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Parent handling of typical infants varies segmentally across development of postural control

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Abstract

Although trunk muscles extend across multiple vertebral joints, recent motor control studies have shown that a **top-down** progression of trunk control in typical infants occurs incrementally, one segment at a time, until independent sitting. The current study merges this surprising developmental pattern with parent behavior by exploring the relationship between how parents hold their infant and the segmental level for which the infant exhibits postural control. We measured trunk control of sixty infants (1–8 months) via the Segmental Assessment of Trunk Control. Spontaneous parental hold and variability was recorded during repeated sitting and standing conditions. Parent hold correlated with infant level of control in both sitting and standing, providing evidence for a positive interaction between parent behavior and segmental trunk development.

Keywords

Trunk control; Development; Parent handling; SATCo

INTRODUCTION

The development of postural control is a complex motor skill that creates the foundation for functional movement and requires dynamic stabilization of all linked segments of the body (Harbourne et al. 1993). It is widely acknowledged that segmental acquisition of postural control is a result of neural maturation, sensorimotor integration, and environmental constraints (Shumway-Cook and Woollacott 2012). Infants first gain control of the head at approximately 3 months and then independent sitting at 7–9 months (Shumway-Cook and Woollacott 2012). However, between these milestones, infants progress incrementally from

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establishing head control against gravity to then controlling upper, mid and lower thoracic regions, and finally upper and lower lumbar regions prior to full trunk control and independent sitting (Rachwani et al. 2013; Saavedra et al. 2012). It is unknown why there is such a clear incremental progression when most trunk muscles extend across multiple joints. Our knowledge is partially limited because historically clinical measures have not considered the incremental development but have instead viewed trunk control as “all or nothing” (i.e., with independent sitting or not). Understanding the incremental progression is important because it is often disrupted during atypical development, resulting in deficits in segmental trunk control that may manifest profound impairments in gross motor function (Curtis et al. 2014; Saavedra and Woollacott 2015; Santamaria et al. 2016). Moreover, a better understanding of the incremental progression may reveal important insights into typical and atypical motor learning of posture.

It is currently unknown whether parents contribute to this segmental progression by intuitively adjusting their handling as their infant progressively exhibits posture control over more segments of the trunk. Few investigators merge the study of parent behavior with the developing infant’s motor control (Ishak et al. 2007; Karasik et al. 2008; Karasik et al. 2014). Understanding parent behavior, and their interaction with their infant, during posture development is important because caregivers have a major influence over infants’ motor development (Jeglinsky et al. 2012; Ostensjo et al. 2005; Strube et al. 2016). Thelen proposed that infant postural development is a complex interaction between “internal genetic predisposition, external environment, and the motor skill to be performed”(Thelen 2005). Caregivers have a major influence on creating the external environment and positioning infants to perform motor skills. For example, it is documented that providing support higher or lower on the trunk influences motor skill performance, such as reaching, in infants (Rachwani et al. 2013; Rachwani et al. 2015) and children with cerebral palsy (Santamaria et al. 2016). If parents anticipate developmental changes in their infant (Jeglinsky et al. 2010), they may adjust their environment accordingly for progressive opportunities for motor skills. When the infant achieves control in a given segment, progression may then move to more sophisticated balance activities such as: reaching, grasping toys, propped sitting, independent sitting, hands-and knee crawling, and independent standing (Shumway-Cook and Woollacott 2012).

While studies have viewed the influence of environmental factors such as anthropometrics, socioeconomic status, ethnicity, and child rearing practices on the rate of development of independent sitting (Ahl et al. 2005; Effgen 2012; Jeglinsky et al. 2010), no study has considered these influences on a segmental acquisition of upright posture in supported sitting and standing. The current paper considers infants ages 1–8 months in order to examine the full range in which postural control develops including head control through full trunk control.

The objective of the present study is to quantitatively determine parental sensitivity to the infant’s segmental level of trunk control by answering the following questions: (1) Do parents adjust their position of holding according to the infant’s level of trunk control? 2) Does parent handling differ when supporting the infant in sitting versus standing? 3) Is variability in parent handling related to nuances in the infant’s development of trunk

control? 4) Is the proximity of parent hold to infant's segmental level of control associated with the infant's general level of motor skill development?

METHODS/MATERIALS

Study Overview and Participant Pool

A cross-sectional study design was selected to measure tendencies of parents of typically developing infants in providing support during sitting and standing. Sixty infants, 1 to 8 months of age were included (Table 1). Inclusion criteria were (1) born between 37 and 40 weeks gestation and (2) absence of genetic, sensory or motor deficits. Infants were recruited using flyer distribution, direct advertising and social outreach. The Human Subjects Committee at University of Hartford approved all testing, recruitment, and informed consent. One parent signed the informed consent before data collection began.

Procedures

All data was collected in a single session lasting about 45 minutes. Video was recorded from two cameras throughout the session. Three assessments were performed in the following order: 1) Parent Hold test (PH), wherein the level of parent hold was measured 2) Alberta Infant Motor Scales (AIMS)(Piper et al. 1992) to assure that the infant was typically developing and to relate parental support to general motor skill achievement, 3) Segmental Assessment of Trunk Control (SATCo) wherein the level of trunk control of the child was measured. All testing was completed on a custom designed 3 foot by 3 foot padded table, with safety rails on three sides (Figure 1 B, D). The height of the table was 38 inches however this could be adjusted to 28 inches if needed to suit the parent's height. This allowed the researchers and parents to stand comfortably around the infant while completing anthropometric measurements (length, weight, head circumference), AIMS, PH measures, and SATCo. Each data collection consisted of the PI (Saavedra) and 2–3 research assistants.

Parent Hold Procedure

In this test, we measured where parents provided trunk support to their infant, termed "PH". This test measured the behavior of both mothers and fathers; however, the majority of parents were mothers (Table 2). In all trials, parents supported their infant on the customized table (Figure 1B). During a visual choice task, one research assistant was assigned to quietly observe and record parent hold while the other researchers engaged with the infant and parent to complete the visual choice task. For visual choice tasks, two iPads were set vertically on stands that were placed within the infant's visual field, with the height adjusted to be at approximately eye level of the infant. The tablets were placed in front of the infant about 24 inches away; the tablets displayed visual images and music designed to be engaging to young infants. While the nature of the pattern display was selected from a bank of media, the same 6 patterns were randomly presented during each infant's sitting and standing trials. Parents were asked to perform one sitting and one standing visual choice task interspersed in the data collection procedures. Parent hold was measured within the following sequence: Anthropometrics→1st set of visual choice tasks/Parent Hold (sit, & stand)→ AIMS→ 2nd set of visual choice tasks/Parent Hold (sit & stand)→ SATCo→ 3rd set of visual choice tasks/Parent Hold (sit & stand). Thus parents repositioned their infant

after each task because the conditions alternated between sitting and standing and other data collection procedures. For each parent, there were three PH values collected for sitting and three PH values for standing. Ipads were adjusted to be at eye level for both sitting and standing trials.

During each 30-second trial, the level of trunk support provided by the parent was recorded with video cameras. Parents were simply instructed to support their child while the child participated in the six visual choice tasks. The parent was informed that the infant would choose between visual stimuli deemed most appealing (i.e. static vs dynamic, sounds vs no sound, black and white vs color images). We performed each set of visual choices once during sitting and once during standing. Each parent was informed when to hold the infant in a standing position versus a sitting position (Duncan 2015). During this test, one camera was placed in front of the infant on a tripod, allowing video providing an anterior view of parent hand placements; another camera was positioned to the right and behind the infant on a tripod to view parent support from behind (Figure 2).

Parent Hold Variables

PH values were expressed using discrete trunk levels defined in the SATCo. Infant level of control (InfC) was determined based on SATCo testing (see next section for details). Thus, InfC and PH both had SATCo units; this allowed the InfC score to be compared directly to PH. In most instances, parents provided support that clearly and consistently corresponded to a SATCo level (0 – 7, Figure 1C) throughout the 30-second trial and were scored accordingly. However, for those cases where parent hold could not be identified as clearly and consistently corresponding to a single SATCo level, we created an additional set of rules for determining the most appropriate PH score. Additional rules were as follows: (1) a score of 0 was given when the infant was supported fully against parent with head leaning against parent, (2) if the parent changed their level of support during the 30 second trial, the score was set to the lowest level of support, i.e. that level which corresponded to the most developmentally advanced, (3) parents who supported their infant with their thumbs pointed up, were scored at the level correlating to thumb position, and finally (4) no score was given if parents provided assistance holding infant's hands without any support directly to the trunk because hand support has no clear equivalent SATCo level. The PH score was discreetly recorded in real-time during data collection by a research assistant; all scores were quality-checked through independent review of videos by two trained raters who assessed each PH video independently; scoring discrepancies between live and video were resolved through discussion and tandem viewing. Reliability testing was done by comparing scores given during the data collection with those from video review. Sitting and standing conditions were observed to have high (ICC(3,1)=0.90) and moderate (ICC(3,1)=0.75) intraclass correlation scores, respectively; we note that while there was high concordance between live data collection and video review in sit (average absolute difference between raters = 0.65 ± 0.77 SATCo levels, P not less than 0.05 in a Welch two-sample t-test), there was greater disparity between raters in stand: 0.76 ± 0.74 SATCo levels, $P < 0.01$).

AIMS Procedures and Variables

The Alberta Infant Motor Scales (AIMS) was completed for each infant. This is a normalized test of gross motor ability in which the infant's movements are observed when placed in prone, supine, supported sitting, and supported standing (Piper et al 1992). The infant's movements were observed while being enticed with toys by the examiner. The infant is then given a total score and a percentile rank of gross motor function.

Segmental Assessment of Trunk Control Procedures

The SATCo provides a simple, non-invasive method to understand the subtleties of postural development. This assessment measures incremental levels of trunk control prior to development of independent sitting (Butler et al. 2010). This assessment has been validated longitudinally in typically developing infants, ages 3–9 months as well as children with motor disability (Butler et al. 2010). It has also been studied with kinematics of the trunk in infants 2.5–8 months of age (Rachwani et al. 2013; Rachwani et al. 2015; Saavedra et al. 2012) and in children with cerebral palsy 2–17 years of age (Curtis et al. 2016; Saavedra and Woollacott 2015; Santamaria et al. 2016). To measure the SATCo, infants were positioned on a small bench with pelvis maintained in a vertical position using a Velcro strapping system to stabilize the pelvis (Butler et al 2010). The SATCo bench was placed on the customized table during testing (Figure 1d). Seven levels of control were tested (Figure 1). At each segmental level, the infant is given a score indicating static, active, and reactive control. Static control is credited if the infant is able to maintain a neutral trunk posture at the level of support given by the researcher. Active control is awarded as the ability to maintain a neutral posture while the infant is encouraged to turn the head. Finally, reactive control is credited if the infant is able to maintain a neutral postural alignment during a brief external perturbation given by the researcher. Testing proceeds in a cephalocaudal direction until the infant has demonstrated a loss of control in each subdomain (static, active, and reactive) (Butler et al. 2010).

Segmental Assessment of Trunk Control Variables

The average sub-domain score for each infant is denoted as "InfC". This represents the infant's level of control. During SATCo testing, one camera was positioned directly laterally and one camera at 45 degrees from anterior to the baby on tripods allowing us to see changes in trunk control in the sagittal and frontal planes; a third camera was positioned on the ceiling above the infant, at midline of infant's head to record forward, backward and lateral lean.

The SATCo score was measured in real-time during data collection by an experienced investigator trained in the SATCo scoring method; all scores were quality-checked through independent review of videos by a trained infant SATCo rater post facto. Research assistants during one academic year collected data, while a research assistant from another academic year did video review for objectivity. All research assistants were required to pass SATCo reliability testing (ICC= 0.8 or higher) before participating in data collection or video review. The PI and each researcher present during data collection discussed the infant's performance during the assessment and arrived at a consensus for each subdomain. Scores were confirmed by video review. Any scores deemed questionable by the rater following the

video review were resolved through discussion between research assistants and the principal investigator. The SATCo scorer was blinded to the parent hold scores. Reliability testing was done by comparing scores given during the data collection with those from video review. The ICC between scores obtained during live data collection and video review was 0.93 for static, 0.94 for active and 0.95 for reactive.

Statistics are described and embedded within the results.

RESULTS

In 8% of sitting trials (14/180) and 10% of standing trials (19/180), parent support was given in a place other than the trunk. These trials were unscored and excluded from the analysis stream. The remaining 91% of trials (327/360) were retained for analysis. In all analyses, PH – InfC data could be modeled as a normal distribution: Shapiro-Wilk test, $p > 0.05$ in three analyses: sit-, stand-, and pooled-data. A direct comparison of PH- InfC in sit versus stand revealed similar distributive properties (Kolmogorov-Smirnov test: $p > 0.05$). In all analyses, outlier data points (defined as >3 standard deviations beyond the mean) were removed from the analysis. In all analyses, a $p < .05$ was considered significant.

Relationship between parent hold and infant trunk control

PH levels were significantly correlated to infant control level (InfC) in both sitting ($R^2=0.48$, $P < .001$, Fig 2A) and standing ($R^2=0.20$, $P < 0.01$, Fig 2B). However, as infants gained more control over their trunk, parents had a tendency to hold their infant at lower positions on the trunk. We note in particular that while the trend was less robust in stand, parents were observed to over-support infants with more advanced trunk control (SATCo > 4) and under-support infants with less trunk control (SATCo < 4).

To fully describe the nature of the relationship between parent hold and infant control level, both signed, and unsigned (absolute values) were used to assess PH and InfC; statistical significance in differences between PH and InfC were tested via paired t-tests. We note that the use of a signed analysis (PH – InfC) provides a useful population average, but whereas a balance between over- and under-supporting parents could yield a population average near zero, absolute differences ($|PH - InfC|$) were also calculated in parallel. Positive proximity (PH-InfC) values indicate the parent under-supported while negative proximity (PH-InfC) values indicate over-support. Proximity differed significantly between sit and stand ($P < 0.001$, Fig 2C). Parents over-supported more in standing (-1.2 ± 1.8) compared to sitting (PH – InfC = -0.2 ± 1.7 , Figure 2c).

We investigated whether there was a correlation between the child's level of control and whether the parents under or over supported. In sitting, parent under or over support was weakly influenced by the infant's level of control, though statistical significance was observed (Figure 3A, $R^2=0.12$, $p=0.01$). In contrast, the correlation between parent over-support and the infant's control level in the stand condition was particularly high (Fig 3B, $R^2=0.70$, $p < 0.001$).

Parent Hold variability

Next, we examined if parents varied their holds and the extent of this variation. We observed that 33% in sit, and 45% in stand yielded zero variance. These parents supported their child at a consistent level across all observations. For the infants whose parents varied their hold across trials (33 for sit, 27 for stand), a Wilcoxon rank sum test was chosen to test the variance in sit and stand conditions; significance was measured in a one-tailed test with $\alpha = 0.05$. PH variance was significantly greater than zero in both conditions (0.5 ± 0.8 in sit, $P < 0.001$, Fig 3C; and 0.3 ± 0.3 in stand, $P < 0.001$, Fig 3D); the PH variance in stand was smaller than the PH variance in sit ($P < 0.05$). There was no relationship between variance in parent hold and InfC level in either sit or stand (Figure 3C–D, $R^2 = 0.05, 0.08$, $p > 0.05$). Thus, parents' variability in providing support was not associated with the infants' level of trunk control. An ordering effect was not shown across three replications (one-way ANOVA, $P > 0.05$ in either Sit or Stand), that is, the order of PH trials did not influence PH scores.

Variability in infant control

Variability in SATCo is related to the sub-domains (static, active, reactive). In typical infants, trunk control usually emerges first with static control followed by active or reactive control. We found that 64% of infants in this study lost control for all 3 subdomains at the same segment, while others demonstrated loss of control across different segments. We expected that a parent whose infant demonstrated subdomains of control across more than one segment might be more ambiguous in their hold compared to a parent whose infant lost control of all subdomains in the same segment. We speculated that parent hold behavior (PH –InfC and variance in PH), might be influenced by heterogeneity between the SATCo subdomains. We postulated that in infants whose sub-domain scores were equal (and thus their variance zero), parent hold proximity might be more conformant to the measured control level and parent hold would be less variable. For these purposes, we used a one-way ANOVA against a two-level categorical variable: infants with zero- versus non-zero SATCo variance. In contrast to our expectation, we found that proximity (PH-InfC) (Figure 4 A–B) and PH variability (Figure 4C–D) were very similar between infants with and without variability in their SATCo.

Relationship between PH and AIMS

The infants in this study ranged between 10th and 90th percentile in gross motor function, classified by the AIMS. In our analysis we opted to use AIMS percentile scores, rather than total scores, as AIMS total scores are highly correlated with age. AIMS percentiles scores are calculated based on normalized standards by age in typically developing infants. We used a Chi Square test to determine if there was a bias in parent under- or over-support when infants were above and below the 50th percentile of gross motor function (AIMS). We did not observe a significant systematic association between AIMS score and parent support level in either condition ($p = .49$ sit, $p = .26$ stand). However, we found that in sitting, 63% of the infants who were over supported were under the 50th percentile, while 66% of infants who were under supported were over the 50th percentile.

Co-variate Exploration

We intentionally formulated our hypotheses without regard to potential co-factors: whereas this work is the first of its kind, we felt it most prudent to test the effects of parental hold in simplistic models. Nevertheless, given the novelty of this research question, there is opportunity to explore potential co-variables for their role in the putative association between parental hold and infant posture control level. Therefore, several of the analyses here were extended to include replication with hierarchical linear regression: models were tested in a standard linear regression, and then re-tested with the inclusion of AIMS score and Age. The two models were then compared via standard ANOVA; $P < 0.05$ indicates that the more complex model provides statistically significant betterment in model fit versus the simplified model, i.e. that the co-variables provide measurable explanatory power.

In the general linear model, PH was significantly associated with InfC at $P < 0.001$, this significant association was also found in the model when AIMS and Age were included. However, while AIMS was not significant in the more complex model, age was ($P < 0.01$); the two models were found to be significantly different following hierarchical modeling ($P < 0.05$).

In the assessment of PH variability as a function of SATCo, we again found results similar to the Wilcoxon test as described above, with the exception of the sit-versus-stand (condition) term: in the linear model, this term was found to be weakly insignificant ($P = 0.051$ in the simpler linear model; $P = 0.048$ in the more complex model). Here again, AIMS did not show significance, but Age did ($P < 0.05$), however, the hierarchical regression showed no significant difference between the two linear models.

We note that while the presentation of multiple separate regression models creates some redundancy, hierarchical regression is itself an iterative procedure, there is value to be had in reporting simple linear regressions as supporting information in complement to the more complex models (Hox 1994; Jaccard and Turrisi 2003).

DISCUSSION

Parent Sensitivity to Child Control

We observed that parents support their infant consistently within two SATCo levels of control. This finding is noteworthy, considering the many strategies available to parents. For example, parents could have supported their infant according to predilections for conservative or aggressive support, or based on anatomical convenience, i.e. major bony landmarks. In particular, we suspected that two regions would be most appealing: SATCo level 2 (axillae), and SATCo level 6 (pelvis). We only observed parents to hold at axillae level 22% of the time and less than 1% of the time at the pelvis in combined sitting and standing tasks.

One explanation of the parent's responsiveness to the infant's level of SATCo is that infants may elicit narrow ranges of parental support level through their behaviors. For example, infants exhibit compensatory strategies, increased postural sway and decreased efficiency of reaching when external support is given below their SATCo level (Butler et al. 2010;

Rachwani et al. 2013; Rachwani et al. 2015). Through these behaviors, the parent may develop awareness of the infant's level of control. This notion is consistent with the theory of synchrony between infant and parent, which identifies the caregiver's careful sensitivity and attunement to the infant's signals as essential for the infant development (Carlberg and Hadders-Algra 2005). This theory has been proposed in the context of socio-emotional growth, however it may have implications for other neurobehavioral development (Feldman and Eidelman 2007). Before mobility is developed, the infant actively engages with the world through the use of visual, facial, and vocal behaviors in response to cues given from parents. Furthermore, the experience of synchrony between parent and infant may have lasting impact on the infant's brain, particularly during early periods of maturation and postural control development. It would be interesting in future studies to examine the iterative process a novice adult takes in finding where to support an infant they do not know. We also note that the present study observes parent/infant interaction in a laboratory setting and not in a natural environment. We understand that parent behavior may differ with respect to the environment they are in. By creating an observation of parents during a task that required that the infant receive postural support for safety and to achieve the visual task, we were able to observe all parents solving the problem of how best to offer manual support to their infant. This would not have been possible in the naturalistic home environment where families have access to a variety of baby carrying and positioning devices. The purpose of our study was to measure parent behavior with respect to segmental development. Specificity of parent holding is important and interesting. This clinical measure is relatively new. Prior to the SATCo, clinicians evaluated trunk control as if the trunk were a single segment. In other words, trunk control was considered "all or nothing", where the infant or child either demonstrated independent sitting or not. It is surprising to see that parents spontaneously adjust their manual support to the infant's level of control in spite of having no didactic information to encourage this. It is a behavioral response to their infant and part of the parent/child interaction.

Parent's sensitivity to their infant's segmental trunk control has implications for assistive technology. Currently, most equipment is designed in relation to bony landmarks and trunk control is not considered on a segmental basis. However, since trunk control is developed segment by segment (Butler et al. 2010; Rachwani et al. 2013; Rachwani et al. 2015; Saavedra et al. 2012; Saavedra and Woollacott 2015) and parents naturally provide support that commensurate with segmental progression, we suggest that assistive technology equipment place a greater emphasis on a child's SATCo level.

Propensity for Over-Support

In general, parents were over-supportive of their children, particularly in standing. We observed that parent's over-supported their infant when the infant exhibited more advanced trunk control and under-supported the infant with less advanced trunk control a natural consequence of the ceiling- and floor effects. We speculate that when under-supporting, parents may be subconsciously challenging their infant while over-supporting may be associated with conservative strategies for safety or increased functional performance during an activity (Rachwani et al. 2013; Rachwani et al. 2015; Santamaria et al. 2016). We note that the observation of over-support is all the more noteworthy given that our coding

algorithm carried a provision for recording the lowest hold-level in instances where multiple hold levels were observed. It is beyond the scope of this paper to speculate on what might be the impact of different coding schema; however we believe that given the low frequency with which these multi-level holds occurred, the impact would be minimal, and would only increase the apparent extent of over-support.

Differences between sit versus stand

We found significant differences in PH in sitting versus standing. Parents tended to over-support in standing more than sitting and parent holds were on average more similar to SATCo in sitting. We found the axillae to be the most common place of holding during standing (45% of trials). We attribute this to parents opting for the safest position to hold the infant in a setting where a fall is more likely and carries higher risk of harm. Differences in base of support between sitting and standing would clearly impact posture control if no external support were provided. However, because parents' hand support essentially became the infants' base of support in both conditions, differences in base of support are not an adequate explanation for the differences we found between sitting and standing. We propose three possible explanations for the differences in sitting vs. standing. First, in standing, the distance from parent's support to the bench was much larger and infants had several segments (pelvis, leg, shank) to control below their parents' level of support. This larger distance from support to floor combined with the potential extra movements in the segments below the level of support may have triggered parents to adopt a more conservative strategy. Another possible explanation is that parents may be more attuned to the infants SATCo level in sitting, given the nature of motor development. Furthermore, standing is a skill that is developed later in infancy towards the end of the first year. Sitting is a more familiar position for parents during the ages observed in this study (ages 1–8 months). Alternatively, it is possible that the infant's trunk control may actually differ in sitting than standing even with the same level of external support. The SATCo is currently only validated in the sitting position, but future studies could extend this measure to standing.

Relation of Parent Hold to Gross Motor Skills

In the current study, we did not observe a significant relationship between parent under- or over support with respect to a gross motor measure (AIMS). However, we do not underestimate the influence of segmental support to improve future motor skill. Studies have explored the influence of an external support at the thoracic and pelvic levels of the trunk on the success of reaching, postural stability, and kinematics while infants reached for a toy (Rachwani et al. 2013; Rachwani et al. 2015). These results suggest that reaching is correlated with progressive segmental acquisition of trunk control. This raises the question of whether parent given support at their level of control during a reaching task would afford the infant more experiences for motor learning. A similar study observed the effects of different levels of trunk support on posture and reaching in children with moderate to severe cerebral palsy (CP). External support below the level of the trunk control showed unfavorable effects on posture and reaching performance (Santamaria et al. 2016). Nevertheless, better postural control is associated with larger success in gross motor ability (Butler 1998; Curtis et al. 2015). If the parent is made consciously aware of the infant's segmental level of control, the infant may be allowed experiences to improve segmental

development and functional skills. Parents of infants with motor delays could potentially intervene by strategically supporting their infant to promote the advancement of trunk control and functional skills.

Limitations and Future research

The purpose of our study was to observe whether parents are attuned to a segmental development of postural control with respect to the validated SATCo measure. Consequently, our study only provides information in relatively static sitting and standing postures. More specific information could explore parent handling during play activities (Ostensjo et al. 2004). In addition we may also look at the differences in sensitivity to postural development between mothers versus fathers, given inherent differences in play style and handling (Ostensjo et al. 2004). While our study provided new information associating parent holding and infant segmental control, a different type of study would be needed to establish a causal relationship. The present study was limited to typically developing infants in the USA. Our findings are also consistent with a financially well off and primarily Caucasian sample. A wider demographic and cultural range may support a relationship between parent hold and development of functional skills (Ahl et al. 2005).

CONCLUSION

In this study, we found that parents adjust their holding levels during the development of postural control similar to the infant's SATCo level. This result is surprising given the novelty of the SATCo in clinical practice and alternative possible holding strategies parent could have used. This suggests that parents are sensitive to the segmental changes in trunk control that infants exhibit. However, a broader cultural sample would more strongly represent parent's attunement to their infant's postural control.

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REFERENCES

- Ahl LE, Johansson E, Granat T, Carlberg EB (2005) Functional therapy for children with cerebral palsy: an ecological approach *Dev Med Child Neurol* 47:613–619 [PubMed: 16138669]
- Butler PB (1998) A preliminary report on the effectiveness of trunk targeting in achieving independent sitting balance in children with cerebral palsy *Clinical Rehabilitation* 12:281–293 10.1191/026921598667577442 [PubMed: 9744664]
- Butler PB, Saavedra S, Sofranac M, Jarvis SE, Woollacott MH (2010) Refinement, Reliability, and Validity of the Segmental Assessment of Trunk Control *Pediatr Phys Ther* 22:246–257 10.1097/Pep.0b013e3181e69490 [PubMed: 20699770]
- Carlberg EB, Hadders-Algra M (2005) Postural dysfunction in children with cerebral palsy: some implications for therapeutic guidance *Neural Plast* 12:221–228; 10.1155/NP.2005.221 [PubMed: 16097490]

- Curtis DJ, Butler P, Saavedra S, Bencke J, Kallemose T, Sonne-Holm S, Woollacott M (2014) The central role of trunk control in the gross motor function of children with cerebral palsy: a retrospective cross-sectional study *Dev Med Child Neurol* 10.1111/dmcn.12641
- Curtis DJ, Butler P, Saavedra S, Bencke J, Kallemose T, Sonne-Holm S, Woollacott M (2015) The central role of trunk control in the gross motor function of children with cerebral palsy: a retrospective cross-sectional study *Dev Med Child Neurol* 57:351–357 10.1111/dmcn.12641 [PubMed: 25412902]
- Curtis DJ, Woollacott M, Bencke J, Lauridsen HB, Saavedra S, Bandholm T, Sonne-Holm S (2016) The functional effect of segmental trunk and head control training in moderate-to-severe cerebral palsy: A randomized controlled trial *Developmental neurerehabilitation*:1–10
- Duncan KS (2015) *Infant Visual Attention and Postural Control: A Comparison with the Segmental Assessment of Trunk Control (SATCo)*. University of Hartford
- Effgen SK (2012) *Meeting the physical therapy needs of children*. FA Davis,
- Feldman R, Eidelman AI (2007) Maternal postpartum behavior and the emergence of infant–mother and infant–father synchrony in preterm and full-term infants: The role of neonatal vagal tone *Dev Psychobiol* 49:290–302 [PubMed: 17380505]
- Harbourne RT, Giuliani C, Macneela J (1993) A Kinematic and Electromyographic Analysis of the Development of Sitting Posture in Infants *Dev Psychobiol* 26:51–64 10.1002/dev.420260105 [PubMed: 8440403]
- Hox JJ (1994) Hierarchical regression models for interviewer and respondent effects *Sociological methods & research* 22:300–318
- Ishak S, Tamis-LeMonda CS, Adolph KE (2007) Ensuring safety and providing challenge: mothers' and fathers' expectations and choices about infant locomotion *Parenting: Science and Practice* 7:57–68
- Jaccard J, Turrisi R (2003) *Interaction effects in multiple regression*. vol 72 Sage,
- Jeglinsky I, Salminen AL, Carlberg EB, Autti-Ramo I (2012) Rehabilitation planning for children and adolescents with cerebral palsy *J Pediatr Rehabil Med* 5:203–215 10.3233/PRM-2012-0213 [PubMed: 23023253]
- Jeglinsky I, Surakka J, Carlberg EB, Autti-Ramo I (2010) Evidence on physiotherapeutic interventions for adults with cerebral palsy is sparse. A systematic review *Clin Rehabil* 24:771–788 10.1177/0269215510367969 [PubMed: 20605857]
- Karasik LB, Tamis-LeMonda CS, Adolph KE, Dimitropoulou KA (2008) How mothers encourage and discourage infants' motor actions *Infancy* 13:366–392
- Karasik LB, Tamis-LeMonda CS, Adolph KE (2014) Crawling and walking infants elicit different verbal responses from mothers *Developmental Science* 17:388–395 [PubMed: 24314018]
- Ostensjo S, Carlberg EB, Vollestad NK (2004) Motor impairments in young children with cerebral palsy: relationship to gross motor function and everyday activities *Dev Med Child Neurol* 46:580–589 [PubMed: 15344517]
- Ostensjo S, Carlberg EB, Vollestad NK (2005) The use and impact of assistive devices and other environmental modifications on everyday activities and care in young children with cerebral palsy *Disabil Rehabil* 27:849–861 10.1080/09638280400018619 [PubMed: 16096237]
- Piper MC, Pinnell LE, Darrah J, Maguire T, Byrne PJ (1992) Construction and validation of the Alberta Infant Motor Scale (AIMS) *Canadian Journal of Public Health-Revue Canadienne De Sante Publique* 83:S46–S50 [PubMed: 1468050]
- Rachwani J, Santamaria V, Saavedra SL, Wood S, Porter F, Woollacott MH (2013) Segmental trunk control acquisition and reaching in typically developing infants *Exp Brain Res* 228:131–139 10.1007/s00221-013-3544-y [PubMed: 23681292]
- Rachwani J, Santamaria V, Saavedra SL, Woollacott MH (2015) The development of trunk control and its relation to reaching in infancy: a longitudinal study *Front Hum Neurosci* 9:94 10.3389/fnhum.2015.00094 [PubMed: 25759646]
- Saavedra S, van Donkelaar P, Woollacott MH (2012) Learning about gravity: segmental assessment of upright control as infants develop independent sitting *Journal of Neurophysiology* 108:2215–2229 10.1152/jn.01193.2011 [PubMed: 22832568]

- Saavedra SL, Woollacott MH (2015) Segmental Contributions to Trunk Control in Children With Moderate-to-Severe Cerebral Palsy Arch Phys Med Rehabil 10.1016/j.apmr.2015.01.016
- Santamaria V, Rachwani J, Saavedra S, Woollacott M (2016) Effect of Segmental Trunk Support on Posture and Reaching in Children With Cerebral Palsy Pediatr Phys Ther 28:285–293 10.1097/PEP.0000000000000273 [PubMed: 27341576]
- Shumway-Cook A, Woollacott MH (2012) Motor Control Translating research into Clinical Practice. 4th edn Lippincott Williams & Wilkins,
- Strube W et al. (2016) Bidirectional variability in motor cortex excitability modulation following 1 mA transcranial direct current stimulation in healthy participants Physiological reports 4 10.14814/phy2.12884
- Thelen E (2005) Dynamic systems theory and the complexity of change Psychoanalytic Dialogues 15:255–283

Fig. 1: (a, b) Experimental set-up during the Parent Hold test. (c) Seven regions of the trunk tested during the Segmental Assessment of Trunk Control (SATCo). The SATCo was used to define the infant's level of trunk control (InfC). (d) Experimental set-up during SATCo.

Fig. 2:

Scatter plot of parent hold level (PH) versus infant trunk control level (InfC) in sit (a) and Stand (b). InfC is the average level across sub-domains. Figure 2c shows proximity of parent hold in sit and stand. Figure 2d shows the absolute value of proximity of parent hold in sit and stand.

Fig. 3: Scatter plots and regression trends of proximity of parent hold level (PH) to infant control level (InfC) as a function of InfC in sit (a) and stand (b), and variance in parent support level as a function of InfC in sit (c) and stand (d).

Fig. 4:

Box plots of disparity between parent hold level (PH) and child trunk control level (InfC) as a function of SATCo sub-score variance in sit (a) and stand (b), and variance in parent support level SATCo sub-score variance in sit (c) and stand (d).

Table 1.

Summary of participant demographics.

Age (months)	N	Infant Gender	Length (cm) (Mean ± SD)	Weight (kg) (Mean ± SD)	AIMs (percentile) (Mean ± SD)
1–2	12	6M / 6F	57.0 ± 2.03	5.15 ± 0.52	66.5 ± 18.4
3–4	13	7M / 6F	61.5 ± 1.71	6.47 ± 0.71	65.0 ± 21.1
5–6	15	7M / 8F	65.5 ± 2.73	7.41 ± 0.84	50.4 ± 24.1
7–8	20	10M / 10F	69.0 ± 2.13	8.26 ± 0.85	41.0 ± 23.7

Table 2.

Summary of parent demographics.

	7% fathers
Gender of parent holding	93% mothers
Percent first time parents	69% first time parents
	7% HS
Parental educational level	49% college
	44% grad school
	87% Caucasian
Race	8% Hispanic
	5% Asian