Jennifer Tompkins, PT
April 5th, 2020
Literature Review

Postural Control Development: Typical, Atypical, and At-Risk Infants and Toddlers

I. Introduction

A pediatric physical therapist encounters countless children who struggle to attain independent sitting and standing skills in the early intervention setting (birth to 3-year population). Upper extremity reaching, head and neck control, balance reactions, and trunk posture in supine and sitting positions are critical components to a child's overall motor skill development.[1–3] Identification of early impairments in postural control, if assessed accurately and systematically, should be targeted to help enhance motor development. Pediatric physical therapists must know when typical gross motor skills emerge. However, we must go beyond this knowledge and develop a deeper understanding of the relationship between static, active, reactive, and anticipatory postural control movements and upright functional mobility.[3] Control of the trunk and pelvis allows for more complex gross motor skills movements and improved antigravity control, which in turn increases exploration, freedom of movement, and enhances cognitive abilities.[1,3,4]

In a child, postural control development occurs in a cephalo-caudal progression with head and neck control emerging first.[3,5] The mid-thoracic, lower-thoracic, and pelvis follow, and the child becomes more stable in an upright sitting position.[3,5] The ability to co-contract and isolate muscles, as well as alter one's center of mass over a stable base of support, allows for full independent sitting to emerge.[5,6] Coordination of visual, tactile, and somatosensory inputs help refine trunk control in infants, enhancing postural control.[7] An early intervention pediatric physical therapist will evaluate and treat infants with a wide variety of diagnoses, as well as those who are otherwise healthy but at risk for developmental delays. Infants and toddlers with vision impairments, abnormal muscle tone, musculoskeletal abnormalities, vestibular impairments, and brain injuries suffer balance and postural control impairments more often than their healthy peers.[7] This literature review will provide a summary of postural control development in the infant. The review is written for the pediatric physical therapist, providing increased knowledge of the complex components that lead to successful upright sitting and mobility.

Additionally, the information in this literature review on postural control will provide evidence to support that using appropriate outcome measurement tools will enhance our ability to pinpoint impairments, help to justify physical therapy intervention and guide intervention choices. The review will focus on upright sitting posture because this developmental stage is key to further development of upright functional mobility and independent exploration.

II. A search of the Literature

The following search terms were used across multiple databases: “infants” OR “children” OR “pediatric” AND “posture OR "postural control" AND “balance” AND “sitting” AND “development.” Fifty-one articles were located using Pub MED, PEDro, EBSCo, ProQuest, CINAHL, Cochrane databases. The search was narrowed to 32 articles when limited to human subjects and articles less than ten years old. Of the 32 articles, inclusion and exclusion criteria were set, which further narrowed the articles to 12 for a full review. The inclusion criteria consisted of 1. studies that included both or either infants and toddlers and 2. infants and toddlers that were either typical, atypical, or at-risk for delay or a combination of these subjects. Articles excluded were studies that included 1. adults 2. only children over the age of three and 3. articles about how weight affects posture and 4. studies that focused on standing and walking as the primary outcome.

III. Postural Control and Reaching

Before infants learn to sit upright and explore their world in a vertical posture on their own, exploration of their environment occurs in supine, prone, supported sitting, and while being held by caregivers.[6] Exploration of their bodies starts with reaching and grasping of the torso, clothes, knees, feet, as well as placing their hands in their mouths. Successfully coordinated reaching and grasping movements generally emerge by 4-months of age.[6] Researchers have found that infants born preterm are more likely to demonstrate a lag in reaching skills and present with delayed motor skill acquisition compared to their full-term peers.[8,9] Preterm infants are more likely to extend their trunk in supine and upper extremity reaching, utilizing non-optimal kinematics.[9,6] Additionally, they tend to use more rigid postural patterns in contrast to infants born full-term.[9]

As reaching trajectories become more and more smooth, visual scanning and information processing further enhances reaching movements.[6] As young as 6-months, infants begin to rely more on their vision and make anticipatory postural movements to reach an object after visualizing the object.[6] Reaching in both supine and sitting requires the infant to use anticipatory postural control, but the recruitment order of muscles activated is "highly variable."[6] Similar to the lag in reaching skill and motor skill delay seen in infant born preterm, infants with CP also present with decreased adjustments during reaching, more rigidity when upright, and less variation in center of pressure data when sitting.[6,9]

Early reaching movements and postural muscle activation prepare the infant for more complex motor skills and upright sitting postures that require control of the trunk, center of mass over the base of support, and activation of antigravity dorsal and ventral muscles.[6] Multiple researchers and clinicians alike have noted that infants with CP do not move as much as their peers, and the decrease in variability potentially decreased opportunities for learned strategies for efficient postural control as the infant develops.[6,7] Dusing et al. reports that young infants who are more likely to have a diagnosis of CP later in childhood demonstrate less fidgety generalized movements.[7] Movements like these early in development have been measured in other studies by looking at center of pressure (COP) data in supine and sitting.[6,7] Preterm infants who were considered both high and low-risk presented in some studies with relatively still COP measures.[6] The authors hypothesize that this "still" behavior (decreased COP movements) affords fewer experiences and decreases learning, leading to decreased opportunity to build postural strategies.[6]

IV. Upright Sitting and Postural Sway

Center of pressure (COP) data has been used to investigate and compare sitting ability between infants developing typically, infants born preterm with motor delays, and infants with CP.[2,9,10] In the home or clinic setting, physical therapists, have limited opportunities to quantify sitting ability, leading to descriptive explanations of a child's sitting ability, and global assessment of a child's gross motor skills compared to age-matched peers. Researchers use COP data to understand how infants maintain their balance in sitting under a variety of conditions.[2,10,11] While this mathematical method of understanding postural sway and balance is feasible within the researcher setting, the clinical applicability of COP data collection is very low. However, understanding and applying the trends highlighted in this literature review will provide a more in-depth understanding of postural control development.

Several studies have revealed that infants with motor delays and/or CP tend to show more regularity and less variability in COP data compared to their typically developing peers.[2,10,12] "Regularity" in COP data is the number of times, or how predictable the COP sway path is used during sitting.[2,10,12] "Variability" in COP data describes how much variety, also known as strategies, is present in the COP sway path as the infant remains upright in sitting.[2,10,12] Harbourne et al. found that typical infants increase variability and regularity over time, as would be expected in the development of sitting.[2] In a study that investigated "look time" during the emergence of sitting, infants with motor delays presented with COP values with more regularity in the anterior-posterior direction in comparison to their typically developing peers.[10] The authors conclude that these values indicated less exploration and fewer strategies for postural control.[10] Kyvelidou et al. compared full-term, preterm, and infants with CP and found similar results; typically developing infants demonstrate more variability in their COP values in all directions than the infants with CP at the onset of upright sitting. [9] Infants later diagnosed with CP presented with decreased linear anterior-posterior directional movements and decreased non-linear movement in both the medial-lateral and anterior-posterior directions.[9] The authors conclude that this data affirms that infants with CP have less variety in their postural sway and less freedom of movement than both typically developing infants and those with motor delays.[9]

When comparing two different intervention types, a perceptual-motor program to a home program group of infants at risk for developing CP, Harbourne et al. found that infants in the perceptual-motor group presented with COP data post-intervention that demonstrated more variability.[2] In contrast, the home program infant group decreased variability while regularity increased.[2] The two intervention types differed with the perceptual-motor groups focusing on dynamic child-led problem solving, and the home program group focused on static sitting skill acquisition and parent coaching.[2] The authors concluded that focusing on dynamic balance and increased strategies for exploration may assist infants at risk for CP with developing more typical postural control.[2] One possible explanation is that the static sitting focus in the home program group did not foster as much dynamic postural control as the perceptual-motor group.[2] Another outcome that differed between the two groups was that 40% of the infants in the perceptual-motor group and 20% of the infants in the home program group moved onto crawling, demonstrating a difference in skill attainment.[2] Progression to crawling indicates more functional mobility, requiring dynamic postural control.[2] A weakness of this study is that the two groups received different frequencies of therapy in different locations. The difference in frequency alone could have influenced the differences in the outcomes. However, the COP data is consistent with other studies that infants born preterm, and infants with CP have COP values that are un-similar to typically developing infants. The quality of movement and ability of these infants to make postural adjustments and use more strategies to remain upright while engaging with their environment is worthy of more in-depth assessment by the pediatric physical therapist.

V. The Emergence of Upright Sitting Posture

Independent upright sitting brings forth new experiences for the infant.[5,9,13] Control of the trunk is the basis for most functional movements in life.[5,9] Researchers have found that trunk control develops in a cephalocaudal fashion, from head to pelvis.[5,14,15] Trunk control is inherently complex as multiple body systems are at play to coordinate this new upright position for the infant. The infant learns to control their head and trunk against gravitational forces, involving biomechanical, neurological, visual, and musculoskeletal control.[5] The very first stage of upright trunk control emerges by around 3-months of age, with typical infants learning to hold their head upright.[5] Soon, the infant sits on the floor with hand support around the 5-months. Finally, infants often learn to sit upright with no hand support between 6 and 7-months of age.[5,9,13] Saavedra et al. described the emergence of upright sitting in typically developing infants by collecting and analyzing EMG data and orientation of the C7 spinous process on infants between ages 3 to 9-months.[5] They used distinct stages on a continuum to further detail early sitting to full upright control.[5] Understanding these stages will help the pediatric physical therapist determine at which point on the continuum of learning to sit up their patients may be. Stage one sitting can be described as "slow collapse," generally noted to occur between 3 and 4-months of age.[5] This stage is characterized by the infant being unable to respond to perturbations, collapsing into gravity, and little organization of muscle activation.[5] Stage two sitting can be thought of as "rise and fall," where the infant makes attempts to remain vertical, but falls away from the midline in the opposite direction during correction attempts.[5] Stage three sitting, the "wobbling" stage, is when an infant attempts to make corrections and wobble around a set point.[5] The last and final fourth stage is characterized "upright control," and the infant spends time interacting with the environment while remaining aligned in a vertical orientation.[5] In this stage, the infants have more variability than in stage three because they can use more range of motion around the setpoint and remain upright.[5] The EMG data from this study revealed that flexor and extensor muscles decreased co-activation responses as the infant moves through the stages and that the responses to the movement (keeping balance) change from erratic to anticipatory.[5] The authors believe that the development of sitting follows a similar pattern to other developmental processes, through stable and unstable states before the skill becomes learned.[5]

Once the infant has attained the ability to sit upright, typically developing infants are very flexible and use many strategies to remain upright. For example, Rachwani et al. studied infants able to sit upright for at least 30-seconds on their own and found that immediate postural responses to changes in slope were possible.[13] The infants remained upright at steeper slopes than expected.[13] Using visual and proprioceptive pathways to perceive and respond to the changes, the infants in this study were quite flexible in their quick response to remain upright.[13]

Using an outcome measure to understand better the level at which trunk control is complete, researchers and clinicians alike can better pinpoint the location of trunk control attained. Researchers have compared the Segmental Assessment of Trunk Control (SATCo) and the Alberta Infant Motor Scale (AIMS) to study the relationship between motor skill acquisition and level of trunk control.[3] Righetto et al. studied infants born preterm and full-term at 6-months and compared their SATCo and AIMS scores. They found that the infants born preterm presented with SATCo scores lower than the infants born full-term by 1-SATCo level, and a delay in sitting skill acquisition.[3] The authors concluded that since the study demonstrated a significant correlation between these two tests, the decreased trunk control seen in the infants born preterm, therefore, is the cause of the delay noted in sitting skill acquisition.[3] A more detailed look at the specific level of control the infants attained revealed that the infants born preterm had upper thoracic control. In contrast, infants born full-term demonstrated mid-thoracic control at 6-months.[3] Similarly, Pin et al. found statistically significant differences in SATCo scores at every age month for infants 4 to 12-months except at the 5th, 6th, and 10th-month when comparing the same two groups.[14,15] Trunk control took longer to develop in infants born preterm in their study than the infants born full-term.[14,15] More specifically, the full-terms infants attained full static and active trunk control by 9-months of age, whereas preterm infants did not attain this type of control until 12-months of age.[14,15]

VI. Visual and Somatosensory Impact on Postural Control

To successfully remain upright, the infant must integrate sensory and motor processes to control their body in space.[4,7] These processes are rapidly changing over time, developing throughout infancy and childhood.[4] The large role vision plays in postural control and balance is well documented, especially for children.[4,5] Infants as young as 2-months of age change or adapt their postural control and center of pressure when presented with a visual stimulus.[7] Visual attention in infancy is linked to experiences and active movements to move towards an object of desire.[7] This type of visual attention encourages reaching movements and increases contact with objects.[6] For example, infants move their hands closer to objects when they can visually fixate on the object versus infants who cannot visually fixate.[6] Anticipatory motor control is also linked to visual attention, as infants can pre-plan a motor event after visualizing others reach for objects.[6] Grounded cognition concepts view number and variety of experiences as enhancing information processing, which in turn supports cognitive development.[7] Therefore, visual attention and desire to move are linked and enhance cognitive development.

Kyvelidou et al. examined infant postural control under four different sensory conditions to examine how vision and somatosensory processes impact postural sway.[4] Based on the results of the study, the researchers concluded that vision plays a more significant role than the infant's somatosensory feedback system.[4] This was evident by postural sway increases in both the anterior-posterior and medial-lateral directions when infants were placed in the lights off conditions.[4] In contrast; infant postural sway was not affected during the somatosensory condition (a foam pad) alone.[4]

Postural control, visual attention, sensory feedback, and movements increase experiences and lead to cognitive development. One way to investigate how these integrated feedback systems and motor control interact is to use “look-time” to investigated how focused attention changes as an infant learns to sit upright [10] A study by Harbourne et al. found that “look time” decreased for infants developing typically as sitting stability increased.[10] However, infants with motor delays had an increase in “look time” during stage two sitting (hands-free sitting emergence).[10] One possible explanation includes that these infants required increased efforts during this stage of sitting compared to infants developing typically, which may indicate decreased ability to gather information from the environment at the same rate as their peers who are developing typically.[10]

VII. Postural Control and Cognition

As postural control develops, the infant moves from supine, prone, and mobility on the floor to upright sitting. This change in body orientation affords increased visual, motor, and cognitive experiences.[3,10,16] These experiences are critical to cognitive growth and development.[3,10,16] Researchers have found that preterm infants with abnormal postures in sitting score lower on cognitive tests than preterm infants with typical postural control.[3] Attaining full trunk control is necessary for the further development of functional mobility in standing, allowing for more interaction with the environment, family, and peers.[7,10,16] These types of interactions have a clear connection to cognitive development and should be supported by the physical therapist by working towards improved postural control for infants and children. Focusing on reaching skills as well as active, reactive, and anticipatory postural responses during motor movements will enhance the child's cognitive development.[7]

Focused attention in infants is the duration of time the infant concentrates on an object during play and exploration.[16] Researchers have found that the development of focused attention is impaired for some infants born preterm and infants with neuromotor deficits.[16] A study by Sukar et al. investigated focused attention trends in children with mild to moderate CP who were undergoing typical physical therapy interventions.[16] They found that children who learned to sit up independently during a 12-week intervention period significantly increased their mean longest focused attention and total focused attention time compared to those who did not learn to sit up.[16] This may indicate a relationship between improved postural control and the ability to focus attention on surroundings and objects. The authors concluded that focused attention to objects advances as play increases, especially for children who learned to sit up on their own during the intervention period.[16] Grounded cognition concepts support these research outcomes and can help inform physical therapy practice, not only encouraging physical therapists to assist in gross motor skill acquisition but to focus on postural control from early in infancy and beyond with careful and accurate assessment and intervention choices.

VIII. Implications for Clinical Assessment

Jennifer Tompkins, PT
April 5th, 2020
Literature Review

The development of postural control requires many body systems working in coordination, advancing the infant from initially requiring manual support by caregivers for head and trunk control, to independent upright sitting postures midway through the first year of life. After attaining an upright standing posture, the infants' exploration of their environment increases as mobility become increasingly independent. As standing, cruising, and walking emerge, exploration increases and, as demonstrated earlier, aids in cognitive development. Infant's with neurodevelopmental delays, birth injuries, and a preterm birth are high risk for delayed or atypical postural control. Clinically, the pediatric physical therapist must be able to pinpoint early impairments that may hinder the typical acquisition of upright sitting postures, like upper extremity reaching or rigid atypical trunk postures in both supine and sitting. Delayed motor skill acquisition alone should not determine intervention choices, but rather a careful assessment of postural control should be included in assessments that determine service delivery for this population. Outcome measurement use to quantify postural control in infancy, and early childhood is not abundant. There are a few outcome measures physical therapists can use to help pinpoint impairments, justify intervention choices, and track progress. Along with this literature review, a guide has been created for practicing pediatric physical therapist to enhance their use of outcome measurements that are appropriate for this age range. Increased attention and assessment of head and trunk control, as well and functional skill development as it relates to postural control during a time of rapid development is needed.

Jennifer Tompkins, PT
April 5th, 2020
Literature Review

Bibliography

1. Lobo MA, Harbourne RT, Dusing SC, McCoy SW. Grounding early intervention: physical therapy cannot just be about motor skills anymore. *Phys. Ther.* 2013;93(1):94-103. doi:10.2522/ptj.20120158.
2. Harbourne RT, Willett S, Kyvelidou A, Deffeyes J, Stergiou N. A comparison of interventions for children with cerebral palsy to improve sitting postural control: a clinical trial. *Phys. Ther.* 2010;90(12):1881-1898. doi:10.2522/ptj.2010132.
3. Righetto Greco AL, Sato NT da S, Cazotti AM, Tudella E. Is Segmental Trunk Control Related to Gross Motor Performance in Healthy Preterm and Full-Term Infants? *J Mot Behav* 2019:1-10. doi:10.1080/00222895.2019.1673694.
4. Kyvelidou A, Stergiou N. Visual and somatosensory contributions to infant sitting postural control. *Somatosens Mot Res* 2018;35(3-4):240-246. doi:10.1080/08990220.2018.1551203.
5. Saavedra SL, van Donkelaar P, Woollacott MH. Learning about gravity: segmental assessment of upright control as infants develop independent sitting. *J. Neurophysiol.* 2012;108(8):2215-2229. doi:10.1152/jn.01193.2011.
6. Hadders-Algra M. Typical and atypical development of reaching and postural control in infancy. *Dev. Med. Child Neurol.* 2013;55 Suppl 4:5-8. doi:10.1111/dmcn.12298.
7. Dusing SC. Postural variability and sensorimotor development in infancy. *Dev. Med. Child Neurol.* 2016;58 Suppl 4:17-21. doi:10.1111/dmcn.13045.
8. Lobo MA, Kokkoni E, Cunha AB, Galloway JC. Infants born preterm demonstrate impaired object exploration behaviors throughout infancy and toddlerhood. *Phys. Ther.* 2015;95(1):51-64. doi:10.2522/ptj.20130584.
9. Kyvelidou A, Harbourne RT, Willett SL, Stergiou N. Sitting postural control in infants with typical development, motor delay, or cerebral palsy. *Pediatr. Phys. Ther.* 2013;25(1):46-51. doi:10.1097/PEP.0b013e318277f157.
10. Harbourne RT, Ryalls B, Stergiou N. Sitting and looking: a comparison of stability and visual exploration in infants with typical development and infants with motor delay. *Phys Occup Ther Pediatr* 2014;34(2):197-212. doi:10.3109/01942638.2013.820252.
11. Kyvelidou A, Harbourne RT, Shostrom VK, Stergiou N. Reliability of center of pressure measures for assessing the development of sitting postural control in infants with or at risk of cerebral palsy. *Arch. Phys. Med. Rehabil.* 2010;91(10):1593-1601. doi:10.1016/j.apmr.2010.06.027.
12. Dusing SC, Harbourne RT. Variability in postural control during infancy: implications for development, assessment, and intervention. *Phys. Ther.* 2010;90(12):1838-1849. doi:10.2522/ptj.2010033.
13. Rachwani J, Soska KC, Adolph KE. Behavioral flexibility in learning to sit. *Dev. Psychobiol.* 2017;59(8):937-948. doi:10.1002/dev.21571.
14. Pin TW, Butler PB, Cheung H-M, Shum SL-F. Longitudinal Development of Segmental Trunk Control in Full Term and Preterm Infants- a Pilot Study: Part I. *Dev. Neurorehabil.* 2019:1-8. doi:10.1080/17518423.2019.1648580.
15. Pin TW, Butler PB, Cheung H-M, Shum SL-F. Longitudinal Development of Segmental Trunk Control in Full Term and Preterm Infants- a Pilot Study: Part II. *Dev. Neurorehabil.* 2019:1-8. doi:10.1080/17518423.2019.1629661.

16. Surkar SM, Edelbrock C, Stergiou N, Berger S, Harbourne R. Sitting postural control affects the development of focused attention in children with cerebral palsy. *Pediatr. Phys. Ther.* 2015;27(1):16-22. doi:10.1097/PEP.0000000000000097.