Published in final edited form as:

Pediatr Phys Ther. 2016 ; 28(3): 304–310. doi:10.1097/PEP.0000000000000272.

The Immediate Effect of Positioning Devices on Infant Leg Movement Characteristics

Crystal Jiang, Joyce T. de Armendi, and Dr Beth A. Smith, PT, DPT, PhD

Division of Biokinesiology and Physical Therapy, University of Southern California, Los Angeles, California, U.S.A

Abstract

Purpose—To determine the immediate effects of constraining or encouraging positioning devices on leg movement of infants with typical development (TD) and at-risk for developmental delay (AR).

Methods—Twenty-six infants (13 TD, 13 AR) were placed in supine, a jungle gym, or a car seat. Movement sensors on infants' ankles measured acceleration and angular velocity. We calculated the number of leg movements, peak acceleration and peak rotational rate of each leg movement. A 2 (Group) $\times$ 3 (Condition) Analysis of Variance with repeated measures on condition tested for a group effect, a condition effect, and a group by condition interaction for leg movement quantity, average peak acceleration and average peak rotation.

Results—Leg movement quantity and average peak acceleration were significantly lower for the car seat condition compared to supine or the gym.

Conclusions—Positioning device use has an immediate effect on infant leg movement characteristics. Long-term effects remain unknown.

Introduction

Infant motor development is largely influenced by movement experience in relation to the external environment. In many households, positioning devices are frequently used to entertain and position infants, especially in families with more than one child.¹ The widespread use of devices is reflected by the vast selection available for parents to choose from. For example, popular baby product retailer, BabiesRUs.com, sells over 100 types of play gyms.² Because infant equipment is a significant component of the infant environment, it is important to investigate their potential influence on movement experience and motor development.¹

It is not clear whether the use of infant positioning devices encourages or constrains development. Infant equipment manufacturers often claim that their infant activity mats or

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Correspondence: Crystal Jiang, 11261 Sherrard Way, San Diego, California 92131. crystacj@usc.edu.

Conflict of Interest statement: The authors declare no conflict of interest

At the time this article was written, Crystal Jiang was pursuing a Bachelor of Science degree in Neuroscience at the University of Southern California in Los Angeles, California, U.S.A.

“jungle gyms” encourage infant limb movement and stimulate infants to move and learn. Although this has not been systematically tested, name brands, such as Fisher-Price, state that their products promote advancements of fine and gross motor skills, sensory skills, balance, and/or coordination.³ It has also been suggested that seating devices, such as an infant car seat, “constrain” infant limb movement, but this too has yet to be experimentally tested.¹

Devices may support and increase experience of different positions, increasing opportunities for movement and learning. Most supporting evidence for the positive effects of positioning devices has been found for populations at high risk for, or diagnosed with developmental disorders. For instance, use of a special non-rigid infant seat in the neonatal intensive care unit reduced the frequency of motor behaviors associated with prematurity such as clonus and startles in infants 30 to 37 weeks gestational age.⁴ Furthermore, individualized adaptive positioning has been shown to increase motor skill improvement in 17-58 month old children diagnosed with cerebral palsy, supporting that devices have a positive impact on test performance.⁵

Alternatively, devices may restrict opportunities for movement and learning. Baby-walkers in particular have received greater attention than other infant equipment, and increased use has been associated with transient abnormalities in motor development and movement patterns.¹ Abbott and Bartlett investigated several other less-researched devices, and found that greater total use of equipment, as well as individual use of an exersaucer, highchair, and infant seat, correlated with lower scores on the Alberta Infant Motor Scale (AIMS) at 8 months of age in infants with typical development.⁶ Similarly, in a group of preterm infants at 8 months corrected age, higher overall use of equipment was associated with lower sit and stand subscale scores.⁷ These results suggest that device use may have a negative impact on infant motor development.

As described above, several studies have attempted to study the effects of infant equipment on motor development. Existing studies are limited, as they have only used correlational analyses to associate motor development with positioning device use.¹ None of them directly measure and compare the effects of constraining or encouraging positioning device use on infant movement.

This study is the first to systematically evaluate the immediate effects of different constraining or encouraging positioning devices on infant leg movement. This is the first step in understanding how device use may influence early motor development. With the use of wireless movement sensors, we aimed to determine whether quantity, acceleration, and rotational rate of leg movements were affected by two commonly used positioning devices: the infant car seat and jungle gym. Furthermore, we determined whether infants with typical development (TD) and infants at risk for developmental delay (AR) were affected similarly. The precise effects of positioning devices are important to understand, and could be used in the future to advise parents and improve intervention strategies for infants AR.

Compared to movement without a device, we hypothesized that:

1. The car seat will have a “constraining” effect, resulting in a decrease in leg movement quantity, rotational rate, and acceleration, and
2. The jungle gym will have an “encouraging” effect, resulting in an increase in leg movement quantity, rotational rate, and acceleration

Methods

Study design

Each infant was tested in three positioning conditions in randomized order. Leg movement characteristics including quantity, average peak acceleration, and average peak rotation were compared between positioning conditions. Furthermore, the effects of positioning condition on leg movement characteristics were compared between the infant TD and AR groups.

Participants

Leg movement data were collected for 13 infants with TD (7 male) and 13 AR (8 male), for a total of 26 infants tested. All infants were between the ages 2 and 8 months chronological age (see Table 1 for chronological and, as appropriate, corrected ages), reflecting the general age range during which jungle gym devices are used. Infants were recruited by word of mouth, and from area early intervention physical therapy providers.

Eleven infants who were AR and 2 who were TD were Hispanic or Latino. In the AR group, 3 families reported their ethnicity as White, 2 as African American, 4 as Other, and 4 declined to answer. In the TD group, 7 families reported their ethnicity as White, 2 as African American, 2 as Asian, 1 as Other (Native Hawaiian), and 1 declined to answer.

Infants with TD were from singleton, full term births and without known visual orthopedic or neurologic impairments. Infants in the AR group were defined as at risk for developmental delay in accordance with the definition set forth by the state of.⁸ The AR group consisted of a broad group of infants at risk, many due to pre-term birth (see Table 1 for further information about risk).

Procedures

Data collection took place in the families' home or in our research laboratory, per the families' preference. After reviewing all procedures and equipment, parents signed a consent form prior to their infants' participation. This research was approved by the Institutional Review Board.

Motor development was assessed using the Alberta Infant Motor Scale (AIMS), a standardized, norm-referenced observational assessment of motor skills in supine, prone, sitting, and standing.⁹ The infants' weight in kilograms, and length and head circumference in centimeters, were also measured and recorded (Table 1).

We placed small, lightweight, wireless movement sensors (Opals, APDM Inc., Portland OR USA) on the infant's ankles using custom socks. The Opals were plastic, measuring $48.5 \times 36.5 \times 13.5$ mm and weighing 22 grams, similar to a wristwatch (Figure 1a). Opals were

wirelessly synchronized to each other and measured 3-dimensional accelerometer, gyroscope, and magnetometer data at a rate of 20 samples per second. In some cases, legwarmers were used instead of socks to accommodate different sizes. All socks and leg warmers were below the knee, and which to use was decided based on securing the sensors snugly but comfortably.

We tested each infant in three positioning conditions, randomized in order: without a positioning device (Figure 1b), in the infant jungle gym (Fisher-Price BMH47 Play Gym) (Figure 1c), and in the infant car seat (Graco SnugRide Click Connect 30) (Figure 1d). For the no device and jungle gym conditions, the infants were placed in supine. For the car seat, infants were seated in a semi-upright position, strapped in using the harness (two shoulder straps and a strap between the legs) as if they were in a car.

Infants were in a calm, alert state during data collection. Sensor data were collected in each condition for 4 minutes, with the PI and parent(s) present throughout. Differences in leg movement quantity, rotational rate, and acceleration among the three conditions were compared. Definitions of each of these leg movement characteristics are described in the Data Analysis section below.

Data analysis

We used MATLAB software to analyze the Opal sensor data by calculating the number of leg movements, and the peak acceleration and peak rotation of each leg movement. Leg movements were identified from the sensor data using a threshold-based algorithm. A separate leg movement was identified each time the infant's leg paused or changed direction, to obtain the total number of leg movements for each infant in each condition.¹⁰ Peak acceleration and peak rotation calculations involved looking at the total data, where "total" refers to the resultant signal calculated from across 3 axes. Specifically, the peak acceleration for each movement was calculated by identifying all of the peaks in the total acceleration data that were above the algorithm-determined positive threshold or below the negative threshold, and then determining the amplitude (absolute value) of the largest peak. The peak rotational rate for each movement was calculated by identifying all of the peaks in the total angular velocity data, and then determining the largest amplitude peak. Lastly, we determined the average peak acceleration and the average peak rotation produced by each infant, in each condition.

Statistical analysis

We used a 2 (Group) $\times$ 3 (Condition) Analysis of Variance with repeated measures on condition to test for a group effect, a condition effect, and a group by condition interaction for leg movement quantity, average peak acceleration and average peak rotation. Post-hoc Bonferroni pairwise comparisons were used to evaluate which specific conditions were significantly different from each other. Statistical tests were performed using SPSS software (Version 22, IBM Corporation, Armonk, NY, USA) and we set our alpha level equal to 0.05.

Results

Leg Movement Quantity

We obtained a significant condition main effect for leg movement quantity ($F[2,37] = 20.385, p < 0.01$). Follow-up pairwise comparisons supported that leg movement quantity was lower while infants were in the car seat compared to supine ($p < 0.01$) or the gym ($p < 0.01$), as shown in Figure 2. There was neither a significant group main effect nor a significant group by condition interaction.

Average Peak Acceleration

The average peak acceleration had a significant condition main effect ($F[2,47] = 8.222, p < 0.01$). Follow-up pairwise comparisons showed that average peak leg movement acceleration was lower while infants were in the car seat compared to supine ($p < 0.01$) or the gym ($p < 0.01$), as shown in Figure 3. There was neither a significant group main effect nor a significant group by condition interaction.

Average Peak Rotation

Peak rotation rate data are graphed in Figure 4. There was not a significant group effect, condition effect or group by condition interaction for average peak rotation of leg movements.

Discussion

This study is the first to directly measure the effects of constraining or encouraging positioning device use on infant movement characteristics. We found that constraining positioning device use had an immediate effect on infant leg movement characteristics. Leg movement quantity and average peak acceleration were significantly lower for the car seat condition compared to supine or the gym.

The car seat was the only positioning condition that had an effect on infant leg movement. In the car seat condition, leg movement quantity and average peak acceleration were reduced compared to the no device and jungle gym conditions, supporting previous notions that certain seating devices may limit infant movement. These results are consistent with Abbott and Bartlett's study, which supported that higher amounts of highchair and infant seat usage were negatively correlated with AIMS scores.⁶ The link between early movement constraint and future delayed development could be explained in several ways. One concern about constraining devices is that they may reduce infant's opportunities to interact with objects and perform actions in their environment, and prior studies have indicated that these types of movement experiences are important for the development of motor, cognitive, perceptual and learning abilities.^{11, 12} Furthermore, movement training has been shown to promote earlier reaching behaviors in preterm infants, suggesting that motor experience is not only necessary for normal development, but may have positive effects for higher risk populations.¹³ Although the car seat had an immediate effect on constraining leg movement (lower quantity and peak accelerations), additional work needs to be done to directly and longitudinally examine the long-term influence of seating device use on motor development.

It is also important to consider that the infants were in a semi-upright position in the car seat, compared to being in supine in the no device and gym conditions. In a previous study conducted by Chapman,¹⁴ 4 to 8-month-old infants with typical development and spina bifida exhibited no differences in spontaneous leg movement frequency when placed in a semi-upright in a conventional car seat compared to in supine. However, when placed in a specially designed, unrestrictive semi-upright seat, the infants moved their legs significantly more often, indicating that the upright position does not decrease spontaneous leg movement frequency compared to the supine position.¹⁴ In regards to why our results showed decreased spontaneous leg movement frequency in the conventional car seat compared to supine, and Chapman's study did not, it should be noted that the Chapman study had a sample size of 6 infants in each group, resulting in lower statistical power for detecting differences.

Contrary to our hypothesis and Fisher-Price's claims regarding their product and movement promotion, the jungle gym did not significantly increase or alter infant leg movement characteristics. Still, it is possible that there was an encouraging effect on arm movement, and anecdotally, we observed that infants concentrated on arm reaching while under the gym, as opposed to reaching for the toys with their feet. One explanation for the lack of difference between the jungle gym and no device conditions may be the presence of a ceiling effect. Since spontaneous leg movements in supine occur in high frequency throughout the first year of life,¹⁵ any further increase due to external stimuli, such as the gym, may be difficult to detect in a 4-minute time period. Another possibility is that although no quantitative differences were found between the two conditions, there may have been qualitative changes in infants' movements, which were not systematically analyzed. Reduced variability and complexity of general movement patterns have been linked to abnormally stereotyped motor performances, delayed developmental rates, and subordinate developmental outcomes for infants with neurological damage.^{15,16,17} It is possible that qualitative attributes of leg movements, rather than quantitative, produced changes when positioned under a gym.

We thought it was possible that the constraining or encouraging effects of the devices might be greater in infants AR. No significant differences were found between the leg movement characteristics of the TD and AR groups, indicating that the immediate constraining effect of the car seat was equal in both groups. The lack of difference between groups could be explained by several factors. First, it is possible that quantity of movement is not different between groups, but the resultant effects of "learning from movements" are different. This is consistent with the findings of a prior study that observed no difference in kick frequency between infants with Down syndrome and infants without.¹⁶ Second, our AR group is defined as at risk, but the infants' neuromotor outcomes are unknown at this point in time as they are still young. Our AR group likely contains infants who will have typical neuromotor outcomes at 24 months of age, moving the AR group average closer to the group average of the infants with TD. Finally, variability in the rate of development in infants with TD is high, and even more so in infants AR. Not only does this challenge early diagnosis of atypical neuromotor development, but it also makes group differences difficult to detect. The fact that we were able to detect a significant constraining effect of the car seat despite high infant variability supports moving forward with a larger, longitudinal study to accurately measure

the effects of positioning device use on rates of infant development in infants with TD and AR.

Limitations

High variance in leg movement quantity, peak acceleration, and peak rotation limited our ability to obtain significant condition and group effects. This variance could be explained by several factors. We included a wide age range of infants (2 to 8 months), and as previously mentioned, infant developmental rates are already extremely variable. This vast developmental range is reflected in the broad range of AIMS scores (6 to 34). Although this range is representative of when parents would be using these devices, infant movement experience and capacity varies greatly depending on age and developmental stage. Due to the small sample size, the effects of age or AIMS scores on leg movement characteristics were not explored. A second limitation was the use of legwarmers and socks to secure the sensors comfortably, as it is unknown whether they may influence infants' leg movements differently. Another limitation to consider is our inability to control the amount of exposure to positioning devices infants have received at home. For example, the jungle gym may have a more significant encouraging effect on infant leg movement quantity if the infant has never experienced one before. Lastly, infant temperament is extremely variable and dependent on many factors outside of our control such as hunger, tiredness, attention, or distraction. Given this extensive variability in infant behavior and development, a 4-minute time period may not be sufficient to observe all effects, and is certainly not enough to observe long-term developmental effects. These factors further support the need for moving forward with a longitudinal study.

Future research

Our ultimate goal is to understand the long-term developmental effects of positioning device use. The presence of an immediate effect supports that continued exploration is warranted. Specifically, future research would involve measuring how the amount of positioning device use in the home relates to changes in leg movement and developmental progress over time. In this longitudinal design, we could also consider the effects of age on leg movement characteristics over time. It may also be useful to study the effects of specific devices during key developmental transitions, such as the jungle gym while learning to reach, or the bumby seat while learning to sit. Lastly, it would be important to systematically observe how positioning condition affects arm movements. It is hypothesized that the jungle gym would have an encouraging effect on infants' arm movements. These findings may impact physical therapy intervention practices by providing evidence-based recommendations for the use of different types of infant equipment.

Clinical significance

Because movement experience is a vital component of infant development, it is important to study elements in infant life that may hinder or enhance this experience. Our study found that when infants are positioned in a car seat, their leg movements are significantly reduced.

Although car seats are vital for vehicle safety, parents should be mindful in terms of the duration spent in these seats, especially outside of the car. While the threshold for any long-

term effects is unknown, for therapists who work with infants with the goal of getting them to move their legs more, it would likely be counterproductive for those infants to spend large amounts of time in a car seat.

Conclusion

The use of a car seat has an immediate constraining effect on infant leg movement characteristics (quantity and accelerations). Long term effects of constraining device use on infant development remain unknown.

Acknowledgments

Thank you to all the infants and their families for supporting this research.

Grant support: This study was supported by funding from the National Institutes of Health grant K12-HD055929 (PI: Ottenbacher) and the University of Southern California Undergraduate Research Associates Program and Provost's Undergraduate Research Fellowships.

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Figure 1.
(a) Wireless Opal sensors, (b) Infant wearing Wireless Opal sensors, positioned in supine without a device, (c) Infant positioned under the jungle gym, (d) Infant positioned in an infant car seat.

Figure 2.

Average number of leg movements (across right and left legs) produced in each condition in infants with typical development (TD) and infants at risk for developmental delay (AR). Error bars indicate 1 standard deviation. There was a significant condition effect; infants moved less in the car seat compared to supine or the gym.

Figure 3.

Average peak acceleration (across right and left legs) produced in each condition in infants with typical development (TD) and infants at risk for developmental delay (AR). Error bars indicate 1 standard deviation. There was a significant condition effect; infants had lower average peak acceleration values in the car seat compared to supine or the gym.

Figure 4.

Average peak rotation (across right and left legs) produced in each condition in infants with typical development (TD) and infants at risk for developmental delay (AR). Error bars indicate 1 standard deviation. There was no significant condition effect.

Table 1

Participant descriptive characteristics

Infant	Group	Risk Summary	Chronological age (days)	Corrected age (days)	Weight (kg)	Length (cm)	Head circumference (cm)	AIMS score (points)
1	AR1	preterm, 3 m in NICU	295	175	7.8	66.0	40.6	21
2	AR2	preterm, 2.5 m in NICU	273	176	5.6	62.0	40.0	26
3	AR3	preterm, intrauterine growth restriction	211	147	5.2	59.0	40.0	17
4	AR4	preterm, on oxygen (nasal canula)	258	168	7.1	71.1	42.0	21
5	AR5	preterm, hypoplastic left heart syndrome	79	49	2.7	52.0	33.4	6
6	AR6	brain damage noted due to lack of oxygen	97	n/a	6.4	61.0	40.0	11
7	AR7	brain damage noted due to lack of oxygen	102	n/a	6.4	62.5	40.0	9
8	AR8	preterm, 3 m in NICU	125	33	4.2	51.5	36.2	9
9	AR9	preterm, cardiac defect	196	88	5.4	59.0	40.0	11
10	AR10	preterm, 3 m in NICU	305	208	7.6	72.2	44.2	17
11	AR11	preterm, on oxygen (nasal canula)	98	18	3.8	50.0	37.0	6
12	AR12	preterm, 2 m in NICU	139	59	5.9	61.0	41.0	6
13	AR13	preterm, 3 m in NICU, on oxygen (nasal canula)	149	73	5.0	54.0	37.5	8
		<i>Mean (standard deviation)</i>	<i>179 (81)</i>	<i>109 (67)</i>	<i>5.6 (1.5)</i>	<i>60.1 (7.0)</i>	<i>39.4 (2.8)</i>	<i>13 (7)</i>
14	TD1	n/a	118	n/a	8.3	63.5	44.4	20
15	TD2	n/a	150	n/a	7.6	70.5	43.8	22
16	TD3	n/a	148	n/a	7.6	63.5	41.0	21
17	TD4	n/a	150	n/a	7.2	62.2	40.5	26
18	TD5	n/a	162	n/a	6.9	62.5	41.5	22
19	TD6	n/a	60	n/a	4.2	55.9	38.6	9
20	TD7	n/a	93	n/a	6.8	60.8	41.2	10
21	TD8	n/a	60	n/a	5.7	58.0	40.0	12
22	TD9	n/a	200	n/a	8.4	71.1	45.5	34
23	TD10	n/a	66	n/a	5.8	57.0	39.0	6
24	TD11	n/a	153	n/a	7.3	61.0	41.0	20
25	TD12	n/a	168	n/a	7.8	69.0	42.2	30

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Infant	Group	Risk Summary	Chronological age (days)	Corrected age (days)	Weight (kg)	Length (cm)	Head circumference (cm)	AIMS score (points)
26	TD13	n/a	189	n/a	8.4	64.0	45.5	31
		Mean (standard deviation)	132.08 (48.18)	n/a	7.1 (1.2)	63.0 (4.8)	41.9 (2.3)	20 (9)

Abbreviations: AR, at-risk for developmental delay; TD, typically developing; AIMS, Alberta Infant Motor Scale; NICU, neonatal intensive care unit