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Determining if wearable sensors affect infant leg movement frequency: Brief Report

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Abstract

There is interest in using wearable sensors to measure infant leg movement patterns, however they were not developed for infant use and their presence may adversely affect infant movement production. Their weight may discourage leg movement production, or their presence may annoy an infant and encourage higher rates of leg movement production. Our purpose was to determine whether wearable sensors affected the frequency of infant leg movements produced. We included 10 infants with typical development and 10 infants at risk of developmental delay, between 2 and 10 months' chronological age. After collecting and analyzing video recordings of infants, we found a negligible difference between the numbers of spontaneous leg movements made while infants wore sensors, compared to without sensors. Wearable sensors have a negligible effect on the frequency of infant leg movement production, supporting their use in infant movement analysis.

Keywords

Infant; leg movement; wearable sensor; movement system

1. Introduction

Wearable sensor technology is a useful tool for studying movement, enabling full-day monitoring. There is interest in using wearable sensors to measure infant leg movement patterns; from our laboratory [1, 2] and others [3, 4, 5, 6]. While these sensors appear to

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Declaration of Interest

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have valuable application for infant neuromotor control research, they were not designed for infant use and their presence may influence infant movement production. Slight amounts of additional weight may impact infants' frequency of movement, since their limited muscle strength must also overcome their own body mass and gravity. In a previous study, it was found that while diapers alone did not alter infant stepping, the addition of electromyography sensors, reflective markers, and cotton tights significantly decreased step frequency [7]. Alternatively, it is possible that the presence of sensors may annoy an infant and encourage higher rates of leg movement production. Our purpose was to determine whether wearing sensors would affect the quantity of infants' leg movements, and if so, whether the effects would be different in infants with typical development (TD) compared to those at risk for developmental delay (AR).

2. Methods

This study included 20 infants total, from two groups: 10 infants with TD and 10 infants AR. Investigators were not blinded to group assignment. All infants were between the ages 2 and 10 months' chronological age, reflecting the general age of interest for studying infant leg movement. Inclusion and exclusion criteria for each group are described in detail in a previous publication [2] and descriptive characteristic of the sample are provided in Table 1.

This research was approved by the Institutional Review Board of the University of Southern California and a parent or legal guardian signed an informed consent form prior to participation. Infants were placed in the supine position (see Figure 1), and their spontaneous leg movements were video recorded at 30 frames per second in two experimental conditions for 4 minutes each, randomized in order: while wearing sensors (sensors) and without wearing sensors (no sensors). Visits were arranged to coincide with each infant's nap and feeding schedule in order to perform the assessment when the infant was in an alert, content, not hungry state. The assessment was conducted in the infant's typical, natural environment in a quiet space with typical amount of lighting. Caregivers were present throughout the assessment, and instructed that they could talk to, but not touch, their infant and that their behavior and the environment needed to stay consistent across the entirety of the assessment period.

We used Opal sensors as they weigh 22 g each. Other commercially available and commonly used sensors are the Actigraph wGT3X+ (19 g) or GT9X (14 g) or the Actical (16 g). Sensors were attached using custom leg warmers with a sensor-sized internal pocket. The pocket assured a snug, yet comfortable, fit with fabric between the sensor and the skin (see Figure 1). Trained behavior coders analyzed video data frame by frame in order to determine the number of left and right leg movements produced. A movement was identified as a change in location of the leg that was visually observable in real time on the video, and then frame-by-frame analysis was used to identify the start and stop of each movement. All behavior coders reached 80% reliability before coding, consistent with previous infant leg movement coding research [8].

3. Results and Discussion

The numbers of right and left leg movements made by each infant, in each condition, are displayed in Table 2 and shown graphically as an average of the right and left leg movements in Figure 2. Additionally, Table 2 includes the group and total mean numbers of right and left leg movements for each of the infant groups.

Data were assessed for distribution using stem and leaf and boxplots, and normality was assessed by the Kolmogorov-Smirnov test. One data point in each group was an outlier (> 450). Sensitivity analyses removing these two data points was performed, though results did not vary from the complete data set, so all possible data points were used in these analyses. We used a longitudinal mixed model [9] to account for the repeated measures between legs and order of sensor wear in examining the effect of sensor versus no sensor. Models were run for both TD and AR combined, as well as stratified by group. Statistical tests were performed using SPSS software (Version 22, IBM Corporation, Armonk, NY, USA). Cohen's D for sensor were computed to indicate the size of the effect.

When groups were combined, the difference in sensor wear was non-existent adjusted for order ($M_{dif} \pm SD = 1.7 \pm 122.2$, $D = 0.01$). When stratified by group, the differences between conditions remained small (TD $M_{dif} = 10.2 \pm 56.2$, $D = 0.18$ and AR $M_{dif} = 24.6 \pm 58.1$, $D = 0.42$). The mean difference of 24 movements observed in the AR group is much smaller than the mean difference of approximately 150 movements we found in previous work when we observed that placing infants in a car seat significantly decreased the number of leg movements they made [2]. These results support that the presence of movement sensors on infants' ankles has a negligible effect on the frequency of infant leg movement production, supporting their use in infant movement analysis.

Limitations

Our small sample size was a limitation for testing hypotheses. We were not anticipating a difference in the conditions, so it was not a case where we could power the study based on the sample size necessary to detect a difference. We chose a representative sample of infants for whom sensor use in this way is of interest, and used a within-subjects design so that we were not comparing infants of different ages or abilities. It was expected that some infants would move more and some less with sensors on; our goal was to determine whether there was a large, systematic difference that would preclude the use of sensors to measure frequency of movement. We included effect sizes in our results, and found non-existent or small effects of sensor wear on leg movement. The amount of sensor weight necessary to impact frequency of leg movements remains untested.

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References

1. Smith BA, Trujillo-Priego IA, Lane CJ, Finley JM, Horak FB. Daily Quantity of Infant Leg Movement: Wearable Sensor Algorithm and Relationship to Walking Onset. *Sensors*. 2015; 15:19006–19020. [PubMed: 26247951]
2. Jiang C, de Armendi JT, Smith BA. Immediate Effect of Positioning Devices on Infant Leg Movement Characteristics. *Pediatric Physical Therapy*. 2016; 28:304–310. [PubMed: 27341579]
3. Abney DH, Warlaumont AS, Haussman A, Ross JM, Wallot S. Using nonlinear methods to quantify changes in infant limb movements and vocalizations. *Frontiers in Psychology*. 2014; 771:1–15.
4. Gravem D, Singh M, Chen C, et al. Assessment of Infant Movement With a Compact Wireless Accelerometer System. *Journal of Medical Devices*. 2012; 6:210131–7.
5. McKay SM, Angulo-Barroso RM. Longitudinal assessment of leg motor activity and sleep patterns in infants with and without Down syndrome. *Infant Behavior and Development*. 2006; 29:153–168. [PubMed: 17138271]
6. Singh M, Patterson DJ. Involuntary gesture recognition for predicting cerebral palsy in high-risk infants. *International Symposium on Wearable Computers*. 2010; 2010:1–8.
7. Groenen AATK, Kruijsen AJA, Mulvey GM, Ulrich BD. Constraints on early movement: Tykes, togs, and technology. *Infant Behavior and Development*. 2010; 33:16–22.
8. Angulo-Kinzler RM, Ulrich B, Thelen E. Three-month-old infants can select specific leg motor solutions. *Motor Control*. 2002:52–68. [PubMed: 11842270]
9. Krueger C, Tian L. A comparison of the general linear mixed model and repeated measures ANOVA using a dataset with multiple missing data points. *Biological Research for Nursing*. 2004 Oct; 6(2): 151–7. [PubMed: 15388912]

Figure 1. Infant wearing sensors

Three-month-old infant positioned in supine wearing sensors, and a close up image of Opal sensors (APDM, Inc. Portland, OR, USA) with a United States quarter included showing size to scale.

Figure 2. Average quantity of leg movements

For each infant, in each condition (sensors and no sensors), the number of right leg and left leg movements were used to calculate an average quantity of leg movements. Each marker represents an infant with or without sensors, and is plotted according to the infant's age in weeks (X-axis), and the average number of leg movements made (Y-axis). If applicable, corrected age was used. Infants with typical development (TD) are shown in blue and infants at risk for developmental delay (AR) are shown in green.

Table 1

Participant descriptive characteristics.

Infant	Risk Summary	Chronological age (days)	Corrected age (days)	Weight (kg)	Length (cm)	Head circumference (cm)	AIMS score (points)
AR1	preterm, 3 m in NICU	295	175	7.8	66	40.6	21
AR2	preterm, intrauterine growth restriction	211	147	5.2	59	40	17
AR3	preterm, on oxygen (nasal canula)	258	168	7.1	71.1	42	21
AR4	preterm, hypoplastic left heart syndrome	79	49	2.7	52	33.4	6
AR5	brain damage noted due to lack of oxygen	97	n/a	6.4	61	40	11
AR6	brain damage noted due to lack of oxygen	102	n/a	6.4	62.5	40	9
AR7	preterm, 3 m in NICU	125	33	4.2	51.5	36.2	9
AR8	preterm, cardiac defect	196	88	5.4	59	40	11
AR9	preterm, on oxygen (nasal canula)	98	18	3.8	50	37	6
AR10	preterm, 3 m in NICU, on oxygen (nasal canula)	149	73	5	54	37.5	8
<i>Mean (standard deviation)</i>		<i>161 (75)</i>	<i>94 (67)</i>	<i>5.4 (1.6)</i>	<i>58.6 (6.8)</i>	<i>38.7 (2.6)</i>	<i>12 (6)</i>
TD1	typical development	118	n/a	8.3	63.5	44.4	20
TD2	typical development	150	n/a	7.6	70.5	43.8	22
TD3	typical development	148	n/a	7.6	63.5	41	21
TD4	typical development	150	n/a	7.2	62.2	40.5	26
TD5	typical development	162	n/a	6.9	62.5	41.5	22
TD6	typical development	60	n/a	4.2	55.9	38.6	9
TD7	typical development	93	n/a	6.8	60.8	41.2	10
TD8	typical development	200	n/a	8.4	71.1	45.5	34
TD9	typical development	66	n/a	5.8	57	39	6
TD10	typical development	153	n/a	7.3	61	41	20
<i>Mean (standard deviation)</i>		<i>130 (44)</i>	<i>n/a</i>	<i>7.0 (1.2)</i>	<i>62.8 (4.9)</i>	<i>41.7 (2.3)</i>	<i>19 (8)</i>

Abbreviations: AIMS, Alberta Infant Motor Scale; NICU, neonatal intensive care unit

Table 2
Quantity of leg movements made

The number of left and right leg movements made by infant, condition, and group (at risk (AR) and typical development (TD)).

Infant	Left leg (# of movements)		Right leg (# of movements)	
	Sensors	No Sensors	Sensors	No Sensors
AR1	492	164	420	223
AR2	75	214	81	199
AR3	189	283	202	306
AR4	145	156	169	199
AR5	244	250	254	224
AR6	371	308	355	250
AR7	352	242	251	257
AR8	247	122	296	154
AR9	151	159	172	162
AR10	157	231	201	241
<i>AR Group Mean (standard deviation)</i>	<i>242 (128)</i>	<i>213 (61)</i>	<i>240 (98)</i>	<i>222 (46)</i>
TD1	73	81	60	85
TD2	210	215	187	127
TD3	217	144	256	149
TD4	202	330	204	471
TD5	185	220	240	220
TD6	224	228	159	170
TD7	217	246	251	253
TD8	221	354	218	256
TD9	259	134	259	103
TD10	167	166	256	209
<i>TD Group Mean (standard deviation)</i>	<i>198 (50)</i>	<i>212 (85)</i>	<i>209 (62)</i>	<i>204 (111)</i>
Total Mean (standard deviation)	220 (97)	212 (72)	225 (82)	213 (83)