Movement Training Advances the Emergence of Reaching in Infants Born at Less Than 33 Weeks of Gestational Age: A Randomized Clinical Trial

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Background and Purpose

This study had 2 purposes: (1) to compare the emergence of reaching in infants born full-term and infants born at less than 33 weeks of gestational age and (2) to evaluate the effectiveness of a movement training program on the emergence of reaching in this preterm population.

Participants

Twenty-six infants born at less than 33 weeks of gestational age and with a birth weight less than 2,500 g were randomly assigned to receive 20 minutes of daily movement training (PT-M group) or daily social training (PT-S group) and were compared with 13 infants born full-term (FT-S group).

Methods

Reaching and hand-object interactions were tested every other week for 8 weeks. At each visit, infants were allowed six 30-second opportunities to contact a midline toy.

Results

The FT-S and PT-M groups reached earlier and more consistently than the PT-S group. Specifically, the subjects in the FT-S group contacted the toy for longer durations and with an open, ventral surface of their hand. The PT-M group demonstrated increases in the number of hand-object contacts, the number of consistent reaches, and the percentage of time interacting with the toy and the surface of hand-object contact.

Discussion and Conclusion

This project demonstrates that there are early gross motor skill differences in infants born at less than 33 weeks of gestational age. A caregiver-based daily training program, however, is effective at lessening some, but not all, of these differences over the short term.

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Reaching emerges over the first months of life from the interplay of multiple factors. These factors include developmental changes in head and postural control,[1,2] hand-eye coordination,[3] interest in objects,[4] knowledge about object affordances,[5] antigravity strength (force-generating capacity) and control of the upper extremities,[6–10] and social interactions with caregivers.[11] In the second half of the first year, infants contact objects more often, for longer durations, with a smoother hand path, and with a more controlled speed.[6,7,12,13]

Prior to reach onset, infants move their arms hundreds of times per day.[14,15] These "prereaching" movements are of interest for several reasons. First, they shape and, in turn, are shaped by the brain areas thought to contribute to purposeful reaching.[16–19] Second, prereaching movements provide the sensorimotor experiences by which infants learn to control their arms and upper body.[7,20–24] Third, these movements provide infants with multimodal information about how their bodies function in the surrounding physical and social environments.[23,25–28] Lastly, and most importantly for pediatric neurorehabilitation, is that our recent work has suggested that movement and postural training provided during the prereaching period advances the emergence of reaching and object exploration in infants who are developing typically.[12–29]

In general, infants born at younger gestational ages (GAs) and with lower birth weights have a higher risk for long-term functional impairments, such as those associated with cerebral palsy (CP), than infants born full-term. Infants born preterm and weighing less than 2,500 g are termed "low birth weight" and are at increased risk for long-term motor impairments.[30] Infants born preterm and weighing less than 1,500 g ("very low birth weight") and those weighing less than 1,000 g ("extremely low birth weight") are of particular concern because they are at the highest risk for the more severe motor impairments associated with CP.[31–36] In addition to GA and birth weight, infants with more complicated medical histories, such as the presence of hemorrhages, are at higher risk for disability. These permanent impairments include moderate to severe incoordination, weakness, and involuntary contractions involving one or more limbs as well as the trunk and neck. As outlined below, reaching and grasping impairments have been studied in children with CP; however, the development of reaching in infants born preterm who are at risk for CP has rarely been studied. Thus, the first purpose of this study was to determine whether the emergence of purposeful reaching differs in hand-toy contact number, duration, and type in full-term infants and infants born preterm with a birth weight of less than 2,500 g.

To date, we have found only one study of reaching in infants born preterm.[37] Despite this lack of direct research, clinicians strongly suspect that infants born preterm will display significant reaching delays for 3 reasons. First, these infants are at high risk for the unimanual and bimanual reaching and grasping impairments associated with forms of CP involving the upper extremities.[38–46] For example, children 5 to 12 years of age with more involved hemiplegic CP reached less smoothly, with longer reach and grasp durations and with poorer anticipatory grasping, than children with milder impairments.[40] In addition, infants born preterm display a range of motor impairments during their first months of postnatal life involving poor postural control of the head and trunk; difficulty extending the arm, head, and trunk in a supine position; abnormal movement patterns of the head, trunk, and limbs[47–49]; atypical kicking rates and kicking coordination[50–52]; and atypical general movement quality.[53]

Second, studies have increasingly suggested that certain impairments in older children are related, in part, to impairments during infancy.[54,55] Two retrospective behavioral studies[56,57] suggested that different forms of CP in children were related to early impairments in leg, arm, and hand movements. Poor postural control and hand function seen in older infants and children may be related to similar impairments and limitations at 9 to 12 months of age.[58–60] For example, infants born preterm reach and interact with objects differently than full-term infants. At 12 months, 18 months, and 7 years of age, infants born preterm show less optimal postural control and hand function,[58–60] and, at 9 months of age, infants born preterm do not use a pincer grasp.[61] Furthermore, when tested in preschool, infants born at less than 33 weeks showed a delay in the development of visuo-manual coordination in a reaching task.[62]

Third, the lone study of infants born preterm who were newly reaching[37] showed that infants born at less than 32 weeks of age reached later and with a slower and less smooth hand path than infants born full-term. The reaching delay as well as the poorer "quality" of reaching may be related to coordination impairments noted later in childhood.[63] We, therefore, hypothesized that our cohort of infants born preterm would contact toys later in development, with fewer contacts of shorter duration and with fewer contacts with the ventral surface of an open hand.

The second purpose of this study was to determine whether daily movement training would improve the performance of reaching and hand-toy contacts in infants born

Table.
Average (±SD) Group Characteristics[a]

Group	GA	Birth Weight (g)	Days in SCN	Age at First Visit (d)
FT-S	39±6/7	3,752.8±341	0	60±4.6
PT-S	30 3/7±1 6/7[b]	1,639.6±454[b]	36.2±28[b]	57.7±13
PT-M	30 3/7±1 5/7[b]	1,602.0±460[b]	27.3±17[b]	61.2±15

[a] GA=gestational age, SCN=special care nursery, FT-S=full-term social training group, PT-S=preterm social training group, PT-M=preterm movement training group. Gestational age is commonly referred to as week, followed by days (expressed in sevenths).
[b] Statistical difference from the FT-S group ($P<.001$). No differences were observed between preterm groups for GA, birth weight, days in the SCN, and age at first visit.

preterm. Early experience is a critical aspect of both brain and behavioral development, including the development of reaching.[18,19] Recent work in animal models suggests that providing specific experiences earlier or more intensively than is typical (ie, training) has positive effects on brain and behavioral development in cases of even very severe developmental disorders such as fetal alcohol syndrome.[64–66]

Blauw-Hospers and Hadders-Algra, in a recent systematic review of early intervention for motor impairments in infants born preterm,[67] found 12 studies that passed basic selection criteria and followed infants after hospital discharge. Their conclusions were threefold and were common to several earlier reviews.[68–73] First, the treatment in 8 of the 12 studies, which was based on traditional motor development theory and used largely passive handling techniques, was no more beneficial than standard care. Similar findings have been reported with children and young adults with CP.[74] Second, the 2 studies of general developmental activities, in which families provided activities that progressed with age, reported benefits such as improved motor performance.[75,76] Lastly, the one task-specific training study, in which families provided treadmill training in the home, reported a reduction in walking delays in children with Down syndrome.[77] Thus, task-specific or general activities, built on more modern theory, such as dynamic systems theory, in which families promote development through complex, interactive, and progressive activities, can be effective at lessening early impairments.

Dynamic systems theory provides a theoretical framework for a basic assumption of pediatric intervention: providing an enhanced environment and providing practice can affect developmental skills. This theory, as applied to development, highlights that behavioral changes emerge from the ongoing interaction of multiple factors. For example, reaching behavior emerges not solely from nervous system changes in isolation, but from these changes in combination with developmental changes in body properties, the physical and social environment of the child, and task requirements.[78] Systems theory then would predict that additional experience or "training" provided to infants who are healthy or infants with disability may help result in changes in motor behavior.[12,79–83] Therefore, we predicted that providing a combination of task-specific and general activities to infants during the period before they were reaching would significantly advance the onset of their reaching.

Our recent work and that of other laboratories on the role of experience in the emergence of reaching and grasping behaviors in infants who are developing typically provide additional support for our training hypothesis. For example, reaching and visual attention to objects were advanced in nonreaching infants, ages 3 to 3½ months, provided with 2 weeks of daily experience interacting with objects using Velcro* mittens.[13] Our recent work[12,29] has suggested that reaching, object exploration, and means-end skills (eg, pushing a lever to activate a toy) were advanced in infants after 2 to 3 weeks of daily training.

Method

Participants

Thirty-nine infants (13 born full-term and 26 born preterm) participated in this longitudinal study. The infants were seen for the first visit at the mean age (±SD) of 59.64±11 days (about 8½ weeks) corrected age. Inclusion criteria for infants born full-term were GAs of greater than 37 weeks and no known development delay, as stated by a parent. Inclusion criteria for infants born preterm were GAs of less than 33 weeks and birth weights of less than 2,500 g. Group characteristics for all infants are shown in the Table. Participants were excluded for prenatal drug exposure, congenital orthopedic or genetic anomalies, and significant visual or hearing deficits. Infants born full-term were recruited from local birth announcements. Infants born preterm were recruited from the

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

special care nursery at Christiana Hospital in Newark, Del, and through word-of-mouth. There were 14 infants with low birth weight, 9 infants with very low birth weight, and 3 infants with extremely low birth weight. Furthermore, there were 4 infants born at less than 33 weeks of GA or at greater than 32 weeks of GA, 20 infants born at less than 32 weeks' GA or at greater than 28 weeks of GA, and 2 infants born at less than 28 weeks of GA.

A parent or guardian of each infant signed an informed consent statement approved by the University of Delaware Human Subjects Review Committee. Families of participants were given an honorarium and a small infant toy for their participation and were reimbursed for any parking costs. Infants were part of larger studies investigating the effects of training across a variety of skills.

Training Groups

Infants born preterm were randomly assigned, via flipping a coin, into 1 of 2 groups: a movement training (PT-M) group or a social training (PT-S) group. Infants born full-term also did social training (FT-S group). Each group received a booklet with step-by-step instructions for their specific training activities and a journal to record the amount of time spent on each activity. On average, the PT-M group completed 85%, the PT-S group completed 90%, and the FT-S group completed 87% of the days in the training period. There were no significant differences in the total amount of training between preterm groups.

Families of infants in all groups were instructed to spend 15 to 20 minutes each day at home for 5 days per week on their specific activities. The primary caregiver was trained by a physical therapist for approximately 30 to 45 minutes. Follow-up questions on how to perform the training activities were addressed over the telephone and during testing visits. Caregivers were observed performing the training activities with the infant by a physical therapist weekly. The PT-M and PT-S groups received activities for 8 weeks, whereas the FT-S group received activities for 3 weeks. The FT-S group received 3 weeks of social training based on previous work suggesting that 2 to 3 weeks of movement training advanced hand-object interactions in infants born full-term.[12] We hypothesized that infants born preterm may require more training and thus provided 8 weeks of training for both preterm groups.

One infant born preterm completed the project but was excluded from data analysis due to a subsequent diagnosis of partial blindness in one eye. No infants born full-term were excluded from the data analysis. An additional 5 infants born preterm were recruited from the special care nursery and started the project, but withdrew secondary to family schedules, resulting in a 16% dropout rate. One infant in the PT-S group received occupational therapy and 1 infant in the PT-M group received physical therapy intervention during the study period. The individual performance of these 2 infants did not differ from their group's performance.

Movement training. Caregivers of infants in the PT-M group were instructed that the training activities were designed to improve their infant's interaction with objects. Caregivers were asked to perform the following activities: position the infant supine on the floor, sit near the infant's feet, and show the infant his or her arm and the toy.[12] Placing the baby in a supine position was chosen for all activities to ensure a standard training position. Materials were purchased at a local baby store and modified by an experimenter, and a set of materials was provided to the families for the duration of the project. Materials included mittens and bells attached with Velcro and a white ribbon.

Caregivers were asked to divide the total time into relatively equal amounts in 3 types of activities: (1) general movements, (2) midline movements, and (3) specific movements (Fig. 1). For general movements, the caregiver held a toy tethered by a ribbon to the infant's wrists so that any arm movement caused movement from the toy. The caregiver responded to any infant arm movement by shaking the toy and verbally rewarding the infant. Caregivers were provided with a white ribbon and instructed to use a small toy that made a noise. For midline movements, the caregiver encouraged the infant to touch a midline toy. The caregiver held the toy in a midline position and assisted the infant's hand to the toy. Then the caregiver allowed the infant time to try the movement independently. Caregivers did midline movements with and without Velcro mittens and toys. Caregivers were provided with Velcro mittens and bells for the Velcro play and were instructed to use a small toy that made a noise for midline movements. For specific movements, the caregiver encouraged multijoint or single-joint movements to interact with a toy. Specifically, the caregiver gently held the infant's upper arm and held a toy over the infant's hand, encouraging primarily elbow movement. Caregivers were instructed to use a small toy that made a noise for specific movements.

Social training. The PT-S group served as a comparison group to account for increased social interaction that accompanies movement training. The FT-S group served as a comparison group in a population

Figure 1.
Movement training activities: (A) general movements, (B) midline movements, and (C) specific movements.

without increased risk of reaching limitations. For both groups, caregivers were instructed to position their infant supine on the floor, sit near infant's feet, and interact with the infant visually and verbally, with or without music. Caregivers were instructed not to touch their infant during this time or to show objects to their infant. Infants were allowed to move and may well have moved a significant amount during each social training session. Thus, infants in both the PT-S and FT-S groups experienced one-on-one time interacting with the caregiver in the same position as the infants in the PT-M group, but without the physical interaction with toys or caregiver.

Testing Visits

Infants were observed by an experimenter every other week for 5 visits during 8 weeks of training to assess the emergence of hand-toy interactions. Infants were secured in a custom-made infant chair with a large chest strap, which allowed full range of motion of the arms. An infant chair was used to ensure a standard testing position. During each testing visit, the same experimenter stood directly in front of the infant and held a toy. Infants were presented with a toy in midline at shoulder height at 75% of arm length for 6 trials of 30 seconds each (Fig. 2). 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 1.2 m to the front and left of the infant to ensure a clear view for behavioral coding.

During each visit, infants were observed during a naturalistic play session on the floor in prone, supine, sitting, and standing positions. The video recording of this session was used to score the Alberta Infant Motor Scale (AIMS), which is a valid and reliable assessment of gross motor behaviors in young infants.[84] Reliability values for AIMS scores were high (ie, greater than 95%) using the formula:

$$\frac{\text{No. of agreements}}{\left(\begin{array}{l}\text{No. of agreements} + \\ \text{No. of disagreements}\end{array}\right)} \times 100$$

between 2 physical therapists in more than 20% of the total sessions.

A one-way analysis of variance (ANOVA) revealed differences in AIMS scores for certain weeks. The

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

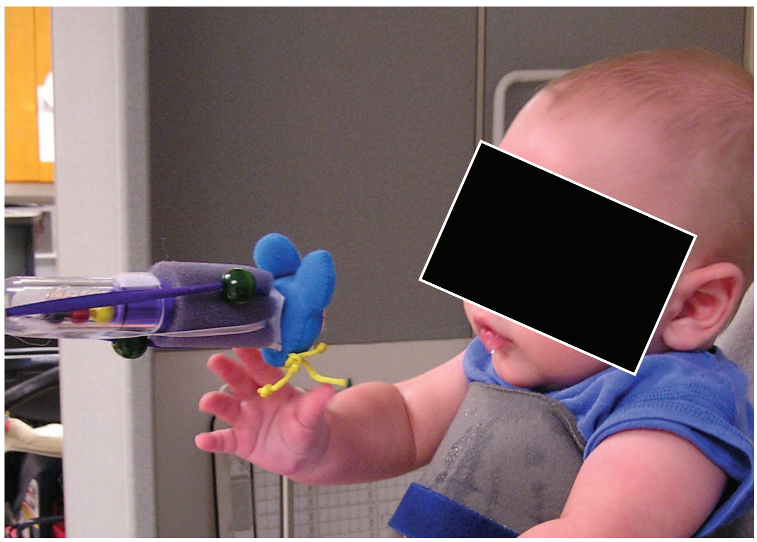

Figure 2.
Infant interacting with the toy.

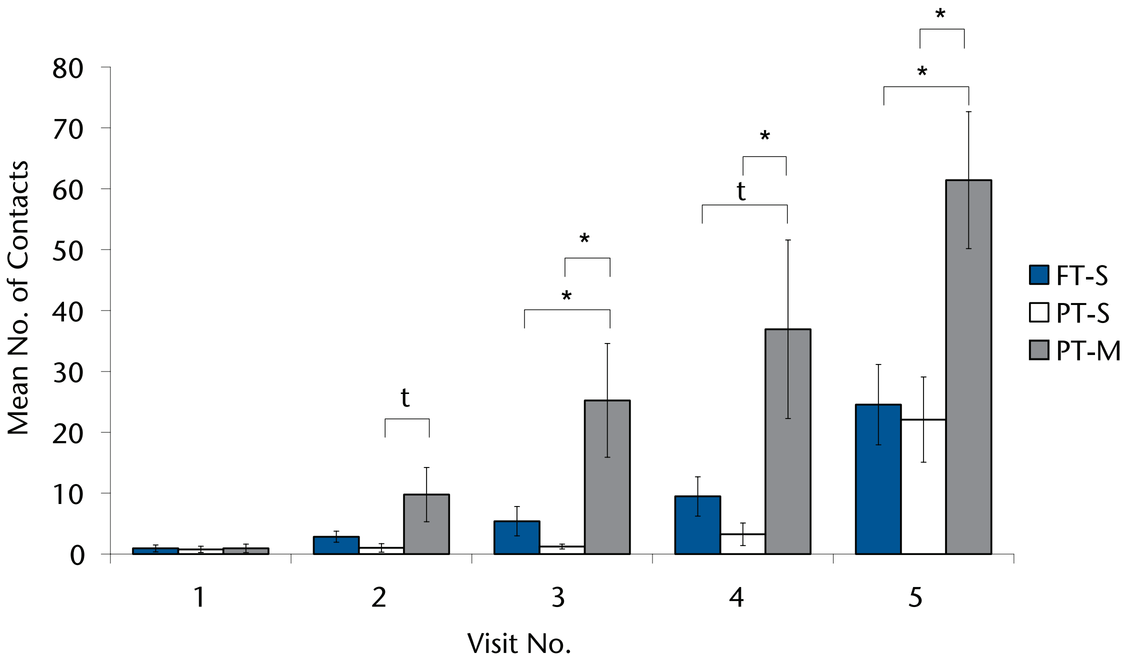

Figure 3.
Mean number of hand-toy contacts over visits. Error bars reflect standard deviation units. Asterisk indicates statistical significance ($P<.05$), t=$P<.10$. FT-S=full-term social training group, PT-S=preterm social training group, PT-M=preterm movement training group.

FT-S group scored higher than the PT-S group (9.8±0.39 versus 7.5±0.71, respectively) during visit 1. The FT-S group and the PT-M group scored higher than the PT-S group (11.46±0.42, 11.78±0.78, and 9.27±0.80, respectively) during visit 2. There were no differences among groups for visits 3 through 5.

Behavioral Coding

Synchronized views of the right and left sides of the infant were coded from a monitor. Coding of all behaviors was done by research assistants who were unaware of the infants' groups. Reliability values for contact data were high (ie, greater than 90%) using the formula shown above among 5 coders. Five coders checked reliability by coding approximately 20% of the data collected from each infant.

Variables

The number of times an infant contacted the toy was averaged per visit. In addition to group results, the numbers of individual infants are presented. The number of infants in each group who contacted the toy more than 5 times each visit is reported. *Reach onset* was defined as the week in which infants in each group met the criterion for the onset of reaching. The *first week of purposeful reaching* was defined as the week in which an infant contacted the toy more than 5 times. The time infants spent in contact with the toy was averaged per visit. Contact duration was reported as a proportion of the total time across all trials per visit (percentage) and as the duration per contact (seconds). The surface of the hand contacting the toy (ventral or dorsal) and the position of the hand during initial contact (open or closed) were reported as a proportion of total contacts during visit 5 (percentage). Visit 5 was selected *post hoc* because it was the only visit in which the infants in the PT-S group had enough toy contacts to compare with infants in the PT-M and FT-S groups.

Data Analysis

A 3-way (ie, group [3] × visit [5]) repeated-measures ANOVA was used to test significance of hand-toy contact number and percentage of time contacting the toy among groups and over visits. Lower-bound corrections for violations of sphericity were used. *Post hoc* testing for simple main effects was used to determine differences among the 3 groups and 5 visits when appropriate interactions or main effects were noted. Tukey corrections were used for multiple comparisons. Data from individual infants also are reported and used to confirm group findings. The Kruskal-Wallis statistic, a nonparametric version of an ANOVA, was used for the proportion of hand-toy contact types and contact durations per contact because each group and individual infants had a different total number of hand-toy

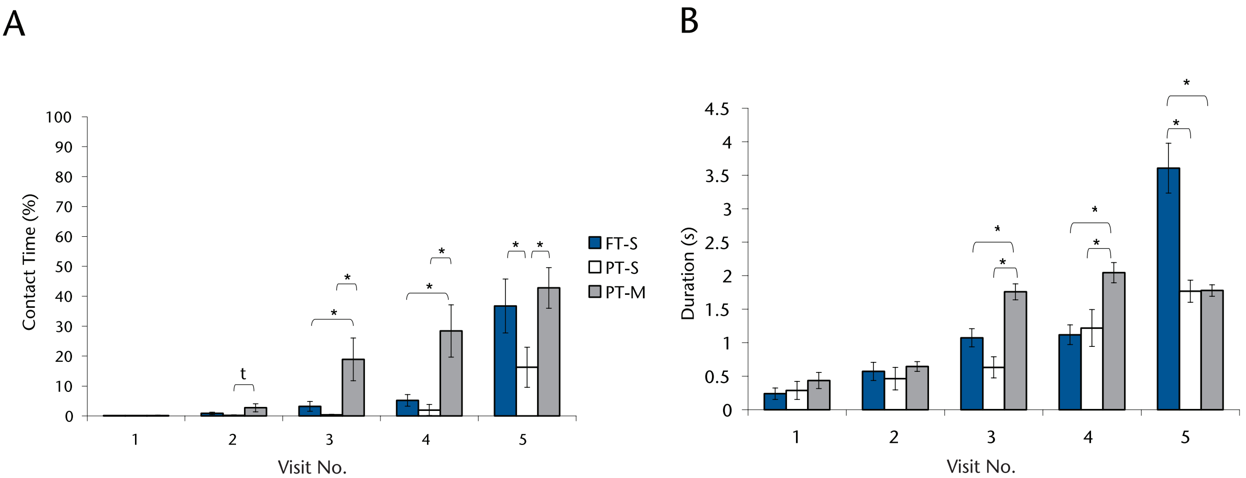

Figure 4.
(A) Mean percentage of hand-toy contact time over visits. (B) Mean duration per hand-toy contact over visits. Error bars reflect standard deviation units. Asterisk indicates statistical significance ($P<.05$), t=$P<.10$. FT-S=full-term social training group, PT-S=preterm social training group, PT-M=preterm movement training group.

contacts. An alpha level was set at less than .05 for a significant difference.

Results

Hand-Toy Contact Number

The PT-M group had the most hand-toy contacts (1,684) over the entire study, the FT-S group had fewer hand-toy contacts (561), and the PT-S group had the fewest hand-toy contacts (345). For average number of hand-toy contacts per visit (Fig. 3), a group × visit interaction ($F=4.67$; $df=8,36$; $P<.001$) was observed, with main effects for group ($F=7.63$; $df=2,36$; $P=.002$) and visit ($F=25.28$; $df=4,36$; $P<.001$). *Post hoc* testing revealed an increase in number of hand-toy contacts over time for all groups and an overall difference among groups, with the PT-M group having a greater number of hand-toy contacts than the PT-S and FT-S groups and the FT-S group having a greater number of hand-toy contacts than the PT-S group. In addition, the PT-M group had more hand-toy contacts compared with the PT-S group at visit 3 (25.2±9.3, range=0–102, versus 1±0.4, range=0–4), at visit 4 (36.9±14.7, range=0–185, versus 3±1.9, range=0–25), and at visit 5 (61.4±11.2, range=0–136, versus 22±7, range=1–73). The PT-M group had more hand-toy contacts compared with the FT-S group at visit 5 (61.4±11.2, range=0–136, versus 44±6.6, range=0–80).

On an individual level, there were differences among groups for the number of consistent hand-toy contacts demonstrating reach onset (more than 5 contacts per visit). The FT-S group had 6/13 infants during visit 4 and 11/13 infants during visit 5 consistently contacting the toy. Similarly, the PT-M group had 7/13 infants during visit 3, 8/13 infants during visit 4, and 12/13 infants at visit 5 consistently contacting the toy. In contrast, the PT-S group reached a majority only at visit 5, with 8/13 infants consistently contacting the toy.

Hand-Toy Contact Duration

The results for hand-toy contact duration are shown in Figure 4. All 3 groups started at visit 1 contacting the toy for less than 1% of the time and increased to 16% to 42% by visit 5. The PT-M group contacted the toy for higher percentages than both the PT-S and FT-S groups. For hand-toy contact duration percentage over visits, a group × visit interaction ($F=3.46$; $df=8,36$; $P<.05$) was observed, with main effects for group ($F=47.12$; $df=1,36$; $P<.001$) and visit ($F=30.47$; $df=8,36$; $P<.001$). *Post hoc* testing revealed an increase in contact duration over time for all 3 groups and an overall difference among groups, with the PT-M group having a greater increase in contact duration than the PT-S and FT-S groups. In addition, the PT-M group had a greater increase in contact duration than the PT-S group during visit 3 (18.9% ±7.1%, range=0%–74%, versus 0.4%±0.2%, range=0%–2%), visit 4 (28.4±8.7%, range=0%–80%, versus 2%±1.8%, range=0%–24%), and visit 5 (42.8±6.8%, range=0%–80%, versus 16.3%±6.7%, range=0%–61%). The PT-M group had a greater increase in contact duration than the FT-S group at visit 3 (18.9%±7.1%, range=0%–74%, versus 3.2%±1.6%, range=0%–16%) and at visit 4 (28.4%±8.7%, range=0%–80%, versus 5.2%±1.9%, range=0%–23%). The FT-S group had a greater increase in contact duration than the PT-S group at visit 5 (36.7%±9%,

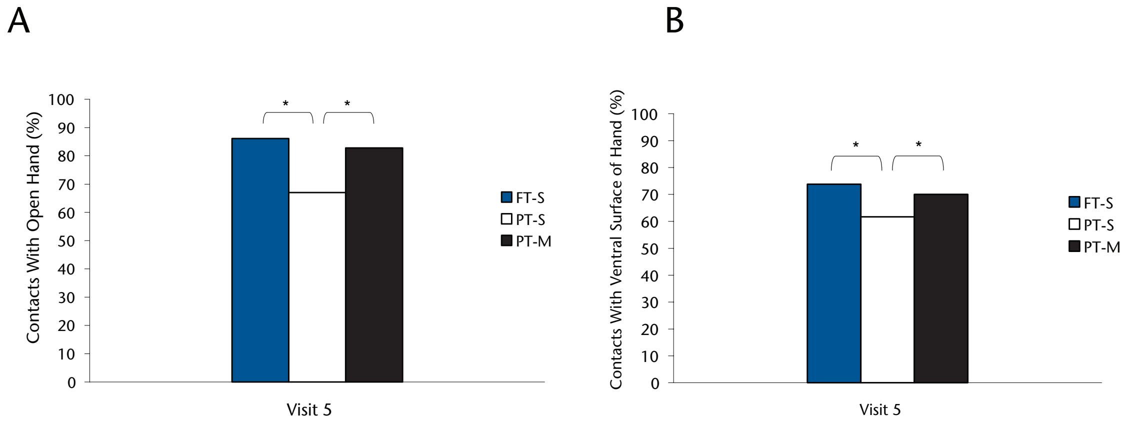

Figure 5.
(A) Mean percentage of total contact with an open hand during visit 5. (B) Mean percentage of total contact with ventral surface of hand during visit 5. Asterisk indicates statistical significance ($P<.05$), t=$P<10$. FT-S=full-term social training group, PT-S=preterm social training group, PT-M=preterm movement training group.

range=0%–89%, versus 16.3%±6.7%, range=0%–61%).

There were group differences in hand-toy contact duration per contact. All 3 groups started at visit 1 contacting the toy for less than 0.5 second per contact and increased to 1.75 to 3.5 seconds per contact by visit 5. The PT-M group contacted the toy for a longer duration per contact than both the FT-S and PT-S groups during visits 3 and 4 ($\bar{X}$=11.17, P=.042, and $\bar{X}$=5.97, P=.015, respectively). The FT-S group contacted the toy for longer durations than both the PT-S and PT-M groups during visit 5 ($\bar{X}$=25.83, $P<.001$, and $\bar{X}$=30.84, $P<.001$, respectively).

Hand-Toy Contact Type

For hand-toy contact type, only data from visit 5, when a majority of infants in all 3 groups touched the toy more than 5 times, were analyzed (Fig. 5). The infants touched the toy 67% to 86% of the time with an open hand and 61% to 74% of the time with the ventral surface of the hand. Differences among the groups were noted. The FT-S and PT-M groups contacted the toy more times with an open hand than the PT-S group ($\bar{X}$=29.37, $P<.001$, and $\bar{X}$=28.56, $P<.001$, respectively). Similarly, the FT-S and PT-M groups contacted the toy more times with the ventral surface of the hand ($\bar{X}$=9.51, P=.002, and $\bar{X}$=6.09, P=.014, respectively).

Discussion

In summary, all 3 groups began without any hand-toy contacts and began reaching over the 8-week period. During visits 3 to 5, when all significant differences in hand-toy interaction were observed, the 3 groups had similar development scores as measured with the AIMS. The PT-M group had the most hand-toy contacts, with more contacts than the PT-S group during visits 3 to 5, after 4 weeks of movement training, and more contacts than the FT-S group during visit 5, after 8 weeks of movement training. The FT-S and PT-S groups had a similar number of contacts during each week, but more individual infants in the FT-S group consistently contacted the toy at visits 4 and 5. Furthermore, all 3 groups began with limited durations of hand-toy contact and improved over the 8-week period. The PT-M group had the highest percentage of time in contact with the toy, but the FT-S group had the longest durations per contact, more than 1 second longer per contact during visit 5. The PT-M and PT-S groups had similar durations per contact during visit 5. In addition, the FT-S and PT-M groups had more contacts with the open hand and ventral surface of the hand than the PT-S group during visit 5, representing a more functional pattern.

There were 3 major conclusions from the results from this study. First, our results support the results of other authors[37,58] in suggesting that infants born weighing under 2,500 g and at less than 33 weeks of GA differ in the development of early motor skills, such as reaching, compared with infants born full-term. Thus, differences in reaching may be identifiable in the first months of postnatal life. Second, daily movement training in the home decreases many aspects of these reaching differences. Thus, future projects can extend this work to preterm populations at even greater risk for long-term reaching limitations, such as infants with extremely low birth weights. Third, this particular 8-week movement training program did not change all of the reaching differences between this cohort of preterm and full-term infants. Thus, future projects may need to modify the intensity, duration, or content of the training.

Infants Born Preterm Display Potential Limitations in Reaching

By comparing the PT-S and FT-S groups, we were able to identify potential reaching limitations in infants born weighing under 2,500 g and at less than 33 weeks of GA. Both group and individual results suggested that, compared with full-term infants, fewer infants born preterm were consistent reachers. The toy contacts made by PT-S infants also were of shorter duration per reach and more often with a closed hand or with the dorsal surface of the hand. These results extend previous findings of poor hand and arm control in preterm infants aged 9 to 12 months to preterm infants at 2 to 4 months corrected age.[58,59]

The development of reaching is a complex and individualized learning process in which infants gradually adapt their ongoing spontaneous movements into purposeful reaching over the first 3 to 5 months of life.[8–10] This process is the result of the ongoing interactions of multiple factors within the infant, as well as within the physical and social environments, including motivation for reaching for the toy, hand-eye coordination, head and trunk control, and neuromuscular control of the arm.[2,85,86] Similarly, we assume that a range of factors contributed to the reaching differences displayed by the preterm infants in this study. For example, impairments in spontaneous movements, muscle performance, postural control, visuomotor coordination, and arousal have been identified during infancy or childhood in various populations of infants born preterm.[60,63,87,88] Some of these impairments, such as lack of control of the center of mass, have been linked to reaching limitations,[46,63,85,89] and other impairments have been related to future functional problems such as problems with crawling, walking, and performance in school.[37,60,90] Lastly, preterm birth has increasingly been associated with a wide range of brain impairments, including those associated with lesions of the cerebellum,[91–95] the basal ganglia,[96–99] and the cerebral cortex.[100,101] Some of these lesions have been associated with long-term impairments in cognition and motor abilities in older children born preterm.

Movement Training Improved Early Reaching in Infants Born Preterm

By comparing the PT-M group with the PT-S and FT-S groups, we were able to identify the short-term effects of movement training on reaching limitations in preterm infants. In total, infants who were provided with movement training contacted toys 3 times more often than full-term infants and 5 times more often than untrained preterm infants. During visits 3 and 4, after 4 to 6 weeks of training, trained infants contacted the toy more often and for longer durations than both untrained preterm and full-term infants. Moreover, during visit 5, after 8 weeks of training, trained infants contacted the toy with a more functional grasp (ventral surface, open hand) than untrained preterm infants but similar to full-term infants. During visit 5, full-term infants contacted the toy for longer durations per contact than both preterm groups. Without training, infants born at less than 33 weeks showed differences from full-term infants in how reaching emerges. Their skill level appeared less than optimal, and their hand positions did not allow grasping and object exploration, both of which are important for continued development of more complex object interaction skills such as tool use.

These results support and extend the results of studies showing training effects on arm behaviors in infants who were developing typically.[12,13,79] Our results also suggest that early experience with objects advances hand-object interactions. In addition, a caregiver-focused daily training program advanced the emergence of an early skill. Interestingly, the largest effects were seen after 4 to 8 weeks of training compared with 2 to 3 weeks of training in previous studies of full-term infants.[12,13] Although the training programs were not identical across these studies, our group of preterm infants appeared to require more training for similar effects than infants who are developing typically. This extended training requirement may signal differences in motor learning and coordination ability in preterm infants, as has been suggested by recent work from our laboratory and others.[102–104]

As was the case with factors underlying reaching limitations, we assume that a range of factors contributed to the training effects displayed by preterm infants in this study. Below we briefly discuss the potential influences of training on arm, head, and trunk control; visual perception; the understanding of object affordances; and infant-caregiver dynamics.

Arm control. Improved perceptual-motor control of the arm would be expected after practice using a variety of arm movements. For example, shoulder and elbow excursion and speed and smoothness of movement may have advanced to a level necessary for reliably placing the hand on a toy.[8–11] Given the demands of gravity placed on the extended arm in midline, we feel that, during the emergence of reaching, a difference of 1 second per contact may be clinically relevant. Training may have increased proximal upper-extremity muscle performance necessary for overcoming gravitational forces to achieve an extended arm position at the toy.[4,105]

Postural control. Postural development parallels improvements in reaching and is an important factor in reaching development.[1–4,85,105] In real time, young infants reach better when supported at the head or hips.[2,81,106] Arm movements produced in a supine position, as in our training, activate muscles throughout the neck and trunk.[85] Thus, our training may have improved the planning and execution of head and upper trunk control to provide postural support for reaching.

Visual perception. The visual system also may have been influenced by our training. For example, the use of both eyes for binocular vision emerges between 8 and 24 weeks of age (reviewed in van Hof et al[107]). Binocularity is used to perceive object distance, orientation, and shape. Thus, it is a key perceptual ability that is integrated with the advancing motor control as infants interact with objects through reaching and catching.[107–109] Our training likely provided this type of multimodal experience, as infants were provided daily opportunities to visually attend to toys while physically interacting with them.

Object affordances. Related but separate from the effects on control and perception outlined above, training may have advanced infants' understanding of the complex physical and social functions or "affordances" of objects.[110–113] That is, infants may have learned that objects afford a range of basic "functions" such as contacting, grasping, shaking, fingering, and mouthing. Infants also may have learned that their interaction with objects stimulates caregiver interaction and encouragement.[114]

Infant-caregiver dynamics. Young infants are heavily reliant on caregivers for structuring their experiences, including those with objects. The experiences that caregivers choose to provide are dependent, in part, on their infants' behaviors. Thus, a cycle exists in which the daily training begins to change infant behavior, which is observed by the caregiver, who, in turn, provides more advanced experiences outside of the formal training time. Studies[115–119] have confirmed that infants and caregivers interact differently before and after the onset of reaching. Specifically, as caregivers observe their infants' advancing interaction with objects, they may increase the opportunities for their infants to physically interact with objects throughout the day. If training altered the caregiver-infant dynamic, then the "training" was much more extensive than 20 minutes daily and involved more activities than those prescribed to caregivers.

Movement Training Program Did Not Change All of the Reaching Differences

By comparing the PT-M group with the PT-S and FT-S groups, we were able to identify what features of early reaching did not change with movement training. During visit 5, when a majority of infants in both preterm groups were consistent reachers, the average duration per contact was not different between preterm groups. Furthermore, at this visit, infants in the FT-S group contacted the toy for longer durations than the infants in the preterm groups. Movement training did not focus on the ability to hold the arm extended and maintain hand-toy contact or focus on grasping or fingering toys. Therefore, future training programs may need to include this component. In addition, the duration per contact for the PT-M group did not improve after visit 3, whereas a continual increase in the duration per contact was observed for the FT-S group.

Our work suggests that infants born at less than 33 weeks show differences in hand-toy interactions at 4 months' corrected age. Keeping the hand at the toy may allow for favorable exploration of texture and shape and contribute to the development of grasping and may be a more difficult skill than transporting the hand to the toy. Our results support the results of other studies[58,59,90] in suggesting that infants born preterm show early grasping differences from infants born full-term. Reaching provides the means for the first independent exploration and manipulation of objects. Thus, one important implication of these early reaching differences is that preterm infants may be restricted in their ability to fully explore objects. Impaired exploration, in turn, may increase the risk for future impairments in a range of cognitive, perceptual, and motor abilities.

Limitations

There are several limitations to this study of movement training in a sample at risk for reaching delay. First, the infants born preterm in this study represent a heterogeneous group. Infants born at less than 33 weeks of GA and with birth weights of less than 2,500 g are characteristically diverse. Future work can build on the results of the current study to determine the effectiveness of training with infants born preterm at greater risk for reaching delay, such as those with extremely low birth weights (less than 1,000 g), those born extremely preterm (less than 28 weeks of GA at birth), and those with specific brain lesions. Second, it is not yet clear whether the initial differences in reaching between infants born full-term and those born preterm are related to longer-term functional problems. These differences may be transient, or they may reflect more significant impairments. Similarly, our outcome measures focused on the short-term effects. Thus, it is not known whether this particular training has longer-term effects throughout the first year. Third, movement training may have improved other aspects of reaching, such as shoulder-elbow coordination,[120] which were not measured. Fourth, there may have been a volunteer bias in our recruited sample.

Conclusions

Participants born preterm demonstrated differences in the quantity and quality of early hand-object interactions. These results suggest that infants born preterm are at an initial disadvantage in the emergence of reaching. The cumulative effect of this type of delay is unknown. Daily movement training improved the quantity and quality of hand-object interactions. This improvement may have been due, in part, to the interactions among motor, sensory, and social systems. These results suggest that young preterm infants respond to specifically designed interventions.

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This study was approved by the University of Delaware Human Subjects Review Committee. The Christiania Care Institutional Review Board also approved the study for the infants born preterm.

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