

Exploring Objects With Feet Advances Movement in Infants Born Preterm: A Randomized Controlled Trial

Jill C. Heathcock, James C. (Cole) Galloway

Background. Previous work has shown that full-term infants who were healthy contacted a toy with their feet several weeks before they did so with their hands and that movement training advanced feet reaching. Certain populations of preterm infants are delayed in hand reaching; however, feet reaching has not been investigated in any preterm population.

Objective. The primary purpose of this study was to determine whether preterm infants born at less than 33 weeks of gestational age contacted a toy with their feet at 2 months of corrected age, before doing so with their hands, and whether movement training advanced feet reaching.

Design. This study was a randomized controlled trial.

Methods. Twenty-six infants born preterm were randomly assigned to receive daily movement training or daily social training. During the 8-week training period, the infants were videotaped in a testing session every other week from 2 to 4 months of age.

Results. Both groups contacted the toy with their feet at 2 months of age during the first testing session prior to training, at an age when no infants consistently contacted the toy with their hands. After 8 weeks of training, the movement training group displayed a greater number and longer duration of foot-toy contacts compared with the social training group.

Conclusions. These results suggest that movement experiences advance feet reaching as they do for hand reaching. For clinicians, feet-oriented play may provide an early intervention strategy to encourage object interaction for movement impairments within the first months of postnatal life. Future studies can build on these results to test the long-term benefit of encouraging early purposeful leg movements.

J.C. Heathcock, PT, PhD, is Assistant Professor, Division of Physical Therapy, Ohio State University, 453 W 10th Ave, Columbus, Ohio 43210 (USA). Address all correspondence to Dr Heathcock at: jill.heathcock@osumc.edu.

J.C. Galloway, PT, PhD, is Associate Professor, Department of Physical Therapy, University of Delaware, Newark, Delaware.

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Full-term infants who are healthy first reach with their hands when they are 3 to 6 months of age.¹⁻³ Certain populations of preterm infants, such as those born at less than 33 weeks of gestational age or weighing less than 2,500 g, show differences in reaching even when age-corrected for preterm birth.⁴⁻⁶ Contrary to an obligatory cephalocaudal progression, full-term infants display adequate control of their legs to repeatedly reach out and contact a stationary toy with their feet, several weeks before they do so with their hands.² In addition, full-term infants improve this ability after several weeks of training.⁷ The purposes of the present study were: (1) to quantify, for the first time, feet reaching in a preterm population and (2) to quantify the effect of 8 weeks of movement training on their feet reaching. The presence of feet reaching and a positive training effect would suggest a novel and easily implemented intervention strategy to encourage early object interaction in infants with special needs. The lack of feet reaching or a training effect would suggest another early difference from full-term infants and a potential coordination impairment requiring further clinical and research focus.

Purposeful Control of the Legs

Full-term infants who are healthy begin to gain purposeful control of their legs within the first months of postnatal life.^{2,8,9} The 2 most commonly studied early leg behaviors are *spontaneous kicking*,¹⁰⁻¹⁵ where infants kick without significant external stimuli or feedback, and *instrumented kicking*, where infants adapt their spontaneous kicks to interact with external stimuli, resulting in various types of feedback.^{9,16-21}

In an extensive series of studies of instrumented kicking, Rovee-Collier and colleagues^{22,23} used the “mobile

paradigm” to study how infants, as young as 3 months of age, learn and remember a simple cause-and-effect relationship. In the traditional paradigm, infants have one leg tethered to an overhead mobile such that kicking results in mobile movement. Full-term infants quickly learn the cause-and-effect relationship during their first session, as evidenced by increasing their kicking frequency compared with periods where their kicks did not result in mobile movement.

In addition to controlling the frequency of their kicks, young full-term infants also can modify the form of their kicks as required to move the mobile. For example, 3-month-olds altered their kicking pattern to include a specific range of knee flexion to move the mobile¹⁶ and even produced patterns of hip and knee movement to touch a panel to cause mobile movement,²⁴ which are behaviors not typically observed in spontaneous leg movements of infants of this age.²⁵

Previous studies from our laboratory and other studies suggest that preterm infants differ from full-term infants in how they control their legs in the mobile paradigm. Preterm infants born at less than 36 weeks of gestational age required 1 additional day to learn this paradigm.²⁶ Moreover, preterm infants born at less than 33 weeks of gestational age did not learn this association—even with 12 sessions over 6 weeks.¹⁷ Preterm infants also kicked at an equal rate with the tethered and nontethered legs, whereas full-term infants preferentially increased the tethered leg kicking rate, suggesting an additional level of leg control in full-term infants.¹⁸ Thus, in the traditional mobile paradigm, preterm infants have more difficulty than full-term infants in controlling the frequency of their kicking, but it is unknown whether preterm infants

display other levels of leg control such as “feet reaching.”

Early Object Exploration With the Feet

From a supported sitting position, full-term infants appear to have greater leg control than arm control for contacting midline objects, resulting in feet reaching being displayed before hand reaching. Gallo-way and Thelen² investigated the emergence of feet reaching in 2 experiments. In the first experiment, full-term infants were longitudinally tested from 8 to 15 weeks of age. They contacted toys in a midline position an average of 4 weeks earlier, and more frequently with their feet than with their hands. In the second experiment, infants contacted a toy in a lateral position with their feet more frequently than with their hands.² In a separate study, full-term infants as young as 2 months of age contacted a midline toy with their feet.⁷ It is unknown whether any population of preterm infant display feet-reaching behaviors. Therefore, the first purpose of this study was to determine whether preterm infants are able to contact a midline toy with their feet during the first experimental session when they are 2 months of corrected age.

Effects of Training

Even very young full-term infants alter their steps, kicks, and reaches when provided with additional movement experiences or “training.” For example, 2-month-olds provided with additional opportunities to step continued to show stepping for more weeks than nontrained infants.²⁷ Three-month-olds increased the number and pattern of their steps after treadmill training.²⁸ Three- to four-month-olds modified their kicking frequency and interlimb kicking patterns after 15 minutes of training with a mobile.^{8,29} Moreover, there was a dose response to training, with

more training resulting in longer-lasting changes in kicking.^{30,31}

In addition to kicking, our work and other studies suggest that training advances the onset and quality of both hand and feet reaching in full-term infants.^{7,32} Infants who received several weeks of daily movement training increased the number and duration of toy contacts and moved closer to the toy.^{7,33} In addition, when prereaching infants were trained to hold toys with their hands while wearing Velcro* mittens, they also increased the number and durations of hand-toy contacts and looked at toys more.³³

After training, infants with developmental disability have demonstrated the ability to change their movements in the form of steps and reaches. For example, infants with Down syndrome walked more than 3 months earlier after daily treadmill training compared with non-trained infants.³⁴ Infants born at less than 33 weeks of gestational age who were delayed in hand reaching contacted toys earlier after movement training compared with non-trained infants.⁴

It is unknown whether movement training improves feet reaching of preterm infants at risk for developmental disability. Given the positive effects with full-term infants, we hypothesized that infants born preterm who receive movement training would show more foot-toy contacts and longer toy contacts. Therefore, the second purpose of this study was to determine whether preterm infants change their feet-reaching behaviors with daily movement training similar to full-term infants.

* Velcro USA Inc, PO Box 5218, 406 Brown Ave, Manchester, NH 03103.

Table 1.
Participant Characteristics

Variable	Movement Training Group (n=13)	Social Training Group (n=13)	P ^a
Sex (male/female)	5/8	6/7	
Gestational age (wk), $\bar{X}\pm SD$	31±2	31±2	.799
Birth weight (g), $\bar{X}\pm SD$	1,651±471	1,635±450	.930
Birth length (cm), $\bar{X}\pm SD$	42±4	42±4	.927
Head circumference (cm), $\bar{X}\pm SD$	28±2.5	28±3.5	.903
Apgar score (1 min), $\bar{X}\pm SD$	7±1	5.5±3 ^b	.117
Apgar score (5 min), $\bar{X}\pm SD$	8±1	8±2	.296
Time in Special Care Nursery (d), $\bar{X}\pm SD$	26±17	37±28	.276
Time on oxygen (d), $\bar{X}\pm SD$	7±15	49±80 ^c	.108
Maternal age (y), $\bar{X}\pm SD$	28±6	30±6	.601
Race/ethnicity			
Caucasian	8	10	
African American	2	3	
Hispanic	1	0	
Asian	2	0	

^a Assessed with Student *t* test.

^b Two infants in the social training group had Apgar scores (1 minute) equal to 1, deflating the mean and increasing the standard deviation in this category. The Apgar scores of these infants were comparable to those of other infants in both groups at 5 minutes.

^c One infant in the social training group was on oxygen for an extended amount of time (200 days) and inflated the mean and standard deviation in this category.

Method

Participants

Twenty-seven infants born preterm completed this project. The infants were recruited from the Special Care Nursery (SCN) at Christiana Hospital, Newark, Delaware, and through word of mouth. Infants were recruited from March 2004 to December 2005.

Infants were eligible for participation if they were born at less than 33 weeks of gestational age and weighed less than 2,500 g at birth. Infants were excluded for prenatal drug exposure, congenital orthopedic or genetic anomalies, and significant visual or hearing deficits. Infant characteristics shown in Table 1 suggest that groups were comparable on these variables. Table 2 shows available imaging summaries from head ultrasounds.

An additional 5 infants were recruited from the SCN and started the project, but voluntarily withdrew due to family time constraints. Guardians of each preterm infant signed an informed consent form approved by the University of Delaware Human Subjects Review Committee or Christina Care Institutional Review Board. Infants who participated in the current project were part of a much larger project on motor behaviors and training in preterm infants. Families of participants were given an honorarium for their participation and were reimbursed for parking costs.

Training

Infants were randomly assigned to 1 of 2 groups: a movement training group and a social training group. Training started when infants were 8 to 10 weeks of corrected age ($\bar{X}\pm SD= 8.9\pm 2$ weeks for the move-

Movement Training in Infants Born Preterm

Table 2.
Available Imaging Summary for Individual Infants in Each Group^a

Participant No.	Head Ultrasound 1	Head Ultrasound 2
Movement training group		
1	N/A	
2	N/A	
3	WNL	
4	Grade 1 IVH	
5	WNL	
6	Patchy area of echogenicity in right parietal lobe	
7	WNL	
8	N/A	
9	N/A	
10	Mostly WNL	
11	WNL	
12	Megacisterna magna	
13	WNL	
Social training group		
1	Grade 3 IVH	Mild ventriculomegaly, no evidence of IVH
2	Suspicious for left choroid plexus bleed	
3	WNL	
4	Grade 2 IVH, mild ventriculomegaly	
5	WNL	
6	Small right choroid plexus cyst	
7	N/A	
8	N/A	
9	PVL	Reduction 90% of cysts
10	WNL	
11	WNL	
12	N/A	
13	WNL	

^a WNL=within normal limits, PVL=periventricular leukomalacia, IVH=intraventricular hemorrhage, N/A=not available or no imaging done.

ment training group and 8±2 weeks for the social training group).

Families of both groups were asked to provide 10 minutes of training with their infants at home, 5 days a week for 8 weeks. Both groups received a training booklet with step-by-step instructions for the training activities and a journal to record how

much time was spent on each activity. The primary caregiver was trained by the same physical therapist on how to perform training activities. Follow-up questions on how to perform these activities were addressed over the telephone and during the testing sessions over the 8-week training period. Each group

completed an average of ≥75% of the training per week.

Movement training. Thirteen infants were randomly assigned to receive daily movement training at home over 8 weeks. Caregivers were instructed that the movement training activities were designed to improve their infant's awareness and ability to reach for and interact with toys with their feet. Movement training activities were divided into 3 categories of feet games: general movements,⁷ midline movements, and distinct movements (Fig. 1).

Specific activities were chosen because there are 2 important factors that influence the typical emergence of independent hand reaching: midline behaviors of the hands and physical interaction with toys.^{2,35,36} Our movement training program incorporates midline movements of the foot and earlier foot-toy interactions. In addition, there are 2 main factors that describe atypical leg movements seen in infants born preterm: a decreased ability to disassociate the joints of the legs and a high frequency of kicking.^{12,15,37,38} Our movement training program incorporates activities that promote dissociation of the joints by using distinct leg movements to interact with toys.

Social training. To control for the increased social interaction that accompanies movement training, caregivers of infants in the social training group were instructed to position their infant supine on the floor and sit near the infant's feet. Caregivers were given a 10-minute CD of children's music. They were instructed to interact with their infant visually and verbally along with the music, but not to touch or present objects to their infant. Infants were allowed to move throughout these interactions. Thus, the infants in the social training group experienced a similar amount of one-on-one time with the

caregiver in the same position as in the movement training group, but they did not physically interact with objects or their caregiver (Fig. 2).

Testing Sessions

Infants and families were seen in the Infant Motor Behavior Laboratory, University of Delaware, every other week for 8 weeks, for a total of 5 sessions. The protocol followed that of previous feet-reaching studies.^{2,7} Infants were seated in a custom-made chair with a strap placed around their chest (Fig. 3). The chair allowed free movement of the arms and legs. The experimenter stood directly in front of the infant and presented a toy in the infant's midline at hip height for six 30-second trials. After each trial, the toy was moved out of the infant's view and repositioned in midline for the next trial. Two synchronized Sony 8mm CCD-TRV608 video cameras[†] were placed approximately 1.2 m (4 ft) to the front and right of the infant and approximately 1.2 m to the front and left of the infant to record a clear view of all leg movements for behavioral coding.

Coding

Synchronized videotapes were recorded on a computer using Broadway Pro version 4.5 software,[‡] and behaviors were coded from the computer image using a custom-made program. Each session was coded twice: once for toy contacts and a second time for duration of the toy contacts. Two research assistants who were blinded to each infant's group coded all videotapes. Interrater reliability assessed with 20% of all trials (reflected by the amount of agreement minus amount of disagreement divided by the total) for



Figure 1.

Three categories of movement training activities: (A) general movements—caregiver encouraging earlier foot-toy interaction by making the bells on infant's socks ring with Velcro attachment, (B) midline movements—caregiver holding a stationary toy in midline and encouraging a midline reach with the foot to contact the toy, and (C) distinct movements—caregiver holding an infant's hip at 90 degrees and encouraging primarily knee motion to contact the toy with the foot.



Figure 2.
Social training.



Figure 3.

Infant during the feet trials of a testing session. For hand trials during session 1, the toy was placed in midline at shoulder height.

[†] Sony Corporation of America, 550 Madison Ave, 33rd Floor, New York, NY 10022-3211.

[‡] Data Translation Inc, 100 Locke Dr, Ste 1, Marlborough, MA 01752-7235.

contact number ($\geq 95\%$) and contact duration ($\geq 91\%$) was high.

Dependent Variables

Number of foot-toy contacts. The number of times the infant contacted the toy with any part of either foot or toes was recorded for sessions 1 through 5.

Number of hand-toy contacts. The number of times the infant contacted the toy with any part of either hand or fingers was recorded for session 1. Hand-toy contacts were used during session 1 to determine whether infants born preterm touched the toy with their feet before touching the toy with their hands.

Foot-toy contact duration (seconds). The average amount of time infants spent touching the toy per foot-toy contact was recorded for sessions 1 through 5.

Data Analysis

Feet reaching during session 1. Descriptive statistics were used to evaluate whether preterm infants contacted the toy with their feet and their hands during session 1. A paired *t* test was used to test significance. The alpha level was set at $\leq .05$ for a significant difference and at $\leq .10$ for a statistical trend. Given the individual variability typical of infant behavior, the number of infants who contacted the toy more than 1, 5, and 10 times was compared between groups.

Feet reaching over sessions 1 through 5. Foot-toy contact number was analyzed with a 2 (group) \times 5 (session) 2-way analysis of variance (ANOVA) for repeated measures on one variable (session). Planned comparisons using independent *t* tests were used for between-group comparisons during each testing session. Foot-toy contact durations required nonparametric statistics because each

group had a different total number of foot-toy contacts. Consequently, contact durations are shown graphically as box plots. Nonparametric Friedman tests were used to assess change over sessions, and the Mann-Whitney *U* test was used to assess between-group differences. The alpha level was set at $\leq .05$ for a significant difference and at $\leq .10$ for a statistical trend.

Role of the Funding Source

This work was partly funded by Foundation for Physical Therapy PODS II awards to Dr Heathcock and was a part of her dissertation in the Biomechanics and Movement Science Program in the Department of Physical Therapy at the University of Delaware.

Results

Session 1, Prior to Training

A paired *t* test indicated the number of foot-toy contacts of both groups combined was greater than hand-toy contacts during session 1 ($t = -4.3$, $P = .000$). Descriptive statistics also suggested that during session 1, when infants were 2 months of corrected age, foot-toy contacts were common, whereas hand-toy contacts were rare. Specifically, 80% (21/26) of the infants contacted the toy with their feet at least once during session 1, for a total of 191 contacts and an average (\pm SD) number of contacts per infant of 7.35 ± 7.89 (range = 0–31). In addition, 54% (14/26) of the infants contacted the toy more than 5 times, and 42% (11/26) of the infants contacted the toy more than 10 times (Fig. 4). In contrast, 27% (7/26) of infants contacted the toy with their hands at least once, for a total of 23 contacts and an average (\pm SD) number of contacts per infant of 0.88 ± 2.1 (range = 0–9). Only one infant contacted the toy 5 times, and no infant contacted the toy more than 10 times. These results suggest that at 2 months of corrected age, preterm infants elevated their feet to

hip height to contact a toy with their feet more often than with their hands.

Sessions 1 Through 5

Foot-toy contact frequencies over time and between groups for the 5 sessions are shown in Figure 5. During session 1, there were no differences in the number of foot-toy contacts between groups. At each session during the training period (after session 1), infants in the movement training group contacted the toy more frequently than infants in the social training group (Fig. 5).

A group (2) \times session (5) repeated-measures ANOVA indicated significant main effects for group ($F_{1,24} = 43.3$, $P = .000$) and session ($F_{4,96} = 3.2$, $P = .016$). The movement training group had a higher mean number of foot-toy contacts during sessions 2 through 5 (Fig. 5). A planned comparison indicated a significant difference ($\bar{X} \pm$ SD) between the movement training group (32.7 ± 22.9) and the social training group (15.4 ± 16.6) during session 5 ($t = 4.86$, $P = .037$). During session 5, after 8 weeks of training, infants in the movement training group touched the toy 425 times, whereas infants in the social training group touched the toy 200 times. The effect size for session 5 using the Cohen *d* statistic was large at .83. On an individual level, 92% (12/13) of infants in the movement training group touched the toy with their feet more than 10 times, whereas 62% (8/13) of infants in the social training group touched the toy with their feet more than 10 times in session 5 (Fig. 4).

In summary, infants in both groups showed an equal number of foot-toy contacts during session 1, before the training program. In addition, both groups showed an increase in the number to foot-toy contacts over each session. Infants in the movement training group out-performed

infants in the social training group over time and during session 5, suggesting that movement training may have improved the infants' ability to contact a toy with their feet.

During our analysis, we noticed that 2 infants in the social training group had the most significant brain injuries (see participants 1 and 9 in Tab. 2). To ensure the difference between the 2 interventions was not attributed to the presence of the most serious brain lesions in the social training group, we ran the above statistical analysis without these 2 infants. A group (2) × session (5) repeated-measures ANOVA indicated significant main effects for group ($F_{1,22}=36.7, P=.000$) and session ($F_{4,88}=2.5, P=.047$). The movement training group had a higher mean number of foot-toy contacts during sessions 2 through 5. A planned comparison indicated a significant difference ($\bar{X} \pm SD$) between the movement training group (32.7 ± 22.9) and the social training group (14.3 ± 17.7) during session 5 ($t=4.7, P=.041$).

In summary, there were no changes in our results. All variables that were significant remained significant. For all variables, these 2 infants performed around the mean of the social training group or better. In addition, both infants touched the toy more than 10 times on visit 5, indicating they were consistent reachers. Therefore, we continued with the statistical analysis including the entire sample.

Foot-Toy Contact Duration

The results for foot-toy contact duration are shown in Figure 6. Because infants in the movement training group contacted the toy more times than infants in the social training group, the average duration per contact was entered into nonparametric statistical analyses. Figure 6 suggests that the movement training group contacted toys for a longer duration than the social training group.

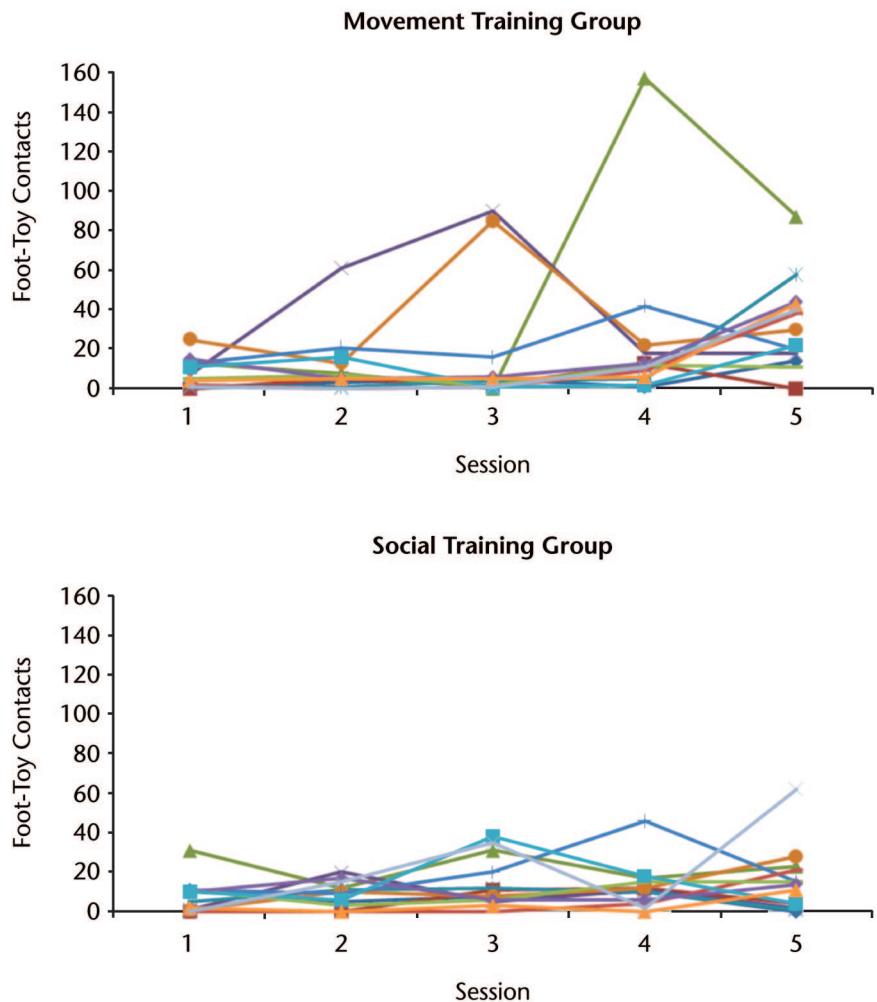


Figure 4. Total number of foot-toy contacts for individual infants in the movement training group (top graph) and the social training group (bottom graph).

A nonparametric Friedman test indicated no significant change in foot-toy contact duration over time. A nonparametric Mann-Whitney *U* test indicated significant differences between groups for session 5 ($Z=-2.00, P=.045$), suggesting that for each foot-toy contact the movement training group touched the toy for longer periods of time.

Discussion

Early Feet-Reaching Behaviors in Preterm Infants

The first purpose of this study was to evaluate whether preterm infants at 2 months of corrected age can

use their feet to interact with a stationary midline toy. Preterm infants were able to contact a stationary toy with their feet before being able to contact the toy with their hands, similar to behaviors seen in full-term infants. Specifically, preterm infants demonstrated a much higher number of foot-toy contacts than hand-toy contacts during session 1. Furthermore, a majority of preterm infants contacted toys with their feet multiple times during session 1, when no infants were able to contact the toy consistently with their hands. Our findings are similar to the findings of other studies of full-term in-

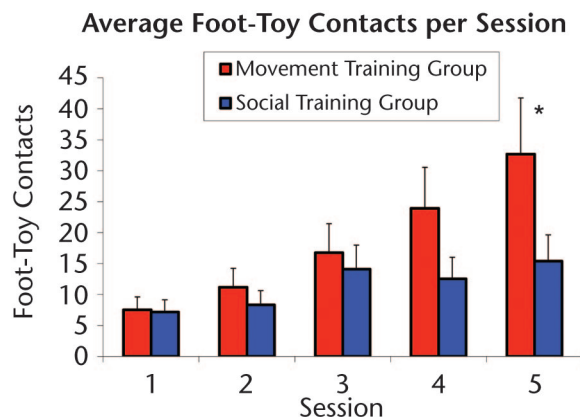


Figure 5.

Mean and standard error of the average number of foot-toy contacts per session for the movement training group (red bars) and the social training group (blue bars). The graph shows that there were more total contacts during each session over time and that the movement training group had more contacts than the social training group during session 5. Sessions were separated by 2 weeks. Asterisk indicates significant difference between groups at $P < .05$.

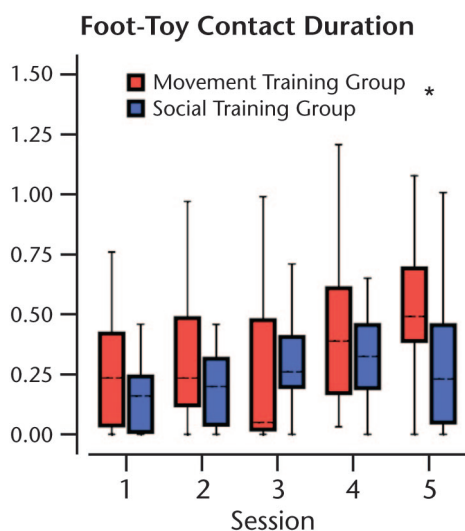


Figure 6.

Box plots for the average foot-toy contact duration in seconds; the median for each group is represented by the dashed line. The error bars represent the maximum and minimum values and the top and bottom quartiles of data distribution. The boxes represent the distribution of data from the 2 middle quartiles. The graph shows that there were no changes in foot-toy contact durations over time and that the movement training group had longer durations than the social training group during session 5. Asterisk indicates significant difference between groups at $P < .05$.

fants^{2,7} and suggested that when they are interested in a toy placed within reach of their feet, both full-term and preterm infants born at less than 33 weeks of gestational age can control their legs to contact the toy multiple times.

Effects of Movement Training on Feet Reaching

The second purpose of this study was to evaluate the effects of daily movement training on the feet-reaching behaviors of preterm infants. Preterm infants in both groups showed an increase in feet reaching over time, with an advantage appearing for the movement training group after 8 weeks of training, when the infants were 4 months of corrected age. Galloway and Thelen² found that over a 1-month period the duration of foot-toy contacts increased, suggesting that nontrained full-term infants increased their leg control for contacting toys with their feet. The duration of foot-toy contacts for preterm infants born at less than 33 weeks of gestational age did not change over the 8-week testing period for either group. This finding may represent an important difference in early leg control between full-term and preterm infants. It is important to note that the duration of foot-toy contacts was 2 seconds less than typically seen for hand-toy contacts.⁴ The hand can easily be used to hold a toy. Indeed, young infants who are not yet reaching will hold on to a toy when it is placed in their hand.³⁹⁻⁴¹ Equipping socks and toys with Velcro during training could increase infants' drive to explore and maintain contact with toys with their feet, similar to how "sticky mittens" have been used to train young infants to explore toys longer with their hands.³³

Our movement training, which focused on midline movements of the feet, earlier experience with foot-toy interactions, and dissociation of the

joints of the leg, had a positive effect on the number of foot-toy contacts and duration of foot-toy contacts. All dependent measures began to improve for the movement training group over the social training group during session 5. It is unknown how changes in foot-toy contacts affect other motor skills and how these foot-toy contact behaviors would continue to evolve in preterm infants with and without movement training.

In combination, these results suggest that preterm infants may need more movement experience, such as via early intervention, than full-term infants in order to improve or learn a motor skill. Full-term infants show immediate changes in behavior with training in the mobile paradigm and significant changes in hand and feet reaching after 2 to 3 weeks of training.^{7,33,42} The movement training group in this project showed improvements only after 8 weeks of training. If there is a difference in training effect between full-term and preterm infants, then it is particularly concerning for 3 reasons. First, the length and amount of training provided to preterm infants were more than have typically been reported in training studies on full-term infants.^{7,27,28,33,43} Thus, full-term infants showed much earlier skill acquisition, even when preterm infants were provided with daily training over many weeks or months. Second, our preterm cohort was not a high-risk population and would be expected to have a training effect more similar to that of full-term infants than that of preterm infants at higher risk. Thus, the effect of training on the early control of the head, arms, legs, and trunk needs additional clinical research focus. Third, certain populations of preterm infants display learning differences from full-term infants, both as younger infants^{17,26} and at older ages.⁴⁴⁻⁴⁷ Thus, the difference in

training effect could reflect, in part, differences in motor learning.

Early Motor Control in Preterm Infants

Various populations of preterm infants show marked differences from full-term infants in terms of postural control,^{48,49} reaching with the hands,⁶ spontaneous kicking,^{12,38,50} and kicking in the mobile paradigm.^{17,18,26} More importantly, these differences often are predictive of future delays in functional skills such as walking or object exploration.^{37,49,51}

Thus, why is it that preterm infants appear to be relatively good at feet reaching, while struggling with other motor skills during young infancy? Galloway and Thelen² proposed that feet reaching was easier than hand reaching due, in part, to the interaction of 2 soft constraints: anatomical differences between the arms and legs and differences in early movement experiences of the arms and legs. Similarly, we hypothesize that the anatomical constraints of a stable base, experience moving the legs in the midline, and the task constraints of the current project make feet reaching less difficult for preterm infants than reaching with the hands.

First, leg movements may benefit from greater mechanical stability. Reaching out to touch a toy with the hand requires hand-eye coordination, head control, trunk control, and the ability to move the arm against gravity to a midline position.⁵²⁻⁵⁶ Providing assistance in these areas, such as postural or head support, increases the number of hand reaches in full-term infants.⁵⁷ Similarly, the pelvis offers a more anatomically stable support surface for feet reaching than the scapula offers for hand reaching and potentially fewer degrees of freedom, requiring active control at the hip versus the shoulder. In addition, when moving the

arms, a certain degree of head and postural control is required secondary to the mechanical effects resulting from the interaction of arm, head, and trunk motion, as well as the effect of gravity.^{6,58,59} This effect is less likely, especially in terms of the head, when the legs are moving. This is especially true in our infant chair, which stabilizes the lower trunk and hip more than the upper trunk, shoulder, and head. Preterm infants may take advantage of this constraint and use it to more easily control their legs when contacting a toy.

Second, infants have more experience moving their legs in the workspace required for feet reaching. Spontaneous kicking is one of the most common behaviors seen from the last prenatal trimester through the first 3 postnatal months. Both preterm and full-term infants kick their legs several hundred, if not a few thousand, times per day.²⁵ As they move, infants are learning about the properties of their limbs and how to eventually control their bodies.^{9,60,61} Compared with early arm movements,⁶²⁻⁶⁴ kicking in young infants is relatively stereotypical within a parasagittal plane, with reliable timing between the legs and among the joints of one leg.¹⁴ In contrast, spontaneous arm movements are much more variable, as the arms move in multiple planes and rarely in the midline until a few weeks before reaching onset.⁶²⁻⁶⁴ Thus, infants have much greater experience moving their feet near midline and have less distance to control their legs in order to contact a midline toy, as compared with the hands.

Lastly, kicking and reaching are different behaviors. The development of leg control in preterm infants over the first few months differs from that of full-term infants. Preterm infants are not able to control

the frequency of their leg kicking or the proportion of leg kicking to make a mobile move.^{17,18,38} The results of this study, however, suggest that preterm and full-term infants may have similar abilities in the development of endpoint control. Kicking behaviors may be too stable and afford less adaptation in kicking tasks such as the mobile paradigm, which positively reinforces any style, speed, or direction of leg movements. In contrast, feet reaching demands a nonkicking movement in which the movement direction and endpoint control are rewarded.

Clinical Implications

At 8 weeks of age, common assessments of infant development are the observations of passive and elicited movements. Foot-to-toy contacts may give clinicians more information about higher-level skills at a younger age. Infants who repeatedly touch a toy with their foot must coordinate the endpoint and joints of their legs and have the strength to move their legs against gravity, sufficient range of motion of the hip, and the motivation to touch the toy. This type of assessment could be used in conjunction with standard assessment tools for preterm infants, such as the Test of Infant Motor Performance (TIMP),⁶⁵ where observations of spontaneous coordination could be paired with those of skilled movements such as feet reaching. Interestingly, at 8 weeks of corrected age, leg control is one of the most discriminating items on the TIMP.⁶⁶ These early measures of range of motion, strength, control, flexibility, and interest in objects may be early precursors to similar variables that contribute to the development of rolling, sitting, crawling, and reaching with the hands.

As an intervention, clinicians may take advantage of this ability to improve coordination and strength of the legs, the learning of cause-and-

effect relationships, and object exploration. At 8 weeks of age, most infants are not able to contact a toy independently with their hands, yet they can do so with their feet. This ability highlights that when given the opportunity, infants are able to explore with whatever means they have available. In addition, infants born preterm demonstrate positive changes in their motor skills during a specific early intervention program, such as the ability to improve how they interact with objects with their hands and feet.

Limitations and Conclusions

Given that this is the first quantification of feet reaching and the effect of movement training on feet reaching in any preterm population, there are several limitations that need to be addressed in future studies. First, our cohort was born at risk for motor impairments, but not at the highest risk. The early identification of impairments and their response to movement training are even more critical for infants at highest risk, such as those with extremely low birth weight and those who are extremely preterm. It is important to study these populations directly and not simply extrapolate findings from studies of lower-risk populations.

Second, although we noted a training effect, we would suggest expanding other components in the protocol such as the role of “sticky socks” to maximize infants’ interaction with objects during training. This may be especially helpful if preterm infants have motor learning issues. Lastly, we suggest that our preterm infants displayed adequate leg control to repeatedly place their feet on a midline toy. Further study is needed to directly quantify the degree of coordination using methods such as principal component analysis⁶⁷ and the uncontrolled manifold technique.^{68,69} Given the potential developmental

connection between spontaneous leg movements and feet reaching, additional work is needed to further test the similarities and differences between these behaviors.

Despite these limitations, our results suggest that preterm infants display a new and potentially important ability to contact objects with their feet before their hands. This finding, coupled with a positive effect of training, provides researchers with a foundation for more-specific hypotheses about the role of experience in early purposeful movements and provides clinicians with a new intervention strategy for encouraging object interaction within the first months of life in infants at risk for long-term motor impairments.

Both authors provided concept/idea/research design, writing, data analysis, project management, and consultation (including review of manuscript before submission). Dr Heathcock provided data collection. Dr Galloway provided facilities/equipment, institutional liaisons, and clerical support.

This study was approved by the University of Delaware Human Subjects Review Committee and the Christiana Care Institutional Review Board.

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