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“Constraints on Early Movement: Tykes, Togs, & Technology”

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Constraints on Early Movement: Tykes, Togs, & Technology

Examining the effects of diapers and other external constraints on infants' leg movements may affect how we collect motor control research data, dress infants to allow optimal movement in the home, and administer therapeutic interventions for infants with motor impairments. To address this issue we supported 12 healthy infants (2-4 months) on an infant-sized treadmill in each of 4 conditions: wearing nothing (None), a swim diaper (Swim), a disposable diaper (Diaper), or a combination of diaper and research recording equipment (All). We recorded the trials with a digital video camera and behavior coded number of steps and step type (alternating, parallel, double, or single steps) to assess both quantity and quality of movements. Infants produced similar numbers of steps in a predominantly alternating step pattern (high quality) during the None, Swim and Diaper conditions, but both quantity and quality of stepping decreased in the All condition. Our results suggest that diapers alone do not alter stepping patterns significantly, but sufficient additional weight and clothing beyond the diaper can affect movement frequency and quality in young infants.

Everyone who has worn tight, uncomfortable clothing can attest to how these items affect both movement amplitude and willingness to produce some types of actions. Popular magazines contain numerous articles on how to select clothing that will allow comfortable movement (Meyer, 1997), wick away sweat from the body during exercise (Olsson, 1998), improve sport performance (O'Driscoll, 2008), assist in weight loss (Enamait, 2008; Johnson, 2005) or protect from the elements (Beers, 2006; Thein, 1995). Despite the wealth of informal observations, scientific publications on how clothing constrains movement in adults are sparse, and in infants nonexistent. Researchers have investigated how clothing constrains movement only in cases of specialized clothing for the military or fire fighting, where limitations on movement cost lives (Malley et al., 1999; Patton, Bidwell, Murphy, Mello, & Harp, 1995). Infancy is another crucial time when bulky clothes and diapers could constrain movement enough to delay exploration and performance of nascent motor skills.

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Advertisers of disposable diapers claim that their brand reduces bulk around the legs so infants can crawl or walk better than in competitors' styles, but research either has not been conducted or is not publicly available. Advancements in diaper technology, including contouring and development of absorbent materials have reduced the bulk around infants' hips and pelvis but diapers must also fit snugly around the hip joints and waist to prevent leaks and remain in place. The weight of clothing, stiffness of fabric, and tightness around the joint all represent external constraints that have the potential to alter infants' movement.

Young infants have internal constraints on their movement patterns, such as limited strength in leg muscles in comparison to their leg mass, as evidenced by developmental shifts in early stepping responses. At birth, infants easily produce stepping patterns when supported upright and moved forward over a firm surface. By four to six weeks of age this behavior becomes hard to elicit as infants increase fat mass. Slowly developing muscles must work hard to overcome both gravity and the weight of their own legs when held upright, especially. The stepping response disappears in this context most quickly in babies who gain weight most rapidly (Thelen, Fisher, & Ridley-Johnson, 1984). At a time when infants are struggling to move and learn to control their legs, the added bulk of clothing and diapers could make a crucial difference in their ability to respond in both a test setting and in spontaneous movement contexts.

Thelen, Ulrich, and colleagues (Thelen & Ulrich, 1991; Ulrich, Ulrich & Collier, 1992) have shown that supporting babies upright on mini treadmills can elicit steps, even when infants have difficulty responding to the newborn stepping paradigm. Further, the treadmill context has been used in a variety of infant research settings (Mussleman & Yang, 2007; Pang & Yang, 2000; Teulier, et al., 2009; Verijken & Thelen (1997) and in clinics and homes as a therapeutic intervention tool for infants and children with varied developmental disabilities (Angulo-Barroso, Tiernan, Chen, & Ulrich, in review; Bodkin, Baxter, & Heriza, 2003; Schindl, Forstner, Kern & Hesse, 2000; Ulrich, Ulrich, Angulo-Kinzler, & Yun, 2001; Wu, Looper, Ulrich, Ulrich, & Angulo-Barroso, 2007). Ongoing research focuses on methods to increase the effectiveness of treadmill therapy by modifying a variety of constraints such as belt speed, intensity of practice, enhanced sensory information, and so on. However, optimal clothing for eliciting treadmill behavior has not been studied empirically.

Our purpose here was to begin with four simple conditions to measure the impact of clothing and research materials on supported treadmill stepping behavior in young infants. We started with two relatively extreme opposites on the continuum from nothing to maximal: infants were simply naked or wore sets of typical motion capture equipment. In between we had two options of clothing that might be used clinically during therapy that minimize apparel yet protect from bowel and bladder leakage: disposable diaper and cloth swim diaper. While these conditions relate well to clinical and research settings the results may have implications for the amount of clothing parents put on young infants during times when they want to encourage infants' spontaneous efforts to explore and learn to control their leg movements.

We predicted that total steps produced would be highest when infants wore nothing, decreasing minimally with a swim diaper, a bit more with the disposable diaper, and significantly with full research equipment. None > Swim > Diaper > All. Further, we predicted that the quality of stepping would not be affected. Because constraints we imposed were distributed equally and bilaterally, only the total number of steps would be depressed.

Method

Participants

Twelve infants with typical development (4 at each age, two, three, four months) with no known cognitive or motor impairments participated in this study. One additional infant was tested whose data could not be included because he did not produce our requisite minimum number of steps: 10 total across all trials. We recruited infants by email, internet, flyers, and bulletin boards. Participant characteristics are described in Table 1. Before infants participated in the study, parents signed an informed consent form. Our study was approved by the Institutional Review Board of the University of Michigan.

Procedures

After families arrived at our laboratory and we allowed infants time to acclimate to the environment and lab personnel we prepared infants for testing. During test trials we held infants upright in a partial-weight-bearing posture so that their feet rested on the surface of an infant-sized treadmill (18cm x 42cm x 82cm, H,W,L). The treadmill was placed on a table (72cm x 116cm x 188cm, H,W,L) and belt speed was set at 0.16 m/s. We collected 2D data of leg movements with a digital video camera (60Hz) placed on the infant's right side, perpendicular to the treadmill at infants' knee height. Infants participated in eight 30-second test trials. They consisted of four conditions, each repeated twice, once in each of two sets. Order of presentation was randomized across infants and sets. We took breaks between trials as needed; generally time between trials was a few minutes only.

To prepare infants for testing we removed all of their clothing, including diapers then placed test trial materials on them, as needed. Our four test conditions consisted of:

1. no additions (no clothing/diaper and no recording equipment) (None)
2. swim diaper only (Swim)
3. disposable diaper only (Diaper)
4. disposable diaper, movement recording equipment, and tights (All) (see Figure 1). Condition 1 was included to allow infants maximum freedom of movement. Conditions 2 and 3 were created to avoid the need to stop eliciting supported stepping when infants void bladder or bowels yet minimize the bulkiness/potential disruption of infants' freedom to move. Swim diapers are thinner than disposable diapers but have similar overall weight. Disposable diapers were selected from among commercially available brands to be of minimal thickness and latex-free. Condition 4 represented equipment that is commonly used to measure limb motion in humans, including infants. We placed pediatric surface electromyography (EMG) sensors, bilaterally, over the muscle bellies of tibialis anterior, gastrocnemius, quadriceps and hamstrings on each leg. The ground was placed on infants' lower spine. Reflective markers (2 cm diameter) were placed on the right leg at the iliac crest, greater trochanter, knee joint, lateral malleolus, and third metatarsophalangeal joint. We placed cotton tights with holes cut out for reflective markers over infants legs to reduce EMG cable movement. EMG and joint marker data were not collected in this study.

Subsequent to testing infants in all treadmill conditions we collected their anthropometric data. We assessed total body weight and length (crown to heel), thigh length (greater trochanter to lateral femoral condyle), shank length (femoral condyle to lateral malleolus). We measured thigh and shank circumferences at the midpoint of length. We administered the motor subsection items of the Bayley Scale of Infant Development (BSID-III) to create a total raw score for number of motor skills the infant was able to perform at that point in development. Total testing time was approximately one hour, including the time to prepare the infant and to

collect data. Parents were given a small amount of money for enabling their infant to participate in this study.

Data Reduction

To determine the occurrence and type of steps, we examined the videos frame-by-frame (60 Hz) using the Peak Motus (Peak Performance Technologies Inc., Centennial, CO) software. We classified each step as one of four types: alternating (step initiated within 20-80% of a step cycle of the opposite leg), parallel (steps initiated before 20% or after 80% of a step cycle on the opposite leg), double (within a sequence of alternating steps a second or extra step was produced by one leg without a concomitant second step by the other leg) and single (step produced by one leg without a step cycle on the other leg that overlapped it in time). Before coders (authors AG, AK) could begin to reduce the data they received significant training and obtained a coefficient of agreement of 0.85 (interobserver reliability coefficient, Kappa), based on a comparison of practice test trials with work of previously validated coded data. Each coder separately viewed all participants' trials and recorded the events observed. Data were then compared; wherever a discrepancy was identified a third, senior staff member was asked to view the tape and make final determination.

Data Analyses

For each infant we calculated a.) the number of steps taken per second and b.) the number of alternating, single, parallel, and double steps per second, within each trial, as our dependent variables. We used SAS (v.9) for all statistical analyses with the criterion for significance set at $p < .05$. When post-hoc pair-wise comparisons were necessary, we used the Bonferroni correction.

Results

Relation Between Age and Steps Taken

In this study we chose to work with very young infants (two- to four-months old), when, based on previous research, the likelihood was high that a ceiling affect would not be evident and that a variety of step patterns would emerge. To confirm that our sample reflected the normal response of infants at this point in developmental time we plotted number of steps produced by age in days. While variability in performance was high, as expected, Figure 2 shows also the anticipated significant nonlinear trend we observed (curve estimation indicated a significant quadratic pattern, $p = .025$) which parallels that found by Thelen and Ulrich (1991).

Order Effects

To determine if there were order effects within or between sets of trials we conducted a $2 \text{ (set)} \times 4 \text{ (order)}$ ANOVA with repeated measures on both main effects. Average number of steps taken per second was the dependent variable. We found no effect of order within a set but the set effect reached significance, $F(1,77) = 14.61, p < .001$. Infants produced more steps in the second set than in the first set. The set by order interaction was not significant.

Effects of External Constraints on Step Quantity

We used a one-way ANOVA with repeated measures to test the effect of condition on number of steps generated per second. The condition effect was significant, $F(3, 33) = 4.01, p = .016$. Post hoc tests indicated that infants produced more steps in the None condition compare to the All condition ($p = .029$). There were statistical trends toward infants stepping more in both the Diaper ($p = .055$) and Swim ($p = .074$) conditions compared to the All condition, as illustrated in Figure 3.

Effects of External Constraints on Step Type

We conducted a 4 (condition) $\times$ 4 (step type) ANOVA with repeated measures on condition and average number of steps taken per second as the dependent variable. There was a significant condition effect, $F(2, 86) = 3.83$, $p = .026$, a significant step type effect, $F(3, 44) = 18.925$, $p < .000$ and a significant interaction between condition and step type, $F(6, 86) = 3.09$, $p = .009$. Post-hoc analysis of the condition by step-type interaction indicated that only the average number of alternating steps taken per second varied significantly over the four conditions, as shown in Figure 4. In fact, during the All condition, of all steps produced, a smaller proportion of them were alternating than in the other three conditions (None, $p < .000$, Swim $p = .016$, Diaper $p = .002$). The other step types, parallel, single, and double, varied to smaller degrees across conditions.

Discussion

Our results show that during the first few months post birth, when infants' muscles are still very weak, the materials placed on their legs that may seem not to inhibit their leg movements, can indeed change both the quantity and quality of their actions. Contrary to our predictions, disposable diapers and swim diapers alone did not significantly reduce the number of steps young healthy infants generated in this context. However, diapers in combination with recording equipment and tights significantly depressed both the step frequency and the proportion of all steps produced that were alternating.

Overall, the alternating step type was the dominant pattern of interlimb coordination demonstrated in all of our conditions, which is consistent with the performance of infants with typical development in other studies (Thelen & Ulrich, 1991; Teulier et al., 2009). Although it is the most desirable stepping pattern for therapeutic intervention purposes, due to its functional link to walking, alternating steps were particularly sensitive to external constraints. For infants with developmental disabilities, alternating stepping is not initially the dominant pattern (Ulrich, Ulrich, Collier, & Cole, 1995; Teulier et al., 2009) and thus, the potential impact on their behaviors is particularly important to recognize. Perhaps alternation is affected more easily than other steps because it involves the most complex of the interlimb patterns, involving each limb to be adaptive and complementary to the behavior occurring on the other side of the body. Each limb must be responsive over time to the activity of the other. Single steps may emerge instead of alternating, for example, when the normal motion or information flow from one leg is constrained in a way that disrupts the natural interlimb coupling. In parallel stepping the limb activity is yoked at the initiation of the swing phase, with legs lifting off in unison but completion of the cycle may be less tightly constrained.

Based on this study we cannot identify which of the features of the all condition could have been placed on our young infants without affecting significantly their leg movements. Limits on infants' patience and endurance precluded us from testing all the possible conditions of clothing and recording equipment. But, was there a tipping point? Anecdotally, we observed less spontaneous leg kicks when infants were supine as we prepared them for test trials, after we placed tights over the other items (diaper, reflective markers, EMG electrodes). Perhaps the knit fabric created an extensor tendency across their small joints that inhibited, to some extent, their inclination to overcome this extensor dominance and flex, or step. A variety of combinations of equipment, diapers, and tights could be designed to test the exact cause of this overall effect. At this point we recommend using the necessary but least amount possible of clothing and technology attached to young infants' legs when the goal is to examine leg movement patterns, particularly in infants with developmental disabilities. Further, we recommend pilot testing the impact on target behaviors of test apparatus to either modify or at least acknowledge the impact.

Our finding of a quadratic relationship between age and the average number of steps taken per second is consistent with early research on treadmill stepping in healthy infants, in which early post-birth treadmill stepping decreases within a month or two, followed within a few weeks by an increase that continues over the next several months (Thelen & Ulrich, 1991). The finding of a set effect, however, is not consistent with prior treadmill research (e.g., Ulrich, Ulrich, & Collier, 1992; Vereijken & Thelen, 1997). Although a learning effect is a tempting explanation, it is hard to support given that other studies have not found significant differences in infants' performance across sets of test trials. One possibility is that this occurred because infants' attention was drawn to the voices of the testers supporting them (AK & AG), for whom English is not their native language; all of our participants lived in households where English was the only language spoken. We have noticed in our lab over the years that infants tend to be particularly attentive to lab group members who speak or sing to them in their native, non-English language. These differences could have caused some attentional focus early, leading to slight reduction in overall leg activity that faded by the second set, resulting in a small increase in stepping movements compared to early trials.

To summarize, for the purpose of research, we encourage pilot testing of clothing and materials infants wear for ways it may change behavior compared to infants' unfettered leg activity. This is particularly encouraged when participants are very young and/or have conditions that significantly reduce their leg muscle strength and joint control. For purposes of treadmill interventions, parents or therapists can safely clothe infants in disposable diapers without reducing the effectiveness of treatment. We found both diaper conditions (disposable and swim) provided excellent protection from bladder and bowel excretions without interfering with leg movements. Performance with tights on, however, suggests that additional clothing that may be restrictive, particularly of joint movements, could reduce the effectiveness of practice. When dressing young infants, especially those with sensorimotor impairments, caregivers may want to consider the constraints they could be adding on movement. Bundling up children in the winter is often necessary to shield them from the cold, but layers of thick garments can reduce activity level as well. When infants are placed in commercially available infant seats leg and trunk movements are also significantly constrained; in most western countries, at least, infants spend copious amounts of time each day strapped into such equipment (Chapman, 2002). Care should also be given to preserve periods of time during the day in which infants are placed in contexts that best facilitate their spontaneous movement exploration and development of leg strength and control.

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Figure 1. Four conditions in which amount of clothing and, or motion-capture equipment was varied during elicitation of supported treadmill stepping: a.) *None*, b.) *Swim* diaper, c.) disposable *Diaper*, d.) *All-* disposable diaper plus reflective markers, EMG sensors, and cotton tights.

Figure 2.

Scatter plot showing infants' age in days as a function of the average number of steps they took per second. The post-hoc curve estimation indicated a significant quadratic relationship between age and steps.

Figure 3.
Average number of steps taken per second, by condition.

Figure 4.

Proportions of total steps taken that were of each of the four step types produced, by condition. (SING=Single, DBL=Double, PARA=Parallel, ALT=alternating)

Table 1

Participants Characteristics

Variable	Group 1	Group 2	Group 3	Total/Mean
Gender				
Male	3	1	2	6
Female	1	3	2	6
Age (days)	68.5 ± 9.7 ^{a/b}	99.5 ± 11.0 ^{a/b}	134.8 ± 8.7 ^{a/b}	100.9 ± 29.6
Weight (kg)	5.6 ± 0.2	5.0 ± 1.5	6.6 ± 0.4	5.7 ± 1.1
Length (cm)	59.2 ± 1.4 ^{a/b}	60.2 ± 2.2	63.6 ± 2.4 ^{a/b}	61.0 ± 2.7
Right leg (cm)				
Total Leg Length	21.0 ± 1.6 ^{a/b}	21.1 ± 1.7	25.0 ± 3.0 ^{a/b}	22.4 ± 2.7
Thigh Circumference	20.4 ± 0.6	19.9 ± 1.7	22.2 ± 3.1	20.8 ± 2.1
Shank Length	11.2 ± 0.8 ^{a/b}	11.4 ± 0.6	12.5 ± 0.2 ^{a/b}	11.7 ± 0.8
Shank Circumference	14.9 ± 0.4 ^{a/b}	15.1 ± 0.6 ^{a/b}	16.4 ± 0.9 ^{a/b, a/b}	15.5 ± 0.9
BSID-III ^I Motor Items	17.5 ± 3.1 ^{a/b}	20.3 ± 6.8	30.8 ± 6.4 ^{a/b}	22.8 ± 7.8

^{a/b} One way ANOVA, significant difference between groups, $p < .05$,

^I BSID-III; Bayley Scale Infant Development, Motor Items Raw Score Total-Means