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**LOWER EXTREMITY ACTIVITY OF INFANTS WITH SPINA BIFIDA:
DOES CONTEXT STILL MATTER?**

by

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Date: April, 27, 2011

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Abstract

BACKGROUND AND PURPOSE: Previous research with infants younger than eight months old has shown that the context in which an infant is placed is directly correlated with leg movement frequency. Increased frequency of leg movements has been linked to earlier ambulation. Infants with Spina Bifida (SB) demonstrate decreased leg movements and delayed ambulation compared to typically developing (TD) babies. Spina Bifida is the most common neural tube defect and leads to delayed functional mobility. Guided by the concept of neural plasticity, our goal was to document the ability of 27 to 44 week old infants with lumbar or sacral SB, to spontaneously move their legs and generate kicks - leg movements that involve flexion and extension of the hip and knee joints - when they were supine, seated in a conventional infant seat and seated in a specially designed infant seat.

METHODS: Infants with SB between the ages of 27 and 44 weeks of age at entry into the study were videotaped in their homes while they were supine, seated in a conventional seat, and seated in a specially designed seat. The videotaped data, collected once a month for three months, were behavior coded to identify leg movements and kicks. These data were summed and then averaged to obtain a per minute frequency.

RESULTS: Our results, consistent with previous research showed that infants with SB generated the most and fewest leg movements and kicks in a special seat and conventional infant seat, respectively. There was not a significant age effect on how often infants moved their legs. There was a moderate correlation between leg movements and kicks with hip abduction, calf circumference, calf skinfold, and thigh skinfold.

CONCLUSION: The results from this pilot study can be used by therapists to design treatment plans that facilitate leg movements and kicks. This will enable infants with SB to strengthen the muscles and neural connections that support the functional leg movements needed to walk. In addition, these data suggest that therapists educate parents about the detrimental effects a conventional infant seat may have on their child's ability to move h/her legs and generate kicks.

The undersigned certify that they have read, and recommended approval of the research project entitled...

**LOWER EXTREMITY ACTIVITY OF INFANTS WITH SPINA BIFIDA:
DOES CONTEXT STILL MATTER?**

submitted by

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in partial fulfillment of the requirements for the Doctor of Physical Therapy Program

Primary Advisor David Chapman PT, PhD Date 4/27/11

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Introduction

Infants and children with spina bifida (SB) represent a unique and challenging population for physical therapists to treat and researchers to study. Although a known neurological lesion develops before birth, it is difficult for therapists, physicians, and nurses to predict *a priori* how this type of lesion will affect a particular child with SB. Will a child with a lesion at lumbar vertebrae 3 and 4 (L3-4) experience a symmetrical loss of sensation, strength and/or movement in both legs? Or, will each leg be impacted differently by the same lesion? Will she have enough lower extremity strength and motor control to generate and coordinate the leg movements needed to walk? Answers to these questions are not easy to provide early in the life of an infant with SB. In part, this is due to the marked paucity in the pediatric physical therapy literature regarding how infants and children with SB move their legs, how their leg movement patterns change over developmental time, and how they learn to produce the coordinated leg movements needed to walk later in life. Thus, our goal for this pilot study was to expand the existing literature by studying the spontaneous leg movements of infants with SB who are older than previously studied babies with SB. We begin with an overview of SB and the extant literature regarding how infants with SB move their legs.

Spina Bifida

Neural tube defects occur in seven out of every 10,000 pregnancies and effects approximately 52 babies born in Minnesota each year.^{1,2} Risk factors for

having an infant with neural tube defect include a previously affected pregnancy, diabetes, obesity, exposure to high temperatures in early pregnancy, certain anti-seizure medications, and low socioeconomic status.¹ However, women taking a multivitamin with the B-vitamin folic acid prior to and during pregnancy may reduce the risk of neural tube defects by 70%.¹ Spina bifida is the most common neural tube birth defect in the United States.³ Myelomeningocele (MM), the most severe form of SB, results when one or more of the spinal vertebral arches do not completely close during the first month of gestation. This causes the spinal cord to protrude beyond the normal limits of the spinal canal.³ Approximately 80% of all SB lesions occur in the lumbar region of the spine, but lesions can be observed at any level of the spinal column.⁴ When a child is born with an open neural tube defect (i.e. MM), surgery is usually performed to place the underdeveloped, protruding nervous tissue back into the spinal canal within the first 24-48 hours of the infant's birth.³ It is covered with as many normal tissue layers as possible to prevent infection and protect the spinal cord from further damage.³ The majority of infants born with SB also have a structural brain abnormality known as Arnold Chiari II malformation resulting in hydrocephalus.³ Infants with hydrocephalus will require implantation of a ventriculoperitoneal (VP) shunt to allow for continuous flow of fluid out of the ventricles and to normalize intracranial pressure.³ Difficulty with bowel and bladder control is common in children with SB due to abnormal sphincter muscle control. Often they will require catheterization and the development of a continence-habit training program by three years of age.³ Most children with SB demonstrate normal

levels of intelligence but often are easily distracted, impulsive, and have difficulty problem solving, organizing, and sequencing tasks.^{1,3}

Spontaneous Leg Movements of Fetuses, Neo-nates and Infants with SB

Fetuses with SB move their legs as often and with similar leg movement qualities as demonstrated by typically developing (TD) fetuses. For instance, ultrasound studies of 16 to 24-week-old fetuses with thoracic, lumbar, or sacral spinal lesions have shown that they flex and extend their hips and knees as often as TD infants.^{5,6,7} More recently, Sival et al videotaped the leg movements of 18-39 week old fetuses using continuous real-time ultrasound registrations. They reported that fetuses with a spinal lesion at the thoracic or lumbar level generated leg movements that appeared normal in amplitude, speed, and fluency.⁸

Following delivery, infants with SB present with neuromuscular systems that are different from TD babies. They lack normal nerve function at and below the level of their lesion.³ This leads to muscles that may be partially to completely paralyzed, diminished sensory information from the joints, and skin sensation that is absent or significantly altered.³ Higher lesions, of course, lead to greater efferent and/or afferent loss. For example, an infant with a lesion located at the level of lumbar vertebrae 3 (L3) may change how they extend their legs at the hips compared to a TD baby because the hip extensor muscles receive their innervations from lumbar vertebrae levels 4 and 5 (L4,L5) and sacral levels 1 and 2 (S1,S2). Likewise, the sensory information available to a child with an L3 lesion would be different from a

TD child below the area of their mid-thigh.⁴ In spite of these types of neural changes infants and children with lumbar and sacral lesions ultimately learn to produce well-coordinated and functional patterned leg movements as is evidenced by their ability to walk.⁹

Controlled observations of neonates with SB have revealed that they show a decrease in the number of leg movements they generate between days 1 and 7 following birth.^{10,11} The leg movements of these same infants also showed reduced variability in amplitude, direction, and velocity within the first week of their birth compared to TD babies. These experimental observations are consistent with Chapman's original work that confirmed anecdotal reports by parents, nurses, and therapists who had noted that young infants with SB seem to be less active than TD babies.¹²

Rademacher, Black, and Ulrich filmed the spontaneous leg movements of infants with lumbar or sacral SB at one, three, and six months of age while they were supine.¹³ These researchers used a sophisticated six camera lab-based video capture system and found that infants with SB in this position at these ages produced leg movements that were less frequent and shorter in duration than TD age-matched peers. They also reported that at the youngest ages, one and three months, the babies with SB generated fewer leg movements than when they were six months old.¹³ These results are consistent with Chapman's work in which he reported that infants with SB move their legs less often than TD babies.¹²

Chapman video-taped the spontaneous leg movements of six infants with lumbar or sacral SB one time per month for four consecutive months beginning when the infants were four months old.^{12,14} He reported that they generated significantly fewer total leg movements and complex patterned leg movements, e.g. kicks, than did age matched TD peers. The infants with SB did, however, produce significantly more leg movements, including single and parallel knee kicks, when they were seated in a specially designed seat compared to when they were supine or in a conventional infant seat. He also noted that these infants generated significantly more single leg kicks and knee waves when they were supine compared to when they were in the other two postures. In addition, Chapman observed that these babies produced the slowest, smallest leg movements when they were in a conventional infant seat, moved their legs with the greatest velocities, i.e. speed of movement, when they were seated in the specially designed seat and with the greatest amplitudes, i.e. largest leg movements, when they were supine. The only developmental trend he described was that infants with SB generated more parallel leg kicks at four months of age compared to when they were five, six, and seven months old.¹⁴

Collectively, these studies reveal that how often infants with SB move their legs and kick – generate leg movements that are similar to the leg movements needed to walk - varies with age and the movement context in which they are placed. These studies also show that infants with SB move their legs less often than

TD infants and with different temporal and spatial qualities compared to the leg movements of TD babies. Perhaps more importantly, Chapman showed that young infants with SB are capable of modifying the kinematic properties, i.e. velocity and amplitude, of their leg movements depending on the movement context in which they were placed. Thus, context continues to be a particularly relevant variable to manipulate as we seek to develop intervention strategies that will facilitate the ability of young infants with SB to generate frequent leg movements that are similar to the leg movements that are used to walk.

Movement Context and Movement Patterns

Only two studies have directly examined the effect that context has on the leg movements babies with SB generate.^{12,14} Several studies have, however, demonstrated the effect context has on the movements produced by TD infants. For example, Thelen and Fisher examined the stepping patterns of healthy full-term infants and showed that these infants had different kicking patterns when they were supine compared to being held upright.¹⁵ A small study by Ferraris et al. investigated the effect of postural support when they observed movement in ten healthy pre-term infants with no known neurological dysfunction, positioned either in supine or supine in a “nest” (an oval shaped cloth made of rolled up blankets that was designed to minimize environmental stimuli, and support the infant in an optimal posture).¹⁶ The authors assessed spontaneous movements toward and across midline, elegant wrist movements, rolling side to side, abrupt movements,

and frozen postures. Spontaneous movements included head rotation from side to midline and back; head rotation side to side; hand to hand, hand to head, and hand to leg contact; and contact with hand to contralateral shoulder and trunk. Elegant wrist movements were defined as wrist movements with superimposed rotations. Abrupt movements were defined as sudden abduction and extension of upper extremities and opening of the hands. Infants displaying frozen postures held a sustained position, up to 30 seconds, of upper extremity flexion and hand fisting, and lower extremity extension. Lying in the nest had a positive effect on postural behaviors across all age groups in this study before and after movement, on spontaneous motor behavior, and was associated with a decrease in frozen postures and abrupt movements.¹⁶ Infants in supine without the nest had more abrupt movements and frozen postures.¹⁶

A similar study examined the effect of being prone or repositioned every three to four hours on a moldable mattress in 60 low risk pre-term infants who were 31-36 weeks gestational age.¹⁷ The control group had significantly more dysfunctional tone than the treatment group, demonstrating a muscle imbalance toward increased neck and trunk extensor tone, and decreased flexor activation. They also had an increased tendency for opisthophonos (hyperextension of the head and neck resulting in the back of head and heels being the point of contact on supporting surface when supine). Furthermore the control group had a greater incidence of abnormal posturing of arms in continuous flexion and abduction, and

tendency to keep their head to one side resulting in plagiocephaly. These postural abnormalities may have contributed to motor abnormalities observed in the control group including inability to reach forward with arms and late sitting, and resistance to postural change. An increase in foot valgus was also noted in the control group, which could have important implications later when the infant begins to stand and walk. In addition the control group had increased over-excitability and were more difficult to calm than the treatment group.¹⁷ This observation is in agreement with the Ferris et al. study, which suggested that improper positioning leads to abnormal posturing that results in infants that are more hyperexcitable and prone to abrupt and frozen movements.¹⁶ An additional study assessing the effect of positioning of infants by Majnemer and Barr, investigated whether four and six-month-old infants who slept in supine and infants with decreased prone exposure during waking hours demonstrate delayed motor skills.¹⁸ Their data showed that infants with less awake “tummy time” had lower scores on the Alberta Infant Motor Scale (AIMS), and Peabody Developmental Motor Scale (PDMQ) Gross Motor Quotient (GMQ) and Fine Motor Quotient (FMQ).¹⁸

These studies illustrate that the context in which an infant is placed may have a significant impact on how that infant moves, as well as implications for how that baby may move later in life. The studies discussed above, although important for showing the potential effect of positioning on infant development, were on neurologically intact infants, not on infants with SB. Infants with SB have unique

neurological systems that create a special set of challenges for them as they grow and develop. Thus, more research is needed on infants with SB to determine how the movement context may influence their demonstrated movements over developmental time, and how it may affect the acquisition of functional motor skills, like crawling and walking.

Motor Skill Acquisition of Infants and Children with SB

Infants and children with SB experience marked continuities and discontinuities in their motor development as well as significant delays in when they learn to produce functional movements like crawling, pulling to a stand, and walking. For instance, most babies with SB learn to sit and crawl between one and two years of age, stand alone when they are three years old, and learn to walk when they are between two and five years old.^{9,19,20} No one has documented when infants with SB demonstrate head and/or trunk control nor has anyone reported when infants with SB show control of their lower trunk and pelvis.

Toddlers and children with higher lesions tend to begin walking later in life than those with lower level lesions.¹⁹ In particular, infants with lower level spinal lesions, i.e. sacral lesions learn to walk, on average, at two years and two months of age while those with lower lumbar level lesions (vertebral levels L4-5) demonstrate the ability to walk when they are three years and 10 months old.²⁰ Children with high lumbar lesions, vertebral levels L1-2, do not begin to walk until they are five years and two months old.²⁰ In comparison, TD infants begin to demonstrate head

control at three months of age, trunk control and independent sitting at six months of age, lower trunk and pelvic control at nine months of age, crawl between nine and 11 months of age, stand alone when they are 11 months old, and begin to walk when they are between 11 and 12 months old.²¹ These developmental milestones are summarized in Table 1 for both groups of infants.

Insert Table 1 Here

Due to the developmental lags demonstrated by infants with spina bifida, the first year of life is dominated by neurological procedures and physical therapy.²² This trend continues into infancy. Pediatric physical therapists provide on-going interventions designed to help the infant achieve the next motor milestone.⁴ At present, physical therapists have little empirical data to guide them beyond the works reviewed above as they seek to develop evidence-based interventions. In fact, most of the literature has examined the leg movements of a small number of infants with SB when they are supine. None of the studies have examined the spontaneous leg movements of infants with SB older than seven months of age. Nor do we have any data that describes how their movement repertoire changes over time between seven months of age and when they learn to walk – usually around two to five years old.^{9,19,20} Thus, we know little about what factors contribute to the delays these infants experience in the onset of functional movement patterns, like crawling and walking. As a result, there is limited evidence for therapists to rely on as they work to develop evidenced based treatment recommendations for infants with SB who

are older than seven months of age. Therefore, the purpose of this study was to document the ability of infants with lumbar or sacral SB who were between seven and eleven months old at entry into the study, to spontaneously move their legs and generate kicks when they are supine, seated in a conventional infant seat, and seated in a specially designed infant seat over a three month period of time.

Methods

Participants:

Prior to participant recruitment Institutional Review Board approval was obtained. The participants were three infants with lumbar or sacral SB who ranged in age from 27 to 44 weeks at entry into the study, none of whom were premature. We selected this age range because there is a relative lack of information about the leg movements of infants with SB beyond seven months of age.^{10,11,12,13,14} We limited our study to infants with SB due to the extensive body of knowledge that currently exists regarding the spontaneous leg movements of TD babies.^{15,23,24,25,26,27} All of the infants were born via planned Cesarean sections and two of the three had a VP shunt placed shortly after birth.

The faculty advisor for this study recruited the participants through the state of Minnesota Spina Bifida Association and the SB clinic of a large metropolitan hospital located in the upper Midwest. None of the participants took any medications during the course of this study. In addition, each infant's surgical

history was noted in detail regarding when and what procedures had been performed. All participants earned a \$10.00 per visit participation incentive. Table 2 presents a summary of characteristics for the participants.

Movement Data Collection

The data collection sessions took place in the infant's home at a time when the parents reported that their baby was typically alert and active. Before videotaping each infant, we videotaped a 1.0-meter long calibration rod that was placed within the space to be occupied by the infant, parallel to the floor for one minute. Then, the baby's clothes were removed to allow for maximal freedom of movement. Next, we placed a small reflective hemispherical marker approximately 2.0 cm in diameter on the sole of each foot at the head of the first metatarsal for use in later data reduction. The spontaneous leg movements of each infant were then videotaped for a total of eighteen minutes per test session. Data were collected in two sets of three 3-minute trials while the infants were: a.) supine on a towel on the carpeted floor of their parents' home, b.) seated in a conventional infant seat and c.) seated in a specially designed infant seat (see Figure 1). Based on previous research^{12,14} three minute trials were used to ensure that a minimum amount of movement for each participant was videotaped. The order of position was also based on Chapman's earlier work in which he reported that this type of data collection process, i.e. moving from supine to a more upright posture was well tolerated by infants with SB. During testing, the parent or faculty advisor was seated

near the infant's side for each trial and interacted with the infant visually and socially to encourage activity. Each infant received a brief rest period between conditions. The two sets of trials were videotaped before and after the anthropometric data were collected. Ultimately the frequency data was compared on a per minute basis.

Insert Figure 1 Here

The primary difference between the conventional infant seat and the specially designed infant seat was that the latter is designed to allow the infant to move his or her legs freely at the hips and knees. The specially designed infant seat positioned the infant's trunk at an angle of 37 degrees from vertical. It provided firm support, but, with the exception of the head support area, did not constrain lateral arm or leg movements. The base of the seat was 33 cm high, thus preventing the infant's feet from touching the support surface. An elastic cloth was positioned around the infant's chest and fastened with Velcro behind the back support to stabilize the infant's trunk.

Test sessions were videotaped with a Sony HD Handycam video camera that allowed for two-dimensional position-time data to be collected during all trials. Sampling rate was 30 hertz. The camera was mounted on a tripod and positioned up to a maximum of two meters from and perpendicular to the infants' feet with the optical axis of the camera lens set at an angle of 22.3 degrees from the floor. This

resulted in a camera height of 82 cm when the camera was two meters from the feet of the baby.

Two-dimensional (2-D) data were collected rather than three-dimensional (3-D) data because our primary interest was in describing how often infants with SB move their legs and kick as well as examining how the movement context impacts the frequency of those leg movements rather, than, for example torque values of infants' leg movements, which would have required a 3-D technique. This approach allowed us to capture the frequency of leg movements and kicks as well as the amplitude and velocity data (the focus of a second paper) for leg movements that occurred in the horizontal and vertical directions in relation to the 1.0-meter calibration rod that was videotaped before videotaping each participant.

Anthropometric Data Collection

After the first set of movement test trials were completed, anthropometric measurements were taken by the faculty advisor to examine the possibility that selected physical characteristics were related to the amount and type of leg movements observed. These included: total body length and weight, thigh and calf lengths, skinfolds, and circumferences, as well as abduction of the right hip and ankle dorsi- and plantar-flexion of the right foot and ankle. Total body length and weight provide a measure of overall size. We anticipated that infants who gained more weight over time or who had larger skinfold measures and/or greater leg circumferences would move their legs and kick less often than leaner babies who

have thinner legs. We also expected that infants with longer leg segments would move their legs and kick less often than infants with relatively shorter leg segments, particularly in the supine position. The range of motion variables were measured to determine if infants with increased joint laxity moved their legs less frequently than babies with less mobile joints. Each of these measures were taken on each test day. See Table 2 for a complete description of the anthropometric measurement technique.

Insert Table 2 Here

Data Reduction

Each set of trials for each baby was rated for activity level by the faculty advisor. Movements were scored at 10-second intervals throughout each trial using a three-point system (zero = no leg movement, 1 = one leg moving, two = both legs moving). After this a total activity score for each set of trials were calculated by summing across trials. The set of trials with the higher score was selected for subsequent analysis. The reliability of selecting the most active set of trials was established by rescoring 50% of the participants.^{12,14,26}

Then, the videotaped data for each baby's more active set of trials was behavior coded frame by frame to determine the video frames in which onset and termination of leg movements occurred for each leg. The onset and end of leg movements was defined as occurring when movement of the marker attached to the bottom of the first metatarsal of the foot stopped or started, or when a change in

direction occurred. For example, if a baby moved his or her leg medially then reversed direction and moved the leg laterally, the first movement ended and the second began at the point of change in direction. Each student researcher achieved a percent agreement with the faculty advisor of $\geq .80$ prior to behavior coding any of the videotaped data.

From each baby's full set of leg movements and based on previous data^{14,23,26} six leg movement patterns were also identified through behavior coding of the videotaped data for each baby. These included: single, parallel, and alternating leg kicks (involving hip and knee flexion/extension) and single, parallel, and alternating knee kicks (involving knee flexion/extension). See Table 3 for a complete description of kick patterns.

Insert Table 3

Data Analysis

The frequency data for leg movements and kicks were tested for significance with two one-way ANOVAs. This allowed us to test the null hypothesis that the babies would generate the same number of leg movements and kicks in each position at each age without increasing the chance of finding a significant difference in the number of leg movements and kicks produced when in reality there was no difference. For significant ANOVA effects, e.g. for context, we inspected the means

for each variable, i.e. total leg movements in each context, to identify the location and direction of the significant difference.

Results

Description of Participants

In Table 4, we present the characteristics of the three participants who completed this pilot study. The group means and standard deviations for the anthropometric data are presented in Tables 5-7. We elected not to run statistical analyses of these data to determine if significant differences existed over time for the a). length measures, i.e. height, thigh length, calf length; b). range of motion variables, i.e. ankle plantarflexion, dorsiflexion, and hip abduction; and the c). mass and girth variables, i.e. weight, thigh circumference and skinfold, calf circumference and skinfold due to the limited number of subjects we were able to enroll in this pilot study. We did, as expected, observe a trend for the length variables to increase over developmental time. We also observed, as anticipated, that there was a trend for weight and thigh skinfold to increase over developmental time. We were surprised to find that there was no trend observed with the other mass variables (ie. thigh circumference, calf circumference and calf skinfold). We were also surprised, however, by the fact that the range of motion variables appeared to increase as the babies became older.

Insert Tables 4-7

Context and Age Effects: Overall Frequency of Movement and Kicks

Figures 2 - 3 illustrate the means and standard deviations for how often the infants' moved their legs and kicked when they were in each position over developmental time. One-way ANOVAs for these variables showed that this small group of infants generated significantly more leg movements ($F_{2,24} = 10.05$, $\alpha = .001$) and kicks ($F_{2,24} = 4.948$, $\alpha = .016$) when they were seated in the specially designed infant seat compared to when they were in the other two positions. These findings confirm our first hypothesis that the context effect would significantly impact how often these infants would move their legs and generate kicks.

Insert Figures 2 and 3 Here

As we anticipated, the age effect was not significant with this small sample of babies with SB. One-way ANOVAs for the age effect revealed an $F_{2,24} = 1.245$, $\alpha = .306$ for the overall frequency of leg movements and an $F_{2,24} = 0.251$, $\alpha = .780$ for the frequency of kicks. Figures 4 - 5 illustrate the mean and standard deviations for leg movements and kicks over developmental time. This is most likely due to the small n ($n=3$) in this pilot study and the amount of variability, i.e. large standard deviations, observed with these three infants.

Insert Figures 4 and 5 Here

Context and Age Effects: Frequency of Individual Kicks

The frequencies of each type of kick generated during the three months of this pilot study are presented in Figures 6. Due to the number of types of kicks (six) and the small number of infants enrolled in this pilot study we chose to not run a statistical analysis for significance. Inspection of the means shows that the babies generated more single leg kicks at age 35.3 the first month of this study. During months two and three of the study, however, they produced more single knee kicks than any other type of kick. The least frequently produced type of kick at all ages were alternating leg kicks.

Insert Figure 6 Here

Relation between Anthropometric Variables and Overall Frequency of Leg Movements and Kicks

The anthropometric variables and their relationship with the overall frequency of leg movements and kicks are presented in Tables 8-10. We calculated Pearson product-moment correlations between the anthropometric measures taken and each of these variables over developmental time to determine which of the anthropometric measures, if any, demonstrated a moderate ($r \geq .40$) to significant ($p \leq .05$) relationship with the frequency of these movement patterns. Because of our small sample size we did not expect any of the anthropometric variables to demonstrate a significant relationship with the frequency of leg movements and kicks, but wanted to present anthropometric measures that showed a moderate

relationship with these movement patterns due to the limited amount of data that currently exists regarding these measures and their impact on how often infants with SB move their legs and kick.

Insert Tables 8-10 Here

None of the length measures demonstrated a moderate or significant relationship with either kicks or the overall frequency of leg movements. Hip abduction demonstrated a moderate and nearly significant negative relationship with the frequency of leg movements ($r = -.626$, $\alpha = .071$) and with kicks ($r = -.585$, $\alpha = .098$) in spite of this small sample size. None of the other range of motion measures showed a moderate or significant relationship with how often the babies moved their legs or kicked. Three mass and girth measures showed a moderate relationship with the overall frequency of leg movements and kicks. These were calf circumference with leg movements ($r = .404$, $\alpha = .280$) and kicks ($r = .423$, $\alpha = .257$); calf skinfold ($r = .564$, $\alpha = .114$) for leg movements and for kicks ($r = .647$, $\alpha = .060$); thigh skinfold ($r = .451$, $\alpha = .223$) with kicks. As with the other anthropometric measures, none of the mass and girth variables demonstrated a significant relationship with the overall frequency of leg movements or kicks.

Discussion

The results of our pilot study are consistent with the previous research which showed that the context an infant is placed in can affect movement patterns and motor development.^{16,17,18} The infants in this current study, who are older than the previously studied infants with SB, were also sensitive to the movement context in which they were placed. The infants generated the greatest number of leg movements and kicks in the specially designed infant seat and the fewest number of leg movements and kicks in the conventional infant seat. This study supports the suggestion that regardless of neural tube defects associated with SB, all infants involved were affected by the movement context in which they were placed. In relation to context, infants with SB between the ages of 27 and 44 weeks move their legs more frequently in a specially designed infant seat compared to a typical infant seat and laying supine. It is promising to see such a robust effect emerging with such a small sample size.

There was not, however, a significant age effect on how often the infants moved their legs or kicked. These results are also consistent with the literature that showed that younger infants with SB did not move their legs more often or kick more frequently as they got older.^{12,14} The lack of effect for age in this paper may be due to the small n in this pilot study.

We had not expected the anthropometric data to show significant correlations due to our small sample size. We did observe some moderate

correlations that may point toward significance with a larger sample size.

Correlations with a moderately strong relationship with leg movements and kicks were hip abduction, calf circumference, calf skinfold, and thigh skinfold. It was interesting to note that the hip abduction demonstrated a negative correlation to the leg movements and kicks. This means that infants with more movement in the hip abduction range had decreased leg movements and kicks.

Clinical Relevance

The results from this pilot study can be used by therapists to design treatment plans for infants with SB that facilitate leg movements and kicks. By placing infants in a specially designed infant seat, they are free to move their legs and explore their environment. This will enable infants to strengthen the muscles and neural connections that support functional leg movements needed to walk early in their development thus increasing the probability of generating similar leg movements in the future.^{14,28} Previous research by Ulrich and Ulrich has shown that the frequency with which infants kick is significantly correlated with the age at which they begin to walk.²⁶ These data suggest that therapists may influence the age of walking attainment in infants with SB by treating infants in a movement context that allows for the greatest number of kicks. In addition, therapists play a pivotal role in educating parents about the detrimental effects a conventional infant seat may have on their child's ability to move h/her legs and generate kicks. For example, infants placed in a conventional infant seat are limited in their abilities to move their hips through flexion, extension, abduction, and adduction. Infants also

have difficulty generating knee movements with greater excursion in this position. The specially designed infant seat was designed to allow for greater range of motion of both the hips and knees in all planes thus giving infants the opportunity for greater muscle recruitment. Thus, the use of a specially designed infant seat may be a valuable intervention tool when treating infants with SB.

Limitations

Limitations of this study include a small sample size. However with the limited number subjects, we found a significant effect for context with a trend toward significance for age. As more participants are observed we expect that the power from the results will be even more robust. One of the subjects observed was already rolling, which made for difficult analysis of movements and kicks in a supine position.

Another limitation was the availability of participants which limited our ability to observe each infant for only three months rather than four as we had originally hoped. Since each infant was observed for only three sessions, our data set was more limited than we planned which may have decreased the significance of our age results.

Two-dimensional rather than three-dimensional video was collected and analyzed. This prevented us from reporting additional kinetic properties of the infants' leg movements and kicks, such as torques. However, our primary goal was to examine the impact that the movement context has on the frequency of leg

movements and kicks generated by infants with lumbar or sacral SB. Thus, two-dimensional data met our research needs.

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Tables

Table 1
Motor Milestones for Typically Developing Infants and Infants with Spina Bifida

Motor Milestones	Typically Development Infants	Infants with Spina Bifida
Head Control	3 months ⁴	Unknown
Trunk Control	6 months ⁴	Unknown
Independent Sitting	6 months ¹⁷	1-2 years ⁹
Lower Trunk/Pelvis Trunk	9 months ⁴	Unknown
Crawling	9-11 ¹⁷	1-2 years ⁹
Standing Alone	11 ¹⁷	3 years ⁹
Walking	11-12 months ^{4,17}	*2-5 years ^{9,19,20}

*Age at independent walking varies with level of spinal lesion

Table 2
Anthropometric and Range of Motion Measures

Measure	Description
Lengths:	(All measurements recorded in cm and measured to the nearest mm)
Total Body Length	Baby is supine, looking up, body aligned with ankle dorsiflexed to 90 degrees. Measurement taken from the top of the head to the bottom of the foot.
Thigh	The distance between the greater trochanter and the lateral condyle of the femur with the leg extended and the ankle dorsiflexed to 90 degrees.
Calf	The distance between the lateral condyle of the femur and the lateral malleolus with the leg extended and the ankle dorsiflexed to 90 degrees.
Circumferences:	(All measurements recorded in cm and measured to the nearest mm)
Thigh	The circumference of the thigh measured at the midpoint of the segment length as measured above.
Calf	The circumference of the calf measured at the midpoint of the segment length as measured above
Skinfolds:	(All measurements recorded in mm and measured to the nearest 0.5mm)
Medial Thigh	The skinfold vertical and taken at the same level as the thigh circumference on the medial surface with the thigh extended
Medial Calf	The skinfold is vertical and taken at the same level as the calf circumference on the medial surface with the thigh and knee extended
Range of Motion:	(All measurements recorded to the nearest degree)
Hip abduction	The leg is abducted at the hip while the infant is supine, knee extended and the leg is in contact with the support surface and rotated slightly laterally
Ankle Plantarflexion/Dorsiflexion	The infant is supine with the knee extended as the ankle is moved into plantarflexion and dorsiflexion

Table 3
Description of Kick Patterns

Type of Kick	Description of Kick Pattern
Single Knee Kick	Observable flexion and extension at the knee joint
Single Leg Kick	Observable flexion and extension at the hip and knee joint of one lower extremity
Parallel Knee Kick	Observable flexion and extension of both knees simultaneously
Parallel Leg Kick	Observable flexion and extension of both legs at the hip and knee joints simultaneously
Alternating knee kick	Observable flexion and extension at the knee joint with some overlap between the beginning and ending of the movement of the right and left lower extremities
Alternating leg kick	Observable flexion and extension at the knee and hip joints with some overlap between the beginning and ending of the movement of the right and left lower extremities

Table 4
Characteristics of Infants with Spina Bifida

Participant	Lesion Level	Length of Pregnancy	Orthopedic Co-morbidities	Surgical History
1	L4-5	Full Term	Bilateral Clubfoot	VP Shunt Bilateral Heel cord Releases
2	L4-5	Full Term	Bilateral Clubfoot	VP Shunt
3	L4-5	Full Term	Right Hip Dysplasia Bilateral Clubfoot	N/A

Table 5
Length Variables: Means and Standard Deviations by Month

Month	Height (inches)	Thigh Length (cm)	Calf Length (cm)
1	28.16 ± 1.6	12.87 ± 2.4	12.1 ± 1.6
2	28.1 ± .80	13.87 ± .61	13.13 ± .11
3	28.83 ± 1.25	14.76 ± 1.12	13.93 ± .11

Table 6
Range of Motion Variables: Means and Standard Deviations by Month

Month	Plantarflexion (deg)	Dorsiflexion (deg)	Hip Abduction (deg)
1	53.33 ± 14.74	23.67 ± 11.01	45.33 ± 6.65
2	52.33 ± 19.1	22.67 ± 20.52	46 ± 5.29
3	54 ± 5.29	29 ± 26.2	55 ± 13.22

Table 7
Mass Variables: Means and Standard Deviations by Month

Month	Weight (lbs)	Thigh Circumference (cm)	Thigh Skinfold (cm)	Calf Circumference (cm)	Calf Skinfold (cm)
1	20.7 ± 1.2	21.18 ± 2.9	25.66 ± 3.2	14.37 ± 3.5	17 ± 2
2	21.3 ± 2.4	27.06 ± 1.0	26 ± 7.9	17.4 ± 2.4	19.73 ± 4
3	21.6 ± 1.7	22.73 ± 1.3	28.66 ± 4.2	16.03 ± 2.6	17 ± 2.6

Table 8
Pearson Correlation Values between Length Variables, Leg Movements and Kicks

	Height	Thigh Length	Calf Length
Movements Correlation	.030	.039	-.145
Sig. (2-tailed)	.938	.921	.710
Kicks Correlation	.270	.059	-.105
Sig. (2-tailed)	.482	.880	.788

Table 9
Pearson Correlation Values between Range of Motion Variables, Leg Movements and Kicks

	Plantarflexion	Dorsiflexion	Hip Abduction
Movements	.195	.297	-.626
Correlation	.615	.438	.071
Sig. (2 tailed)			
Kicks	.169	.487	-.585
Correlation	.664	.183	.098
Sig. (2 tailed)			

Table 10
Pearson Correlation Values between Mass Variables, Leg Movements and Kicks

	Weight	Thigh Circumference	Thigh Skinfold	Calf Circumference	Calf Skinfold
Movements	.184	-.211	.372	.404	.564
Sig. 2 tailed	.636	.586	.324	.280	.114
Kicks	.334	-.238	.451	.423	.647
Sig. 2 tailed	.380	.538	.223	.257	.060

Figures

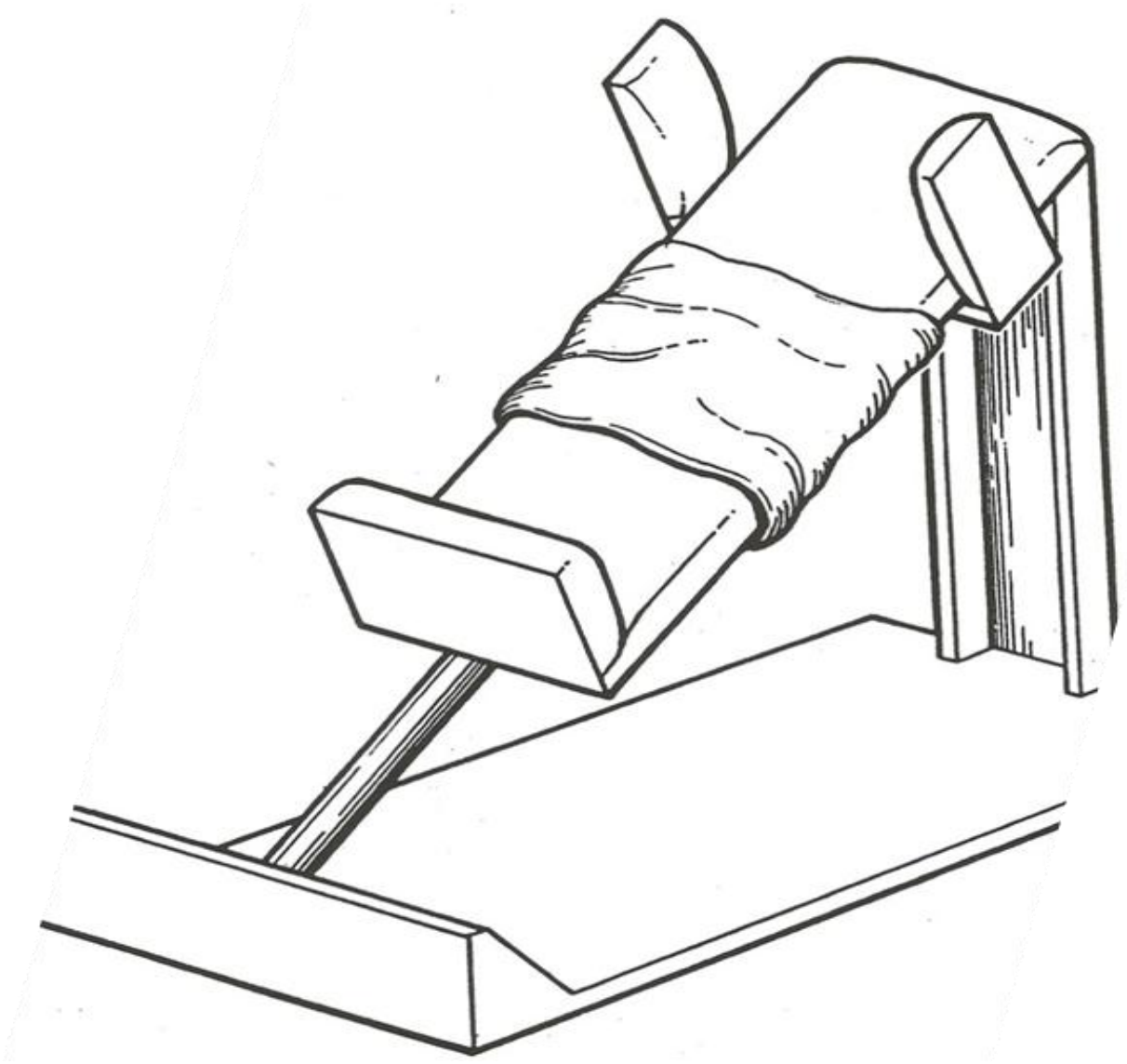


Figure 1. Specially Designed Infant Seat.

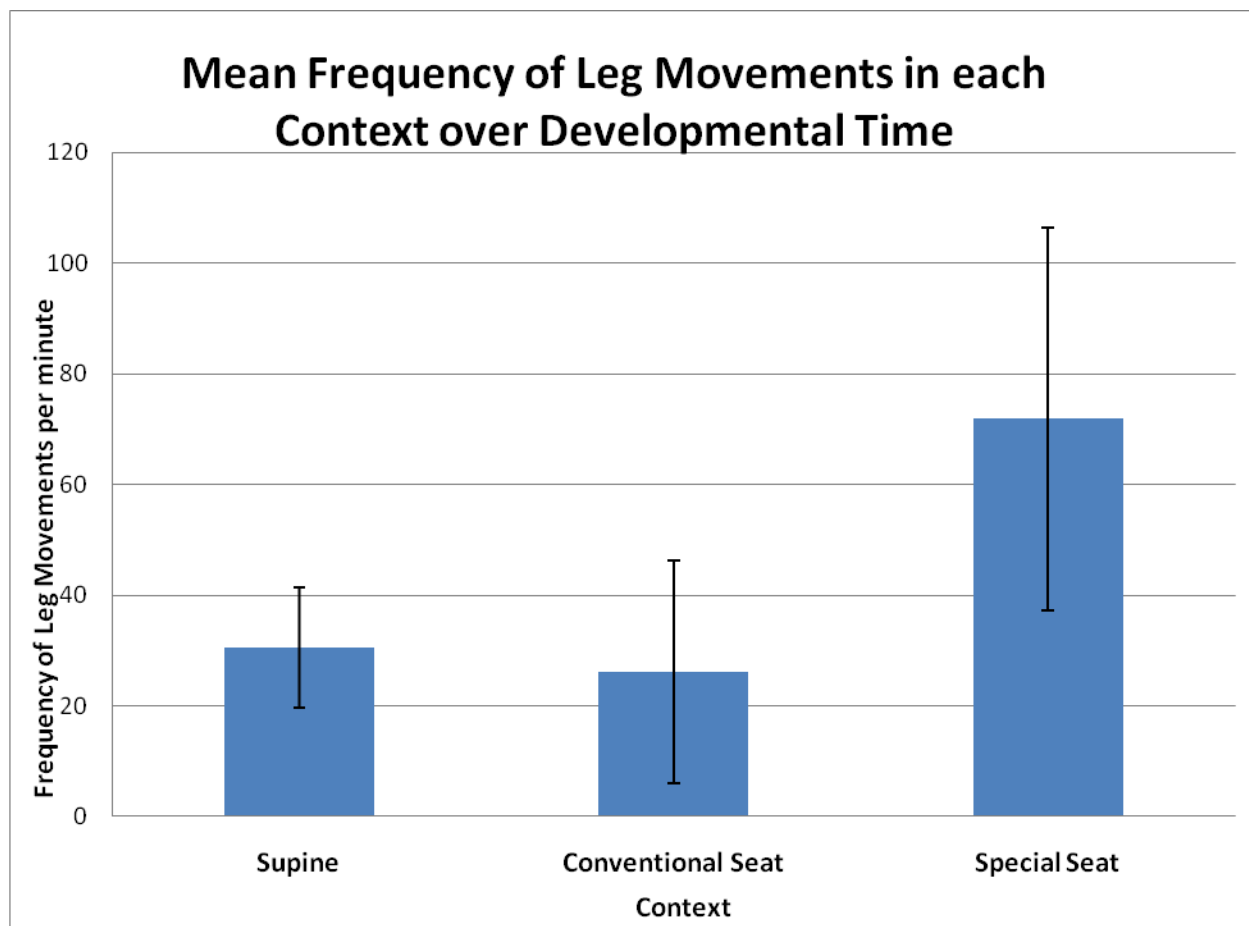


Figure 2. Bar graph illustrating the mean frequency of leg movements in each context over developmental time. Error bars represent one standard deviation.

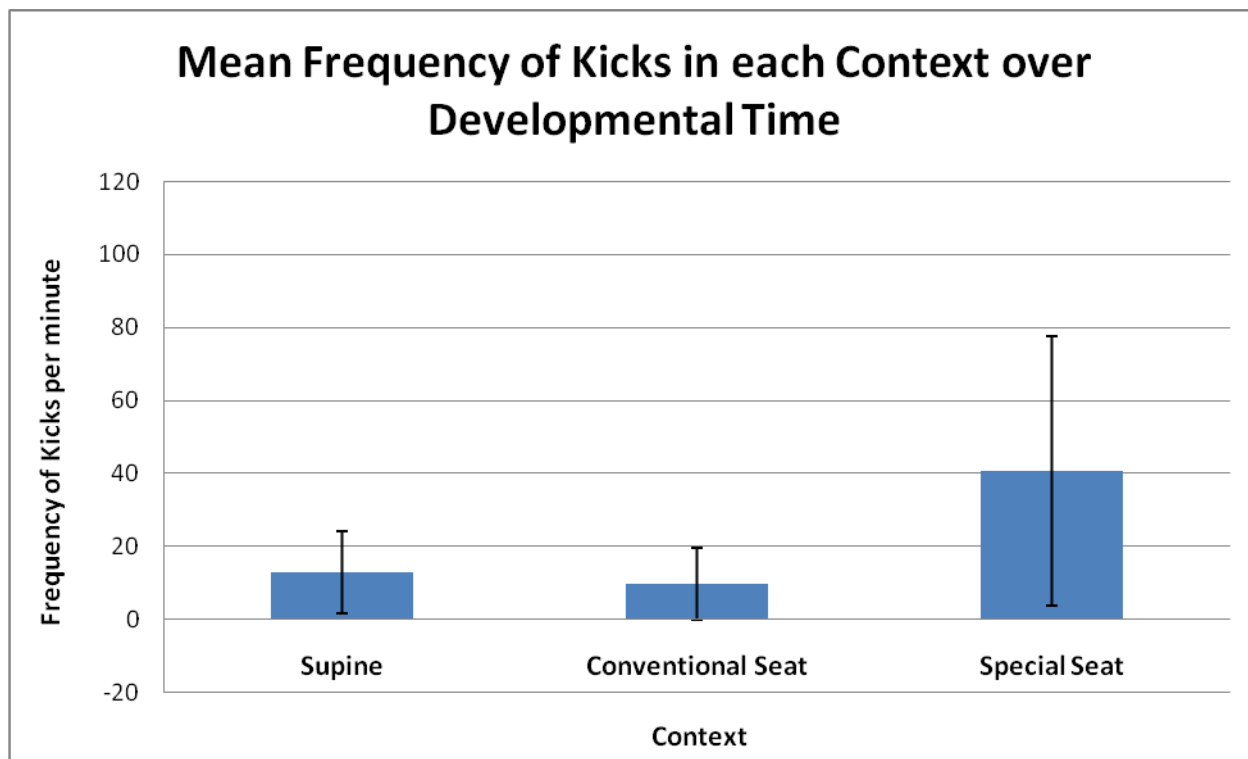


Figure 3. Bar graph illustrating the mean frequency of kicks in each context over developmental time. Error bars represent one standard deviation.

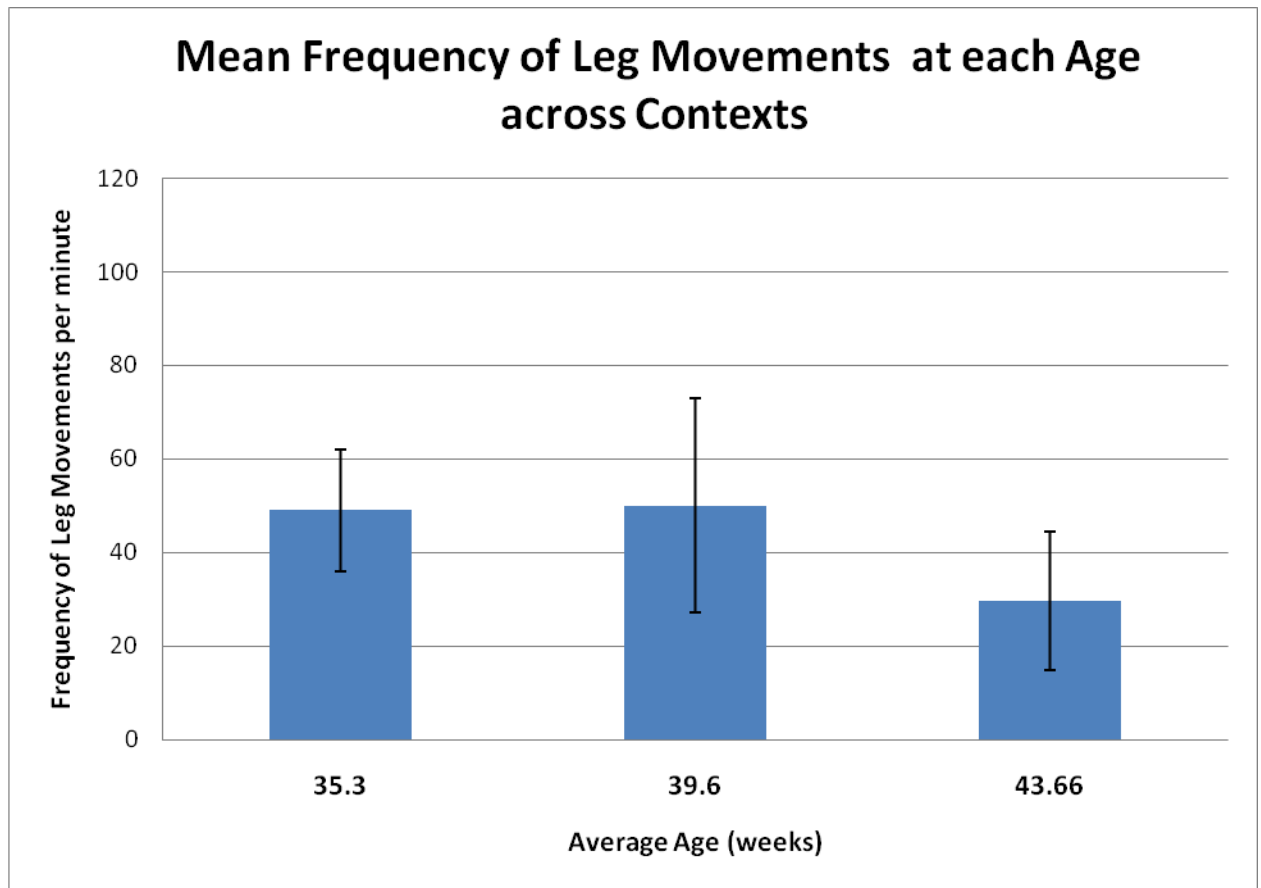


Figure 4. Bar graph illustrating the mean frequency of leg movements at each age across contexts. Error bars represent one standard deviation.

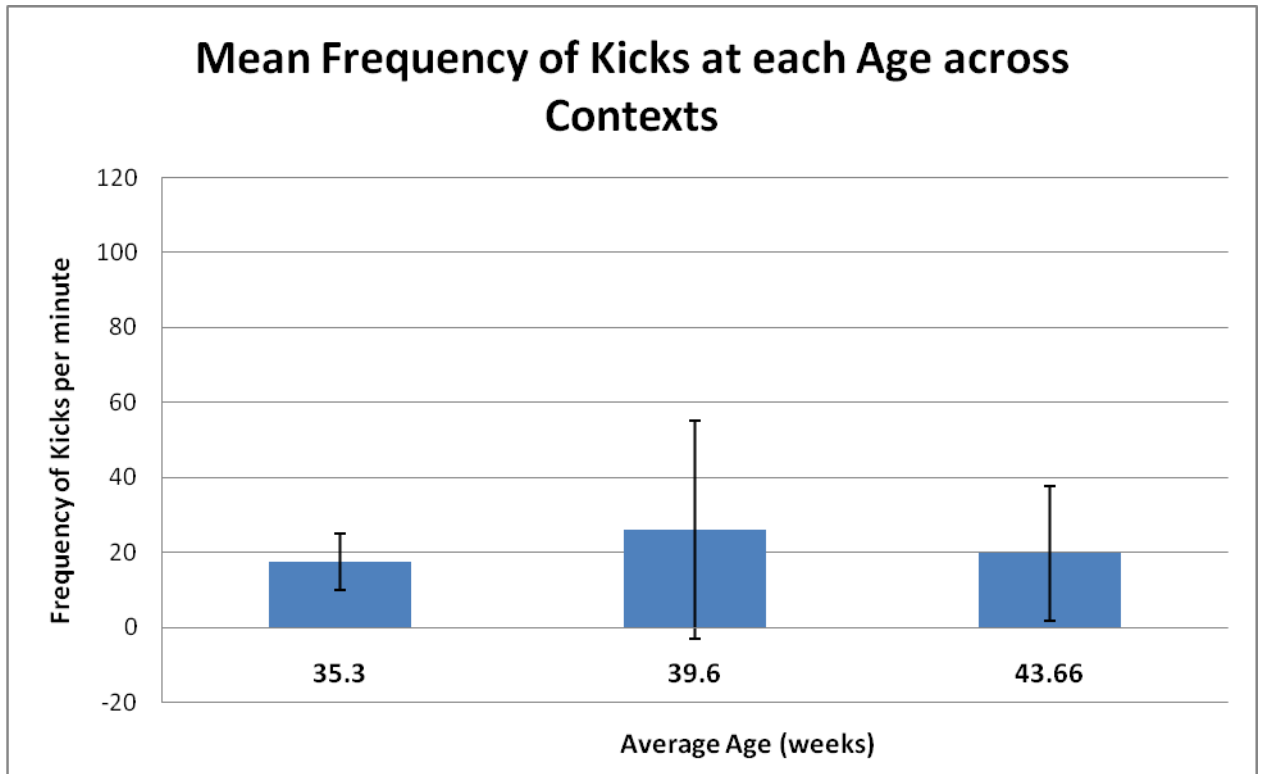


Figure 5. Bar graph illustrating the mean frequency of kicks at each age across contexts. Error bars represent one standard deviation.

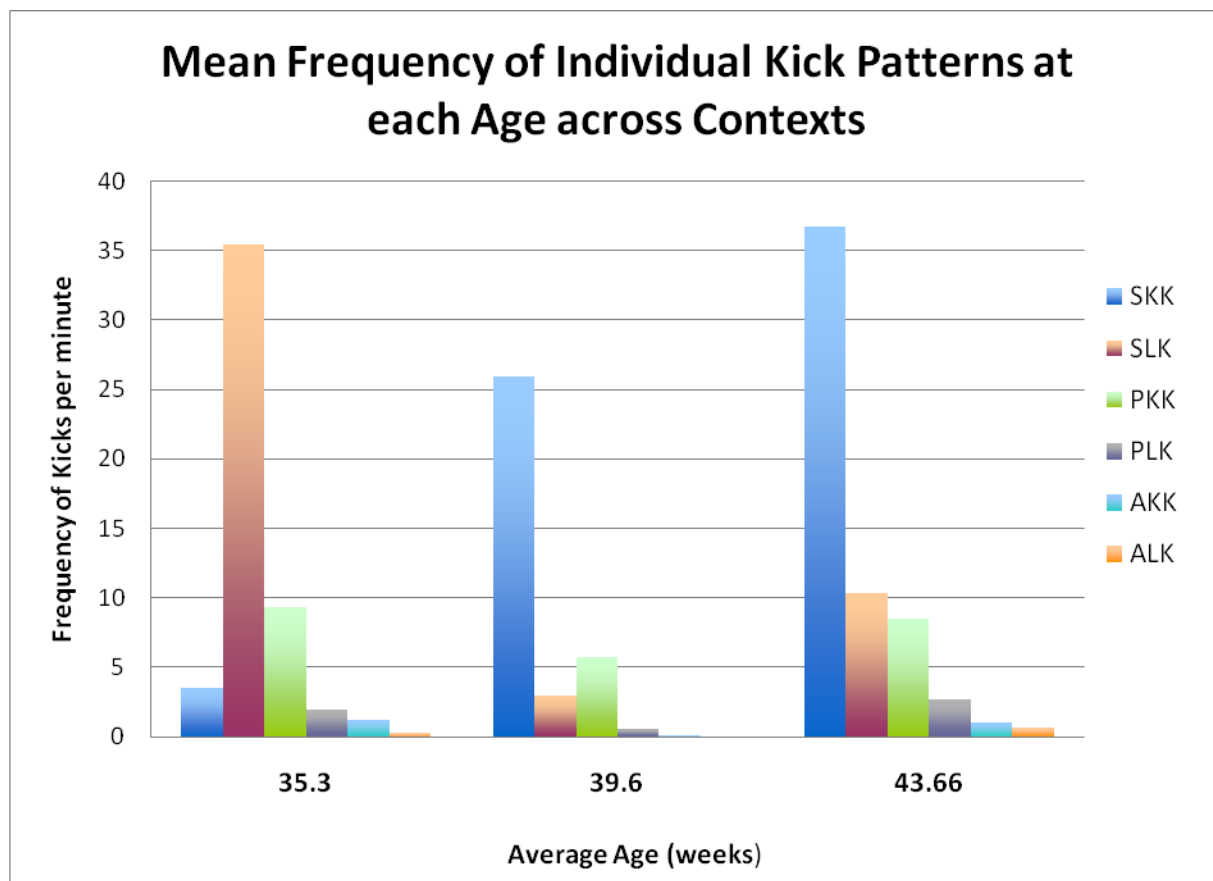


Figure 6. Bar graph illustrating the mean frequency of individual kick patterns at each age across contexts.