to 50% by week 0. Interestingly, despite the hand’s ability to grasp, infants were contacting the toy for an equal amount of time with their feet as with their hands at the first week of consistent grasping (week 0 in Fig. 2).

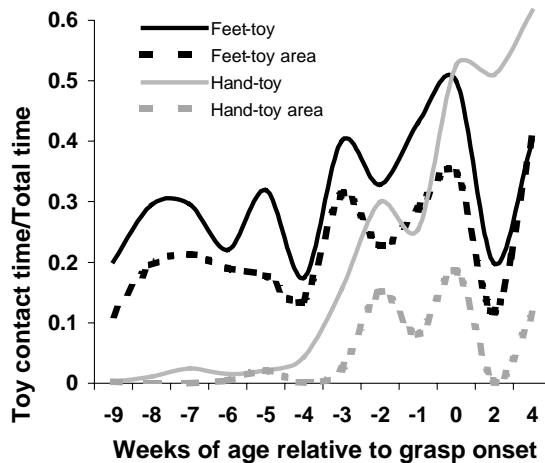


Fig. 2. Time in contact with toy during experiment 1. Comparison of the average toy contact time for feet (black lines) and hands (gray lines) during toy trials (solid lines) and no toy trials (broken lines) for experiment 1. X-axis shows the week of age relative to the first week of consistent grasping by the hands.

In experiment 1, we found that infants' natural arm movements often carried the hands away from the standard midline toy position. Also, because infants' feet contacts were more frequent, they received more frequent feedback from the sounding toy during leg trials versus arm trials. Thus, in a second experiment, we equalized the distance to the toy at the start of each trial and did not provide any additional reinforcement for toy contacts.

For experiment 2, we offered 10 non-hand-reaching infants (age range 9–12 weeks, 4 male and 6 female, all Caucasian) toys at their hands and feet during a single session. Each trial contained a 20-s familiarization period followed by a 20-s test period, with 4 trials for *each* arm and leg (16 trials per infant). During familiarization, we touched a non-sounding toy to the infants' hands or feet, and encouraged infants to touch the toy. During the test period of each trial, the toy was positioned 4 in. anteriorly in the sagittal plane of wherever the hand or foot moved at the end of familiarization. For example, if during the familiarization period for a right hand trial, an infant moved her right hand in a lateral and elevated position, then during test period the toy was placed 4 in. from this position. Thus, rather than predetermining a midline toy placement for every trial, each infant's own limb movements during each familiarization period determined where the toy was placed for each trial. There was no additional reinforcement provided by the toy or experimenters during test periods.

We coded the number of contacts from video (coding agreement: intra-rater 90%, inter-rater 87%). Although the limb–toy distance to start each test period was 4 in., where the toy was held relative to the infant during test periods varied from trial to trial for both the arms and legs, and included both medial and lateral placements. Similar to experiment 1, 9 of 10 infants displayed more feet contacts (mean 22 S.D. 13) than hand contacts (mean 6 S.D. 8). As a group, the absolute number of contacts and the percent of total (hand + feet) contacts were greater for the feet (paired *t* tests, absolute contacts, $P < 0.01$; percent of total contacts $P < 0.001$). Thus, even when we equalized the amount of reinforcement, standardized the initial limb to toy distance, and adapted the toy position to the common movement area of hands and feet for each trial, infants used their feet to reach more than their hands.

Given the opportunity to interact with toys, infants as young as 8 weeks of age were able to do so with the feet a month before they could reach with their hands. This is in clear violation of a strict cephalocaudal progression. Moreover, our results contradict another traditional view that in the first months of life the legs move in simple, reflexive, non-purposeful patterns controlled by spinal centers (Forssberg, 1985; Lamb & Yang, 2000). Reaching for and contacting objects in 3D space involves multijoint control associated with multiple brain regions (Brashers-Krug, Shadmehr, & Bizzi, 1996; Galloway & Koshland, 2002; Kalaska, Scott, Cisek, & Sergio, 1997; Shadmehr & Holcomb, 1997). Thus, the finding that young infants in this study repeatedly aimed their feet to contact the toy suggests the use of supraspinal centers for purposeful control much earlier than traditionally envisioned.

How is it that 2–3-month-old infants were able to control their legs before their arms? Differences in the anatomy and movement patterns of the arms and legs may be important. Structural differences between the deeper, more stable hip and the shallower, more mobile shoulder result in the legs having fewer anatomical degrees of freedom than the arms. That is, due to hip joint anatomy, the leg may be softly constrained¹ to move less freely in lateral workspaces. This reduction in workspace in turn reduced the amount of motion to be actively controlled. Without this anatomical constraint, the arm moved freely through a wide range of motion, which increased the degree of control required to place the hand on the toy.

¹ Soft constraint is used here to reflect how joint tissues may restrain movement within a range of motion by increasing the effort needed to move into that range. This is in comparison to a hard constraint that limits movement completely.

The pattern of early leg and arm movements also differ. Namely, young infants' leg movements display less spatiotemporal variability (Thelen, 1979, 1985; Thelen & Fisher, 1983), and result from relatively simple muscle activation patterns compared to arm movements (Spencer & Thelen, 2000). As arm and leg movements are repeated many thousands of times across a variety of contexts during the first months of life, the particular neural pathways associated with the movement patterns are strengthened as are those pathways associated with the perceptual experiences of moving the limbs (Hebb, 1949; Sporns & Edelman, 1993). The resulting sensorimotor mapping for the legs may be more circumscribed compared to the arms. Infants may find it easier to adapt the leg's well-established pathways for purposeful activities when an opportunity arises. In contrast, an equally motivated infant provided the same opportunity to contact a toy may find it harder to control the arm due to a more diffuse sensorimotor map as well as the greater degrees of freedom. Of course, the complex mapping and mechanics that delay hand reaching for several weeks in infancy is likely the same factors that contribute to the arm's functional versatility in later months and years.

This general advancement in control of the legs as compared to arms may also explain why these infants did not need weeks of 'task specific' practice to display feet reaching. Instead, the opportunistic use of the legs to explore the immediate environment fits within a continuum of results suggesting that infants gain increasingly precise control of their legs over the first months of life. By 8 weeks-old, infants will purposely increase kick frequency to cause a toy mobile to move (Rovee & Rovee, 1969). By 3 months of age, infants will produce specific intra- and interlimb patterns required to move the mobile (Angulo-Kinzler, 2001; Angulo-Kinzler et al., 2002; Chen, Fetters, Holt, & Saltzman, 2002; Thelen, 1994). Thus, these data join others in suggesting that purposeful behavior develops not so much from strict behavioral patterns predestined by autonomous brain maturation as from the confluence of physiological and anatomical constraints, experiential history, and contextual opportunities (Edelman, 1988; Gibson, 1997; Gottlieb, 2002; Michel & Moore, 1995; Oyama, 2000; Thelen & Smith, 1994).

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