

The Performance of Infants Born Preterm and Full-term in the Mobile Paradigm: Learning and Memory

Background and Purpose. By 3 to 4 months of age, infants born full-term and without known disease display associative learning and memory abilities in the mobile paradigm, where an infant's leg is tethered to a mobile such that leg kicks result in proportional mobile movement. The first purpose of this study was to examine the learning and memory abilities of a group of infants born full-term compared with those of a comparison group. Little is known about the learning and memory abilities in infants born preterm, a group at known risk for future impairments in learning and movement. The second purpose of this study was to determine if and when an age-adjusted group of infants born prematurely display associative learning and memory abilities over a 6-week period. **Subjects.** Ten infants born full-term (38–42 weeks gestational age [GA]) and 10 infants born preterm (<33 weeks GA and <2,500 g) who were tethered and had control over the mobile movement were independently compared with a comparison group of 10 infants born full-term who were tethered and viewed a moving mobile but did not have control over the mobile movement. Infants in all 3 groups were seen at 3 to 4 months of age and were excluded from participation for any known visual or orthopedic diagnoses. **Methods.** Infants were tested using the mobile conjugate reinforcement paradigm, where one leg is tethered to an overhead mobile such that kicking with that leg results in proportional mobile movement. The kicking rates of the full-term group and the preterm group were compared with their own initial (baseline) kicking rates and with those of the comparison group. **Results.** After exposure to the conjugate relationship between kicking and mobile movement, the full-term group kicked more frequently compared with their own baseline levels and compared with the comparison group, fulfilling both criteria for learning and memory. In contrast, the preterm group did not increase their kicking rate according to both criteria. **Discussion and Conclusion.** These results suggest that infants born prematurely differ in their performance in the mobile paradigm as compared with age-matched infants born full-term. The mobile paradigm may provide clinicians with an important early assessment of infants' associative learning and memory abilities. Follow-up studies are needed, however, to further validate this paradigm as a clinical assessment tool. [Heathcock JC, Bhat AN, Lobo MA, Galloway JC. The performance of infants born preterm and full-term in the mobile paradigm: learning and memory. *Phys Ther.* 2004;84:808–821.]

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Advances in obstetric, neonatal, and pediatric medicine continue to decrease the mortality rates of infants born preterm,¹ whereas the rate of preterm birth has remained the same or increased over the past 20 years.² Accordingly, there are increasing numbers of infants born preterm who are at risk for cognitive and sensorimotor problems that can impair their learning and movement abilities.^{3,4} For example, toddlers and school-age children born prematurely show a higher prevalence of learning disabilities,³ cerebral palsy,⁵ developmental dyspraxias, and poor eye-hand coordination⁶ and a higher use of specialists and community resources such as physical therapy services⁷ than those born full-term.

Learning and memory impairments have been readily identified once infants born preterm enter childhood.⁸ In early infancy, however, infants born preterm are a diverse population in terms of risk factors for problems learning and moving. A range of factors increase an infant's risk including periventricular leukomalacia (PVL), gestational age (GA), birth weight, ethnicity, and socioeconomic status.^{1,5,9} Moreover, a growing body of evidence suggests that infants born preterm without definitive neurological involvement or major medical complications are also at risk for learning and memory impairments.^{10,11} Thus, infants born preterm may display impairments in learning and memory early in infancy.

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Physical therapy testing of young infants at risk for developmental delays often focuses on the evaluation of sensorimotor development. For infants under 4 months of age, certain assessment tools have focused on testing of reflexes and reactions.¹² During this kind of testing, infants are relatively passive participants in that the focus is on elicited movements with little opportunity for the infant to interact with the environment. Typically, clinicians must wait until infants manifest purposeful skills, such as reaching and grasping, in order to evaluate the child's ability to use movement to interact with and manipulate the environment. More recently developed assessment tools focus on observational assessment (eg, Alberta Infant Motor Scale [AIMS])¹³ or on observational assessment and elicited active behaviors of infants (eg, Test of Infant Motor Performance [TIMP]).¹⁴

Among pediatric clinicians, an infant's interaction with the environment is thought to reflect both the child's ability to move and the child's ability to learn and remember basic cause-effect associations between body movement and manipulations of the environment. For "prefunctional" infants (ie, infants who have not yet acquired early functional skills such as reaching or rolling), there is no clinically useful measure of associative learning and memory. Consequently, clinicians must extrapolate these abilities from sensorimotor assessments. The relationship between learning and sensorimotor abilities, however, is complex.^{15,16} For example, children with learning disabilities may or may not also display developmental coordination disorders.¹⁷ Children with autism also display a wide range of intelligence and sensory differences, and deficits in each area are not always equal in severity. Thus, extrapolating learning ability from movement ability, or vice versa, may not always be valid.^{18,19}

There is a need, we contend, for a clinical measurement of associative learning and memory in young infants who are at risk for developmental problems. We believe that the "mobile paradigm," a protocol commonly used in infant developmental psychology research, has the potential to address this need. The general aim of our study was to compare the learning and memory abilities of infants born preterm and infants born full-term with a comparison group using the mobile paradigm.

For 35 years, the "mobile paradigm" has been a standard research tool for studying the development of associative memory in typically developing infants between 2 and 6 months of age.^{20,21} In this paradigm, an infant is placed in a supine position with one leg tethered to an overhead mobile. The infant's spontaneous kicks result in proportional mobile movement. Optimal conditioning occurs when the object has characteristics that are both

familiar (ie, an overhead mobile in a crib) and novel (ie, a mobile with unfamiliar blocks and colors that shakes in a novel manner). Movement of a visually appealing mobile is thought to reinforce kicking. The kicking rate when the leg is tethered to the mobile is compared with the kicking rate during an initial (baseline) period where tethered leg kicking does not cause mobile movement. The tethered kicking rate for the group is also compared with that of a comparison group, where mobile movement is not related to tethered leg kicking. Initially, infants who are exposed to the conjugate nature (ie, that leg kicks produce proportional mobile movement) of the mobile paradigm may kick more because they are excited by the moving mobile. We define *associative learning* in the mobile paradigm as having occurred: (1) when tethered leg kicking rate remains elevated during the extinction period when kicks no longer cause mobile movement and (2) when this extinction period kicking rate is greater than that of a comparison group.

The definitions of learning and memory in the mobile paradigm differ somewhat from those traditionally used in the motor learning literature, in which *learning* is defined as a relatively permanent change in behavior and often must be demonstrated via a retention test.²² The terms "learning" and "short-term memory" in the mobile paradigm are most synonymous with the terms "change in performance" and "learning," respectively, in the adult motor learning literature. The differences in definitions arise because the mobile paradigm was developed as an operant conditioning procedure in developmental psychology.^{20,21} Recently, however, researchers²³⁻²⁵ also have used the paradigm to assess motor skill acquisition. We view the paradigm as useful both as an operant conditioning procedure and for assessing motor skill acquisition. Thus, we have investigated the basic associative learning aspects as well as the kicking movements used by infants as they learn this association. In this article, we use the more traditional mobile paradigm terminology for consistency with the large body of infant learning and memory literature.

Although the mobile paradigm is well established for typically developing infants, only 2 groups of researchers^{10,26} have applied it to young infants who are at risk for developmental delays. Ohr and Fagen²⁶ found that 2- to 3-month-old infants with Down syndrome displayed learning and memory abilities similar to those of infants born full-term. Gekoski et al¹⁰ found that infants born preterm at GAs of <36 weeks and without major medical complications needed an additional session to display learning and did not show long-term memory. In the study by Gekoski et al, there was no full-term comparison group, and the preterm group was tested for only 1 week.

The first purpose of our study was to examine the learning and memory abilities of a group of infants born full-term compared with those of a comparison group of infants born full-term. The second purpose was to determine if and when infants born at <33 weeks gestation show learning and memory abilities compared with the same comparison group. From the relatively complex and varied populations of infants born preterm, we chose to examine a heterogeneous sample of infants born preterm with no definitive neurological, orthopedic, or visual diagnoses at the time of testing for an initial study of learning and memory abilities. Based on the limited literature using the mobile paradigm in pediatric populations and the increased prevalence of impairments later in childhood related to learning and moving, we hypothesized that infants born preterm would show differences in learning and in short-term and long-term memory.

Method

Participants: Infants Born Full-term

Twenty-seven infants born full-term were initially recruited from public birth announcements and by word of mouth within Newark and Wilmington, Delaware. Infants were recruited until each group had 10 infants. All infants were of singleton birth. Parents reported that the infants were born between GAs of 38 to 42 weeks, without known illnesses and were developing typically. Infants were excluded from participation for any known visual, orthopedic, neurological impairment or complications during birth. As is typical in this paradigm, infants also were excluded for excessive crying (>120 seconds) because crying infants were likely not paying attention to the mobile and therefore did not have an opportunity to explore the relationship between their leg kicks and mobile movement. A total of 7 full-term infants were excluded from participation. Three infants were excluded from the comparison group (2 for excessive crying and 1 for experimental error). Four infants were excluded from the full-term group (2 for excessive crying, 1 for experimental error, and 1 for parental involvement during the testing session). Infants were randomly assigned with replacement until the full-term group and the comparison group each had 10 infants.

The full-term group ($n=10$) consisted of 7 female infants and 3 male infants with a mean age at initial visit of 106.6 days ($SD=9.9$, range=98–117). The comparison group ($n=10$) consisted of 5 female infants and 5 male infants with a mean age at initial visit of 109.3 days ($SD=14.5$, range=93–124). A 2-tailed independent t test showed that the age of the infants did not differ between groups ($P=.49$). Infants were admitted into the study following informed parental consent as approved by

the University of Delaware Human Subjects Review Committee.

Participants: Infants Born Preterm

Twelve infants born preterm were initially recruited through the Christiana Care Neonatal Intensive Care Unit and by word of mouth. Infants were neither recruited nor excluded based on single- or multiple-birth pregnancy, although it is more common for infants of multiple-birth pregnancies to be born preterm than infants of single-birth pregnancies.² All infants had a GA of <33 weeks and were born with low birth weight (<2,500 g). Infants were excluded from participation for any known visual or orthopedic impairment. Two infants were excluded for frequently rolling into the prone position because they were unable to complete all 15 minutes of the paradigm. Infants were recruited until the preterm group had 10 infants.

The remaining 10 infants born preterm comprised the preterm group (Tab. 1). The preterm group consisted of 1 female infant and 9 male infants with a mean adjusted age at initial visit of 103.6 days ($SD=13.9$, range=83–139). A 2-tailed independent t test showed that the adjusted age of the preterm group infants did not differ from that of the full-term group ($P=.51$) or the comparison group ($P=.32$). Nine of the 10 infants were part of a set of fraternal twins, and 1 infant was a singleton. Infants in the preterm group had a mean GA of 30.3 ($SD=2.8$, range=26–33). Infants were admitted into the study following informed parental consent as approved by the University of Delaware Human Subjects Review Committee and the Christiana Care Institutional Review Board. Infants were seen between June 2001 and December 2002.

Apparatus

Two identical white plastic mobile stands were attached to the right and left sides of each infant's crib (Fig. 1). A white ribbon and small soft cuff were used to tether the infant's right leg to the right stand. The custom-made mobile consisted of six 3.8-cm-diameter (1.5-inch-diameter) wooden blocks. Each block had a primary color background and a white X on each side. The mobile was placed approximately 38 cm (15 in) above the infant on either the right or left stand at different parts of the testing procedure. All sessions were videotaped with either a Panasonic VHS AG-45* or Sony 8-mm CCD-TRV608† video camera placed at the foot of the crib at a slight angle to ensure a view of both legs. Videotapes were recorded on a computer using Broad-

* Matsushita Electric Industrial Co Ltd, 1006, Kadoma City, Osaka, Japan.

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

Table 1.
Preterm Group Characteristics^a

Infant No.	Gestational Age (wk)	Type of Birth	Sex	Birth Weight (g)	VLBW (<1,500 g)	ELBW (<1,000 g)	SGA
1	28	Singleton	M	963	Y	Y	N
2	29	Twin	M	1,587	N	N	N
3	29	Twin	M	1,332	Y	N	N
4	33	Twin	M	1,955	N	N	N
5	33	Twin	M	2,181	N	N	N
6	32	Twin	M	1,895	N	N	N
7	26	Twin	M	963	Y	Y	N
8	26	Twin	M	595	Y	Y	N
9	32	Twin	M	1,810	N	N	N
10	33	Twin	F	1,275	Y	N	Y
\bar{X}	30.1			1,456			
SD	2.8			515			
Range	26–33			595–2,181			

^aM=male; F=female, Y=yes, N=no, VLBW=very low birth weight, ELBW=extremely low birth weight, SGA=small for gestational age.



Figure 1.
In-home setup of mobile paradigm.

way Pro[†] 4.5 software and coded from the computer image.

Procedure

The study was conducted in the infants' homes. Infants were undressed with a diaper or one-piece undershirt left on for the testing session. On the first day, infants were videotaped while playing on the floor with a parent or researcher, and this videotape was used to score the Alberta Infant Motor Scale (AIMS).¹³ This scale was used to measure general motor development in an effort to ensure that the 3 groups had similar motor skills at the time of the initial visit.

General motor development. All play sessions were scored using the AIMS. One primary examiner and 2

secondary examiners, all of whom were physical therapists, scored the AIMS for 10 infants, picked at random, to assess reliability. Intraclass correlation coefficients (ICCs) using a 2-way mixed-effects model for intrarater and interrater reliability were both high (ICC=.97 and .98, respectively). The primary examiner, therefore, scored all sessions. The AIMS scores for the comparison group (\bar{X} =13.6, SD=3.5) and the full-term group (\bar{X} =14.9, SD=2.2) were not different from the AIMS scores of the preterm group (\bar{X} =10.9, SD=4.6) (P =.15 and P =.2, respectively) for the first visit.

The mobile paradigm. Each infant was placed supine in the crib by a parent who was instructed to remain out of the infant's sight during the 15-minute testing paradigm. Infants were scheduled to be seen during a time that parents described as "playtime." In general, each infant was seen at a consistent time of day for all visits. A researcher tethered the infant's right leg to the right mobile stand, and the right leg remained tethered for the entire 15-minute test session. During minutes 0 to 3 (baseline period), the mobile was attached to the left stand so that kicking did not produce any movement of the mobile. During minutes 3 to 9 (acquisition period), the mobile was switched to the right stand for the full-term and preterm groups so that kicking resulted in proportional movement of the mobile. For the comparison group, the mobile remained on the left stand while a researcher, who was out of the infant's sight, used a transparent wire to randomly move the mobile for a total of 30 seconds per minute. This amount of mobile movement was based on pilot data on the typical kicking rate during the acquisition period of infants born full-term. During minutes 12 to 15 (extinction period), the mobile was on the left stand for all groups so that kicking did not produce any movement of the mobile.

[†]Data Translation Inc/Broadway, 100 Locke Dr, Marlboro, MA 01752-1192.

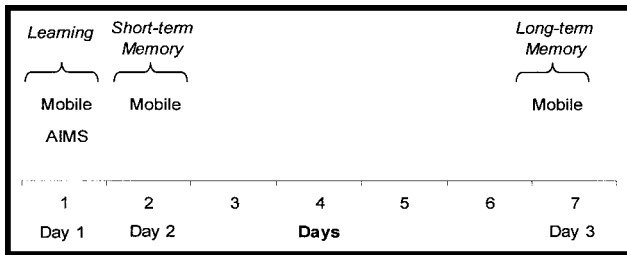


Figure 2. Schedule of sessions for full-term and comparison groups. AIMS=Alberta Infant Motor Scale.

Testing sessions. Full-term group and comparison group infants were seen for 3 sessions: 2 consecutive days and then 1 week later (Fig. 2). The session on day 1 was used to measure learning. The session on day 2, 24 hours after the initial session, was used to measure short-term memory. The session on day 3, 7 days after the initial session, was used to measure long-term memory. Based on the literature,¹⁰ the preterm group was not expected to display learning during the first session or either short-term or long-term memory during the first week. Therefore, we needed to follow the preterm group for more than 1 week in order to determine if and when this group displayed learning and memory. We chose to follow the preterm group for 2 consecutive days for 6 consecutive weeks. As shown in Figures 2 and 3, this schedule repeated days 1 and 2 (outlined above) for 6 consecutive weeks. After the first week, the first day of each week was used to measure either learning for that week or long-term memory for the preceding week (Fig. 3).

Learning in this study was thought to occur during a session when 2 criteria were met: (1) the kicking rate was higher after exposure to the mobile contingency (extinction) than before exposure (baseline), and (2) the kicking rate was greater than that observed in the comparison group during a single session. When kicking rate remained elevated for both criteria during subsequent sessions separated by 24 hours and 7 days, short-term and long-term memory for the connection, or associative learning of kicking and mobile movement, was believed to have occurred.

Data Analysis

A *kick* was operationally defined as a simultaneous extension of the hip and knee with immediate recoil into flexion.²⁷ Hip and knee range of motion were not measured during kicking; however, we estimated a kick to include >15 degrees of simultaneous hip and knee extension. For this analysis, only the frequency of kicking of the right (ie, tethered) leg was analyzed. A secondary coder, who was unaware of the infants' group assignments, coded 3 minutes of data for 5 infants across each group for reliability (45 minutes). Assignment of infants and time period coded (baseline, acquisition,

extinction) by the secondary coder was random. Intra-class correlation coefficients using a 2-way mixed-effects model for intrarater and interrater reliability of kicking rates were both high (ICC=.96-.98); therefore, the primary coder (JCH) scored all sessions (2,700 minutes).

Each daily 15-minute session was broken down into 5 separate 3-minute periods, and each minute was coded. Then, the kicking rate was averaged over each 3-minute period. Baseline and extinction consisted of one period each, and acquisition consisted of 3 periods (acquisition periods 1, 2, and 3). Kicking rates for all baseline, acquisition, and extinction periods were normalized to baseline kicking rates. Normalizing the conditioned response (tethered kicking) to the unconditioned response (nontethered kicking during the baseline period) is common to the mobile paradigm.^{21,23,28} Normalizing kicking rates, we believe, is particularly useful as the baseline kicking rate per minute for infants at 3 to 4 months of age can range from 0 to 80 kicks per minute.

Kicking rates for the full-term group and the comparison group were normalized to the kicking rate on baseline day 1. Kicking rates for the preterm group were normalized to the baseline kicking rate of the week being tested for learning. For example, if the preterm group did not show learning during week 1, the kicking rates for week 2 would be normalized to the baseline kicking rate on day 1 of week 2. This pattern of normalizing the data to day 1 of each week continued until the preterm group satisfied both criteria for learning. Subsequently, tests of short-term and long-term memory were based on a baseline measurement for the day and week that the preterm group showed learning. Statistical analysis then was performed within and between periods for all 3 groups using an analysis of variance (ANOVA) for one repeated measure (time period) for within-group analysis and independent *t* tests for between-group analyses. In addition, data for individual infants were shown to provide additional support for group findings.

Learning. *Learning* was operationally defined as: (1) having a normalized kicking rate during at least one acquisition or extinction period greater than the baseline kicking rate of the same day as determined by a within-group, repeated-measures ANOVA (group [1] × period [5]) and by planned comparisons testing using least significant difference (LSD) tests between baseline and the other periods that identified which period displayed elevated kicking and (2) having a normalized kicking rate during the extinction period greater than that of the comparison group as determined by independent *t* tests.

Memory. *Short-term memory* and *long-term memory* were operationally defined as: (1) having a normalized kick-

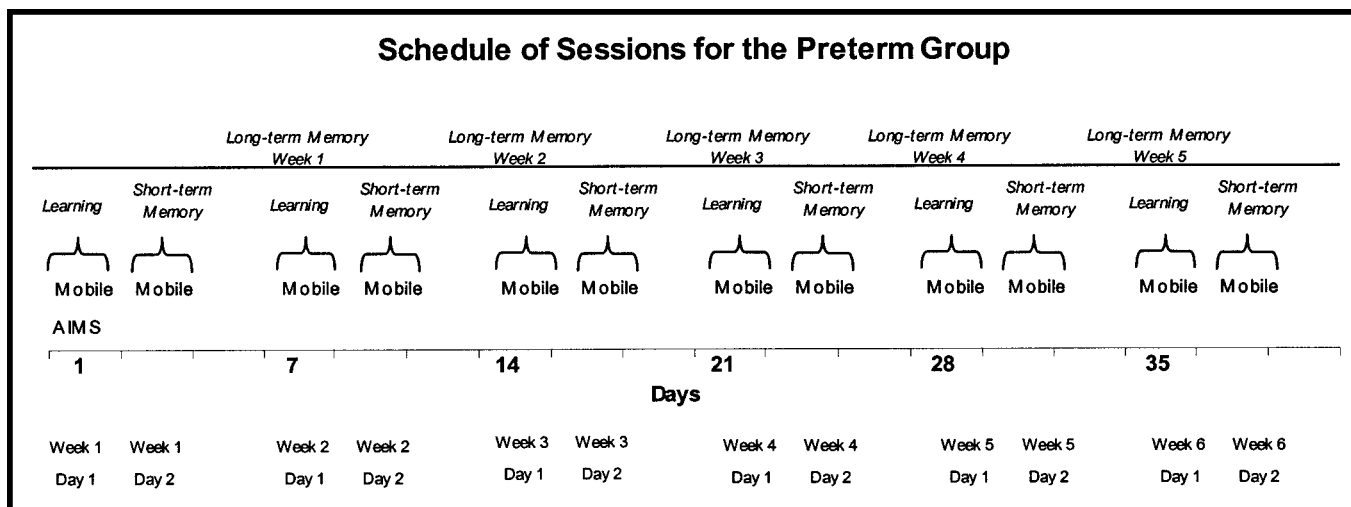


Figure 3. Schedule of sessions for preterm group. AIMS=Alberta Infant Motor Scale.

ing rate during baseline day 2 (short-term memory) and day 3 (long-term memory) greater than the normalized kicking rate during baseline day 1 as determined by a within-group, repeated-measures ANOVA (group [1] × period [3]) and by planned comparisons testing using LSD tests between baseline and other periods that identified which periods displayed elevated kicking and (2) having a normalized kicking rate on baseline days 2 and 3 greater than that of the comparison group as determined by independent *t* tests.

Results

As expected, infants in both the preterm group and the full-term group displayed a range of non-normalized kicking rates (Tab. 2). Preterm infants, in general, appeared to kick more frequently than the infants in the full-term group or the comparison group. For example, the range of average kicking rates per minute for the full-term group (6.1–11.2) and the comparison group (3.7–7.6) was smaller than that of the preterm group in general (5.5 on baseline day 1 of week 5 to 20.1 on extinction day 1 of week 2) as well as within each week. All 3 groups showed individual variability as reflected in standard deviations that were 50% to 100% of the mean. As outlined in the “Method” section, statistical analysis related to learning and memory was performed on kicking rates normalized to baseline data. The remaining results reflect these normalized rates.

Learning: Full-term Group

The full-term group learned during the session on day 1. This finding was reflected by both an increase in the normalized kicking rate within the group as compared with the infants’ own baseline data and an increase during the extinction period as compared with the comparison group (Fig. 4). A repeated-measures ANOVA showed a difference during day 1 across time

($F=2.93$; $df=4,36$; $P=.03$). Planned comparisons testing showed that the infants increased their kicking rate during the extinction period ($P=.006$) compared with their own baseline kicking rate. Comparison group infants did not increase their kicking rate during any acquisition or extinction period compared with the baseline period ($F=0.53$; $df=4,36$; $P=.80$). The normalized kicking rate of the full-term group during the extinction period also was greater than that of the comparison group as measured with an independent *t* test ($P=.02$). Eight of the 10 infants in the full-term group had an extinction/baseline ratio of >1 , indicating a greater kicking rate during the extinction period than during the baseline period. In contrast, only 2 of the 10 infants in the comparison group had an extinction/baseline ratio of >1 , with 7 of the 10 infants kicking less during the extinction period than during the baseline period (Fig. 5).

Short-term and Long-term Memory: Full-term Group

The full-term group displayed both short-term memory (24 hours) and long-term memory (7 days). This finding was reflected in the retention of an elevated normalized kicking rate within the group compared with their own baseline (day 1) data, on both baseline day 2 (short-term memory) and baseline day 3 (long-term memory), as well as by an increase in the normalized kicking rate during the baseline period compared with the comparison group (Fig. 6). A within-group, repeated-measures ANOVA showed a difference among normalized kicking rates during baseline days 1, 2, and 3 ($F=3.48$; $df=2,18$; $P=.05$). Between-group tests showed that the full-term group’s normalized baseline data for short-term memory ($P=.03$) and long-term memory ($P=.04$) were greater than for the comparison group. A within-group, repeated-measures ANOVA for the comparison group also showed a difference among baseline days 1, 2, and 3

Table 2.
Raw Data of Average Kicks Per Minute for All 3 Groups Across All Sessions^a

Subjects	Day 1					Day 2	Day 3
	Baseline	Acquisition 1	Acquisition 2	Acquisition 3	Extinction	Baseline	Baseline
Full-term group							
X	6.1	8.1	8.4	8.0	10.9	9.6	11.2
SD	6.4	8.5	8.4	6.9	9.4	6.8	10.9
Range	2.3–24.0	2.0–30.0	2.0–27.0	0.7–20.7	3.0–32.3	1.3–24.0	2.0–31.7
Comparison group							
\bar{X}	6.5	6.3	6.6	7.6	5.7	3.7	3.9
SD	3.6	3.8	3.9	6.2	4.5	2.0	3.3
Range	2.7–13.7	2.0–11.7	1.7–13.7	1.0–19.7	1.7–15.7	1.0–7.0	1.0–11.0
Preterm group, week 1							
\bar{X}	8.6	9.2	13.9	16.6	15.5	11.6	12.7
SD	5.2	6.6	9.9	15.8	15.6	8.7	6.3
Range	3.0–7.7	3.0–18.7	3.0–29.3	2.0–54.0	0.7–52.7	0.7–23.0	4.7–22.0
Preterm group, week 2							
\bar{X}	12.7	15.4	17.0	16.3	20.1	14.6	9.2
SD	6.3	7.6	10.1	9.7	9.7	10.8	4.7
Range	4.7–22.0	5.7–24.3	5.0–39.7	3.3–39.0	5.3–43.7	0.0–35.7	3.7–16.3
Preterm group, week 3							
\bar{X}	9.2	11.6	10.5	11.0	10.6	13.0	6.6
SD	4.7	9.0	7.2	5.1	4.5	9.4	4.1
Range	3.7–16.3	2.7–32	2.7–26.7	2.3–17.3	4.3–17.7	1.7–30.0	1.3–14.3
Preterm group, week 4							
\bar{X}	6.6	8.7	9.1	11.2	9.2	8.7	5.5
SD	4.1	8.1	4.9	7.9	5.5	7.3	3.3
Range	1.3–14.3	1.3–29.0	2.0–16.0	3.3–28.7	3.3–17.0	3.0–27.7	0.7–10.0
Preterm group, week 5							
\bar{X}	5.5	7.5	10.1	11.3	9.5	8.1	7.2
SD	3.3	5.7	7.8	9.2	5.9	6.8	5.7
Range	0.7–10.0	2.3–18.7	1.3–23.7	2.7–32.3	2.7–24.3	0.7–21.7	1.0–17.0
Preterm group, week 6							
\bar{X}	7.2	11.9	11.8	8.7	8.5	9.6	
SD	5.7	11.5	9.7	6.8	8.8	7.8	
Range	1.0–17.0	3.0–33.3	2.7–30.7	2.0–23.3	1.7–31.7	3.0–28.7	

^aNon-normalized values for day 1 are the same as those for day 3 of the preceding week.

($F=6.46$; $df=2,18$; $P=.008$); however, for both baseline day 2 and day 3, the kicking rate showed a *drop* in frequency. Thus, the mean kicking rate for baseline days 2 and 3 increased for the full-term group and decreased for the comparison group (Fig. 6). Eight of the 10 infants in the full-term group had a short-term memory baseline measurement of >1 , indicating a greater kicking rate during day 2 than during day 1. In addition, 8 of the 10 infants in the full-term group had a long-term memory baseline measurement of >1 , indicating a greater kicking rate during day 3 than during day 1. In contrast, only 2 of the 10 infants in the comparison group had baseline measurements of >1 for short-term memory, and only 1 of the 10 infants had baseline measurements of >1 for long-term memory.

Learning: Preterm Group

The preterm group did not meet both criteria for learning during any testing session across the 6-week

period. The preterm group, however, did kick greater than their own baseline level during some test sessions. A within-groups, repeated-measures ANOVA showed a difference compared with the baseline data for day 1 of weeks 1, 2, and 4. Planned comparisons testing showed that infants born preterm increased their kicking rate at various periods of acquisition or extinction during certain days. The preterm group's normalized kicking rates during the extinction period, however, were never greater than those of the control group for any of the 6 weeks. We also looked at the learning measurements for the preterm group during day 2 of each week (data not shown). The preterm group did not fulfill both learning criteria during day 2 for any week.

The preterm group also differed from the full-term group in the performance of individual infants. For each day of weeks 1 through 6, 40% to 70% of the infants born preterm kicked above their baseline levels during

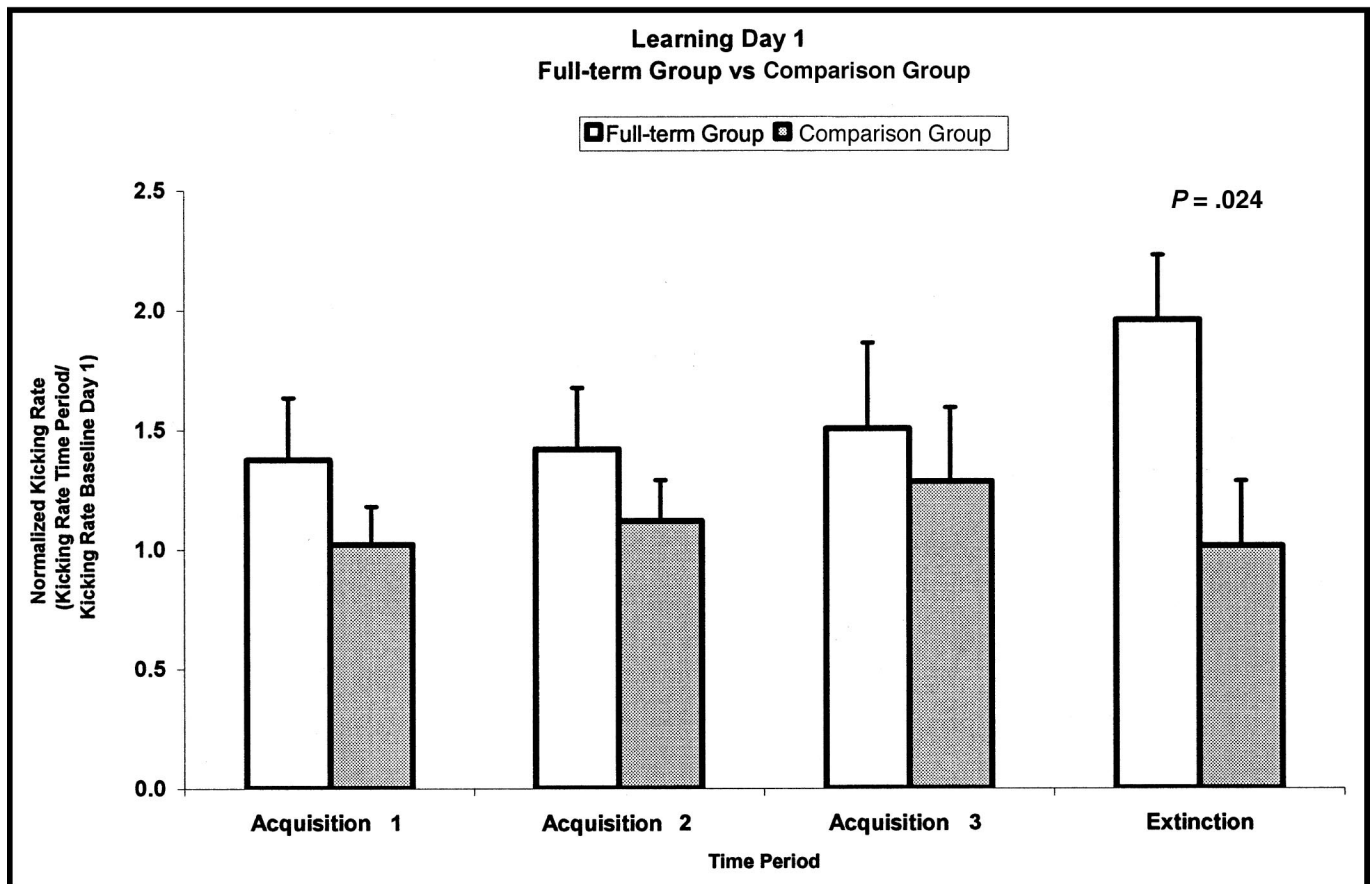


Figure 4. Learning, day 1: Group means and standard deviations of normalized kicking rate between the full-term and comparison groups.

the extinction period. This performance was in contrast to that of the full-term group, in which a majority (80%) of the infants kicked at rates higher than their baseline levels, and in contrast to that of the comparison group, a majority (80%) of the infants had decreased kicking rates.

Memory: Preterm Group

Infants born preterm came closest to fulfilling both criteria for learning on day 1 of week 2. They fulfilled the first criteria by increased kicking during extinction compared with baseline. Therefore, memory was tested for week 2. Both within-group and between-group analyses, however, were not significant (Fig. 7). Short-term and long-term memories were not displayed during the 6-week period.

Discussion

Our hypotheses that infants born preterm would differ from infants born full-term in terms of learning and short-term and long-term memory were supported by both group and individual data. Our results are in agreement with the results of other studies^{20,23,24,29,30} where infants born full-term rapidly learned the association between leg movement and mobile movement

within the first 15-minute session as well as 7 days later. We included a comparison group of infants who were tethered and viewed a moving mobile but whose tethered leg kicks did not cause mobile movement. Thus, the learning and memory performance by the full-term group did not appear to be confounded by arousal, fatigue, or the mobile setup itself.

The major finding of this study was that the performance of infants born preterm, compared with their baseline results and with a comparison group, was different from that of infants born full-term, compared with their baseline results and with the same comparison group. Other researchers¹⁰ found differences in performance in the mobile paradigm over a 3-day period. Our data extend this finding to 12 exposures over a 6-week period. Although the preterm group increased their kicking rate over baseline levels during certain periods across the 6 weeks, their kicking rate did not differ from that of the comparison group for any session. Thus, the preterm group did not fulfill both criteria required to display basic associative learning or memory at any time during the study. Taken together, the results suggest to us that the preterm group did not learn the association between their kicking and movement of the mobile.

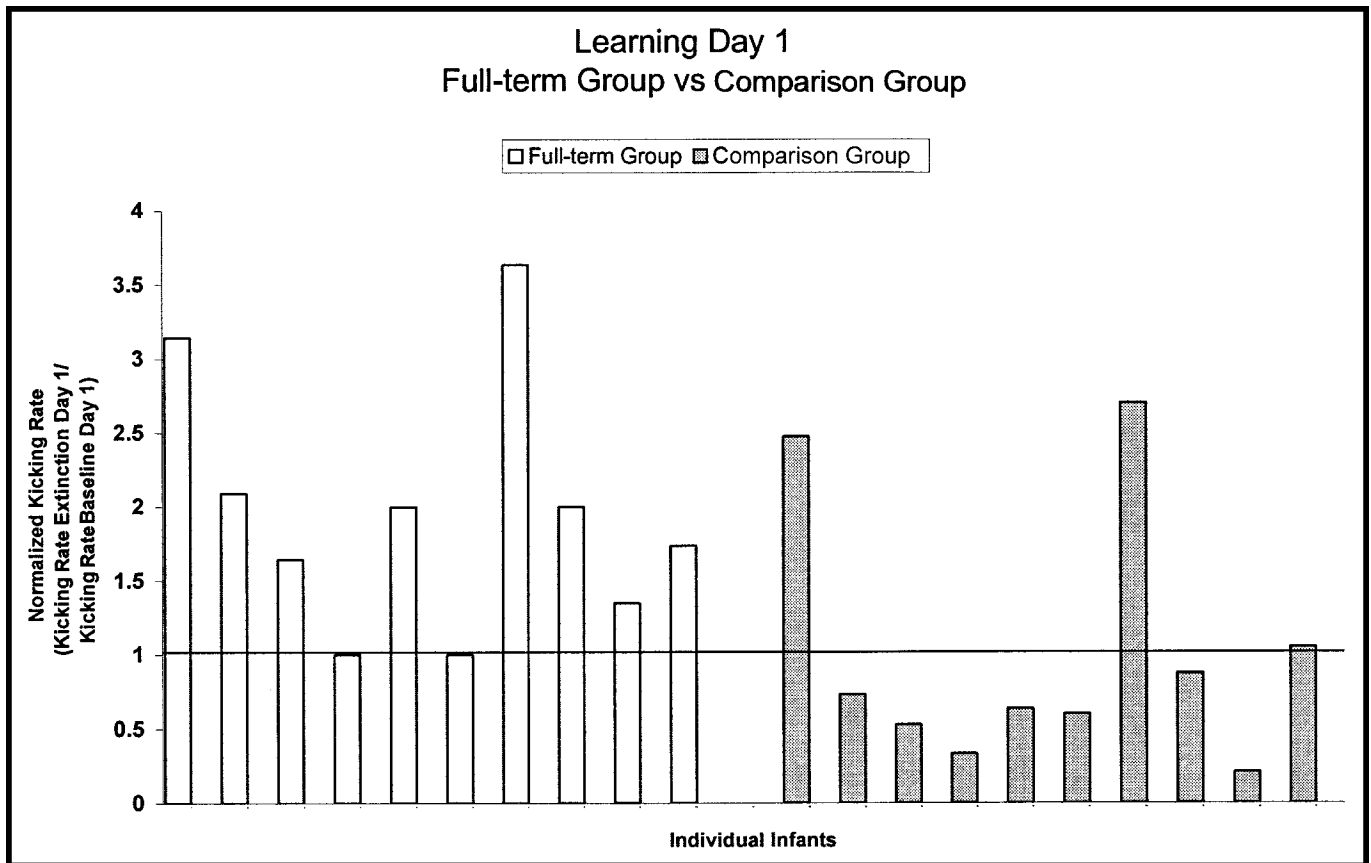


Figure 5. Learning, day 1: Individual infants from the full-term and comparison groups during the extinction period. A normalized score of >1 indicates a greater kicking rate during the extinction period than during the baseline period (black line).

Mechanisms of Early Learning and Memory Impairment

The mobile paradigm provides infants with the opportunity to manipulate their immediate environment without supervision. Infants must be able to actively explore and independently associate movement of their body with movement of the mobile.^{23–25,31} This demands several prerequisite cognitive, perceptual, and motor abilities, including a degree of spontaneous leg movement, adequate visual attention, and arousal and self-regulation. Infants born preterm, even those born at moderate to low risk for future cognitive and sensorimotor problems, have been found to have impairments in each of these abilities during the first years of life.³

Spontaneous kicking. Infants born preterm with various medical complications show differences in the amount and type of spontaneous leg kicks as compared with infants born full-term. Infants born preterm who are at low risk for future cognitive and sensorimotor impairments kick differently compared with infants born full-term, such as a higher kicking frequency at 4 months of age.^{32–36} Furthermore, infants born preterm who are at higher risk for future impairments display atypical movements of their sucking patterns, kicking patterns, and general body movements.^{35,37–41} Our preterm group

infants appeared to kick differently than the full-term and comparison group infants, in that some preterm infants had a higher average rate of kicking. Thus, the preterm group produced sufficient kicking movements to move the mobile in the paradigm.

Although it is not immediately clear how the preterm group's elevated kicking rate would have influenced their performance in the mobile paradigm, there are several possibilities. The infants in the preterm group may have kicked so much during the baseline period that they simply could not increase their kicking rate during the acquisition or extinction period. We do not believe such a "ceiling effect" occurred because there were many weeks that the average kicking rate during the acquisition and extinction periods was greater than during the baseline period (Tab. 2). The variability of non-normalized kicking rate displayed by the preterm infants suggests that there may be subgroups of infants, with some kicking with a higher rate and some kicking at a lower rate. This may have resulted in subgroups of infants who learned and infants who did not learn. If this were the case, then the infants in the preterm group who showed an increase in kicking rate during the extinction period (one criterion for learning) should, in general,

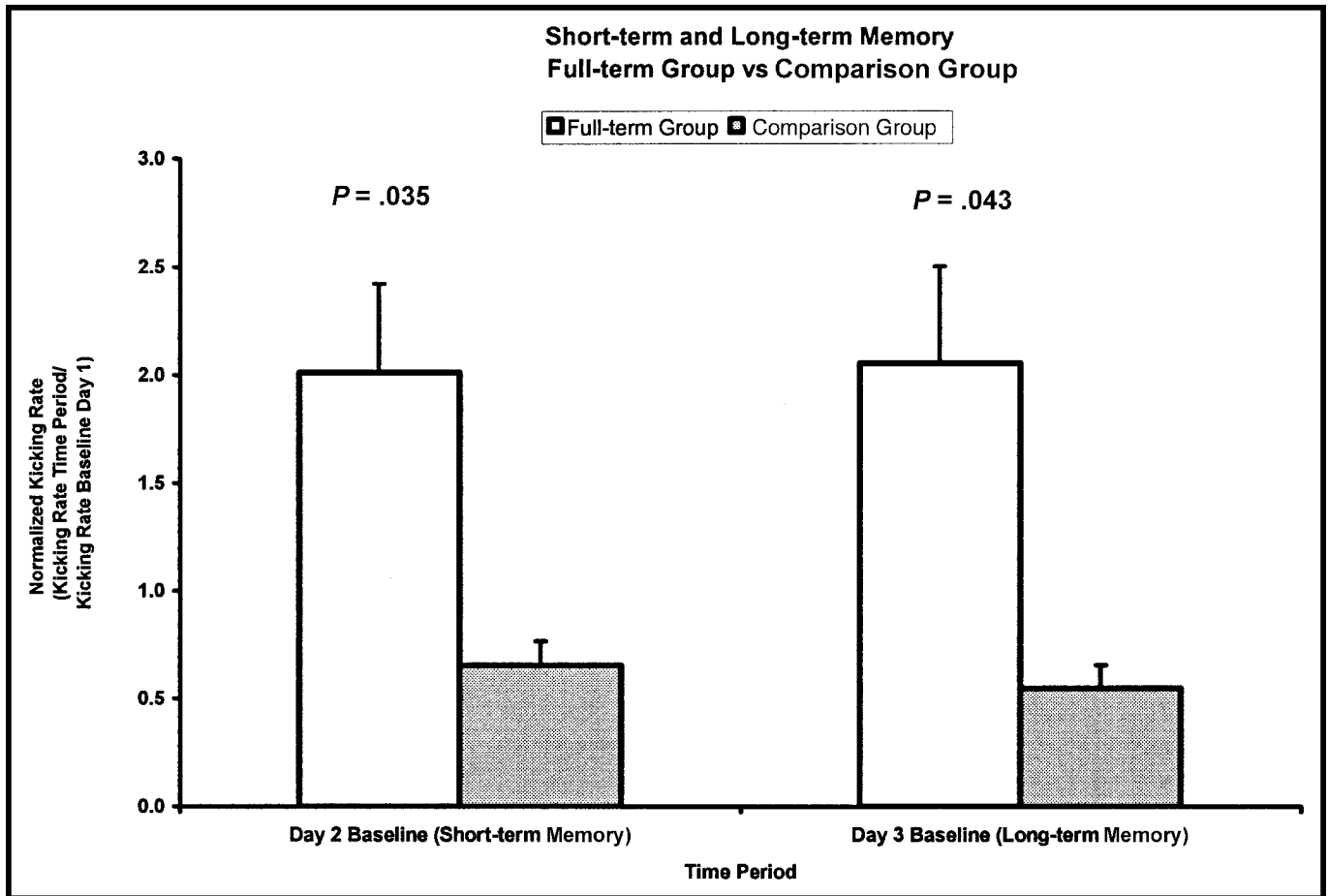


Figure 6. Short-term memory, day 2 and long-term memory, day 3: Group means and standard deviations of normalized kicking rate between the full-term and comparison groups.

be the same infants who continued to display an elevated kicking rate on the baseline of the following day (test for short-term memory). This was not the case. Again this is not to say that individual variability did not influence the preterm group results, but rather that the difference in preterm group performance as compared with that of the full-term group was probably not greatly influenced by differences in absolute kicking rate.

Visual attention. The ability to maintain visual attention to the mobile and its immediate environment also is required to learn and remember within the mobile paradigm. In previous studies,^{42,43} infants born preterm without medical complications displayed impairments in visual attention and visual perception. In a study by Rose et al,¹¹ for example, 5-month-old infants born preterm displayed more off-task behavior, longer look durations, and slower shift rates in a visual attention task as compared with controls. These infants had difficulty shifting their attention appropriately, which is necessary in normal scanning of the environment.⁴⁴ In a study on visual attention during the mobile paradigm,⁴⁵ 3-month-old infants born full-term showed more visual shifts

during the mobile paradigm than did 2-month-old infants, who attended only to the mobile. Moreover, the older infants who scanned the entire environment also learned more quickly. Although not examined in our study, impairments in visual attention and perception could have contributed to the performance of the preterm infants in our study.

Arousal and self-regulation. Infants born prematurely may react differently to stimulation than infants born full-term. For example, newborn infants born preterm have difficulty regulating their arousal level and are easily overstimulated. By school age, children born prematurely also show difficulty with arousal and may be more frequently diagnosed with hyperactivity compared with children born full-term.^{3,15,46} One indication of arousal in infants is body movement. Our results suggest that the preterm group kicked with a non-normalized rate equal to, if not greater than, that of the full-term and comparison groups. Thus, if infants in the preterm group were overaroused during the paradigm, mobile movement may have influenced the ability of these infants to associate kicking with mobile movement. This

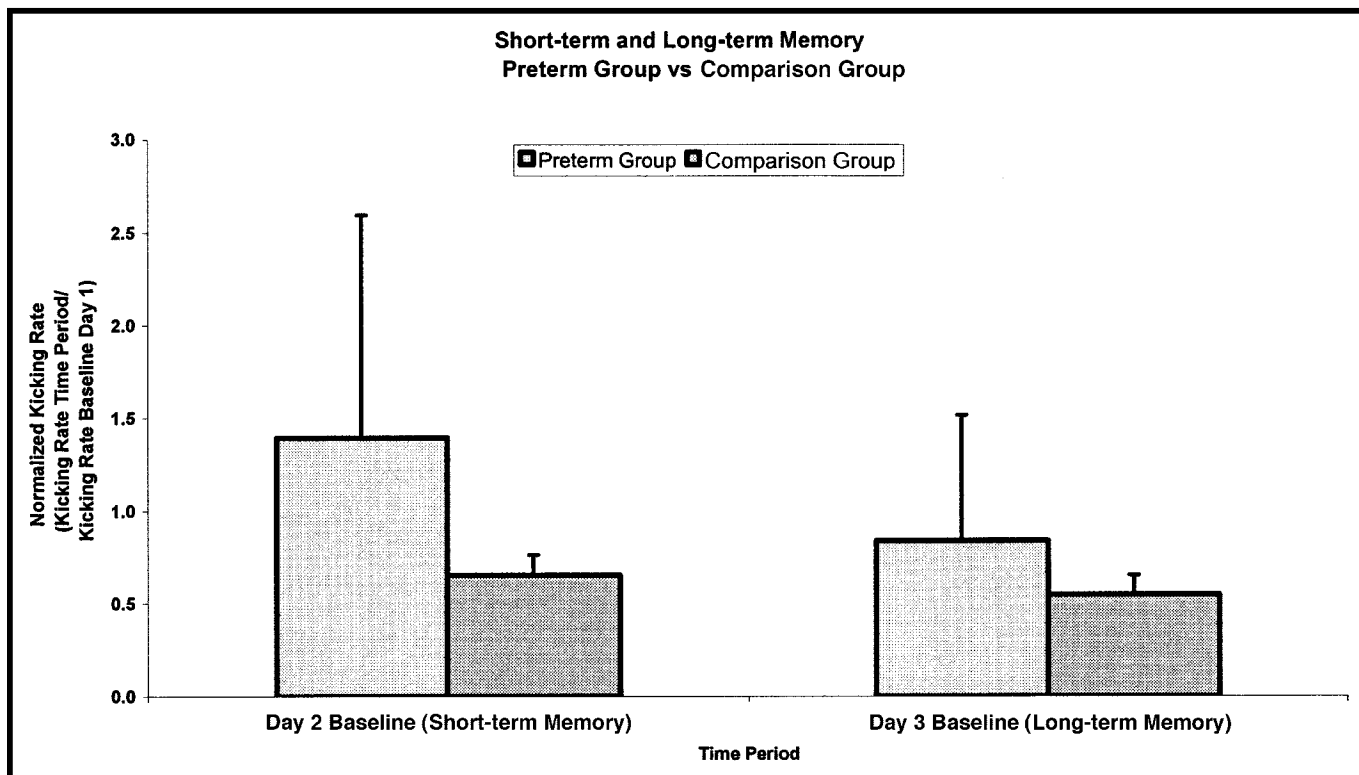


Figure 7. Short-term memory, day 2, and long-term memory, day 3: Group means and standard deviations of normalized kicking rate between the preterm and comparison groups.

relationship between arousal and performance is outlined in the classic Yerkes-Dodson law (1908), which states that performance increases as arousal increases from low to moderate levels yet performance decreases at high levels of arousal.⁴⁷ It is possible that the preterm group displayed arousal levels that were not optimal for performance in the mobile paradigm.

Implications for Future Function

Although the differences in performance in the mobile paradigm exhibited by the preterm group are notable, it is not clear what impact such differences might have on their future function. Some studies of motor dystonias, such as that of de Vries and de Groot,⁶ have shown “catch-up” of some slight delays in infants who are at moderate to low risk for future cognitive and sensorimotor impairments. However, infants born preterm, even those with relatively few risk factors, are at risk for cognitive impairments later in childhood. One longitudinal study³ showed that 75% of children born preterm displayed learning disabilities, attention-deficit disorder, language impairment, mild neurological impairment, or general school concerns by fifth grade. Interestingly, these impairments were related to earlier developmental patterns of visual attention at 13 and 15 months of age.³ Other researchers^{44,48-51} have found that children born prematurely, even those without risk factors, display impairments that could be related to early performance

in the mobile paradigm such as in visuospatial reasoning, attention, working memory, and processing speed. Lastly, the risk for impairment and disability can increase with age and experience, even in infants born preterm without additional risk factors.⁵² Further study is needed to determine what relationship exists between performance in the mobile paradigm and performance in both motor and cognitive skills later in childhood.

Clinical Application

The mobile paradigm provides infants with the opportunity to actively and independently use their typical movements to interact with and manipulate their immediate environment. The testing uses a low-cost, low-technology apparatus making it relatively easy to use in clinical situations. Such a paradigm has realistic potential to address the need for a clinical measure of young infants’ abilities to use movements to interact with their environment. Understanding the status of young infants’ abilities to explore, learn, and remember a basic cause-effect relationship would provide important complementary information to that provided by current tests of young infants.

Many games and toys designed for infants demand the understanding of cause-effect relationships. In addition to providing assessment information to the clinician, the mobile paradigm could provide an important interven-

tion option for young infants who are at risk for future cognitive and sensorimotor impairments. Tethering of a salient object (toy) to an infant's leg causes the infant to move more. This type of play may be useful in encouraging infants who have decreased limb movements.⁵³ Because early leg movements appear to be related to walking⁵⁴ and early arm movements appear to be related to reaching,⁵⁵ variations of the mobile paradigm may help teach the early movement, learning, and memory abilities important for future functional skills.

Limitations

There are several limitations to this initial study of learning and memory in infants born preterm. First, learning and memory were assessed as group effects. Although we present individual data, a larger-scale study is needed to validate the use of the mobile paradigm in measuring individual infant performance. Second, experiments were conducted at each infant's home. Some studies^{56,57} have shown the importance of context for learning and memory in this paradigm. Additional research is needed to determine whether these results generalize to a clinical setting. Third, measuring performance of infants in the full-term and comparison groups over multiple weeks would have allowed a more direct comparison with the preterm group. Several studies of early screening and tests^{19,41,58} have shown the potential for multiple tests to provide more valid information for predicting outcome and guiding early intervention. Similarly, a profile of multiple weeks' performance in the mobile paradigm may be a more robust determinant of future impairment.

Future studies can focus on the various subpopulations of infants born prematurely, each of which may perform differently than the preterm group in this study. For example, infants born at earlier GAs or with PVL are at an increased risk for movement disabilities such as cerebral palsy.⁵ In these future studies, we hope to relate mobile paradigm performance with neuroimaging such as cranial ultrasound and magnetic resonance imaging to investigate the specific brain-behavior relationships in infants born prematurely. Birth weight is also an important predictor of future function as infants born <2,500 g fare better than infants born <500 g,⁷ as is socioeconomic status of the caregiver.⁵⁹ In addition, the majority of infants in the preterm group were part of a set of twins. It is unknown whether multiple-birth pregnancies have any effect on the learning and memory abilities of infants. A further limitation in this study is that the coding was done by a reviewer who was not unaware of the infants' group assignments.

Conclusion

Young infants born preterm differed in their performance in the mobile paradigm compared with age-

matched infants born full-term. These results suggest that infants born preterm with low to moderate risk factors for long-term disability may display impairments in associative learning and in short-term and long-term memory. Future study is needed to validate this paradigm as a clinical test for infants born preterm, including those with neurological insults such as intraventricular hemorrhage or PVL.

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