165 Postural Control in Children and Youth with Cerebral Palsy

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Abstract

Deficits in movement and postural control are defining characteristics of cerebral palsy. Postural control is defined as the ability to align and adjust body segments against gravity without falling or collapsing. Posture involves complex neural processes that must be coupled to biomechanical and environmental constraints and can be categorized in terms of static, active (or anticipatory), and reactive control. Because ability to control posture is an integral part of all movement, deficits in the posture system contribute to challenges in body structure and function, daily activities, and participation. There is a very high burden of care for those with severe posture deficits. This chapter (1) defines postural stability from a systems perspective; (2) reviews the impact of posture deficits on body function and structure, daily activities, and participation across levels of the Gross Motor Function Classification Scale (GMFCS); (3) summarizes

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assessments of postural control for sitting and standing; and (4) describes current interventions from the perspective of motor learning principles. The number of published interventions directly aimed at improving postural control is limited. Moreover, the type of intervention, outcome measures, and quality of studies vary significantly between ambulatory and nonambulatory children. For those at GMFCS levels I and II, interventions refine the existing posture. For those at GMFCS level III, children must often choose between task performance and postural control and typically prioritize the functional task. Children at GMFCS levels IV–V have undeveloped postural control and require contextual modifications to enable opportunities for basic acquisition and practice of head and trunk control.

Keywords
Balance · Posture · Segmental · Sensory · Motor learning

Introduction

Systems Underlying Posture

Deficits in postural control have been consistently included in definitions of cerebral palsy (CP) since it was first recognized in 1861 (Rosenbaum et al. 2007). Impairments in CP can exhibit as clumsiness or frequent falls during ambulation, difficulty reaching, or difficultly developing or maintaining an upright sitting position. However, before describing deficits in posture associated with CP, this chapter begins with a brief overview of postural control and how it is typically developed.

Postural control refers to the ability to control our bodies above our base of support, to hold and adjust a specific position to accomplish a task. The base of support often refers to the area under the feet in standing or the area in contact with a seat in sitting. However, the base of support can significantly increase if another body segment is in contact with a stable object, such as when a person grabs a rail during stair climbing. Postural control must be maintained within environmental constraints and in response to perturbations. For the purposes of this chapter, we will focus only on upright posture with respect to gravity in sitting, standing, or walking activities.

For typically developing populations, postural control is "behind the scenes" and typically involves automatic processes that require little cognitive effort. However, postural control is anything but simple (Fig. 1). For those with severe impairments, posture is not automatic. Posture is considered inherently unstable in that a small deviation from upright results in gravitational forces that further accelerate the body away from upright. There are many body segments that are all under the influence of gravity. Also, the motion of one segment generates an interaction torque on adjacent segments. Thus, all segments must be stabilized for robust postural control. The possible movements from the segments of the body are referred to degrees of freedom. For children with impairments in posture, controlling the many degrees of freedom in the body against gravity is difficult. Postural alignment and stability are further complicated by the fact that muscles used for posture serve multiple purposes. For example,

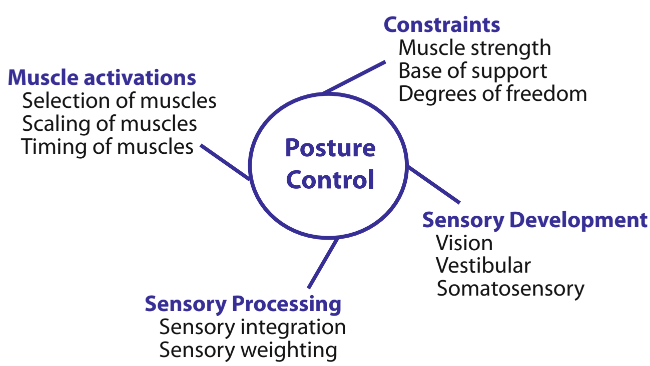

Fig. 1 Postural control refers to the ability to control our bodies above our base of support to hold and adjust a specific position to accomplish a task. Posture requires a complex array of neural processes that function within the constraints of the body

trunk muscles must simultaneously participate in expanding and contracting the ribcage during respiration, maintain stable alignment of the body and head in space, adjust postural activations to counterbalance for positional changes of the extremities, and anticipate and respond to external load requirements. Coordination for these different tasks must allow more than one functional goal to be accomplished at the same time, often by the same muscles (Hodges et al. 2002).

Sensory guidance for postural control is also complex. There is not one single sensory input that controls posture. Instead input from multiple sensory systems is integrated and weighted by the structures in the brain in determining the best response (Shumway-Cook and Woollacott 2016). The three systems that most often contribute to posture include: vision, vestibular (inner ear sense of gravity), and somatosensory (touch and muscle/body position) (Peterka 2002; Goodworth and Peterka 2012). Reliable input from these sensory systems is needed for postural stability and for interaction with the environment. The head serves as the frame of reference for motion detection by the visual and vestibular systems. Vision may be our best guide for balance when walking in daylight; however, we are able to remain upright and walk in the dark. In the dark, when vision is less helpful, our brains rely more heavily on input from touch, muscle position sensors, and the vestibular system. The brain's ability to interpret and shift reliance from one system to a different system is remarkable.

Development and Theory

The first year of life represents the most rapid change in postural control. Pathways associated with vision (Hubel and Wiesel 1970), hearing (Tees 1967), and touch (Simons and Land 1987) develop during a critical period of infancy where sensory stimuli are required to calibrate each system. If deprived of sensory stimuli during this period, neural pathways may never develop. Evidence also supports a critical period for refining vestibular processes where exposure to gravity information is needed (Jamon 2014). Similarly, the postural control system requires sensory stimuli and practice with gravity to calibrate and integrate multiple sensory systems.

Typically developing infants gain postural control from the top-down. Infants first learn to raise their head upright, followed by development of postural control over their trunk, leading to independent sitting, and then pulling to stand and beginning to walk (Shumway-Cook and Woollacott 2016). As infants achieve upright alignment of each new body region, they need to expand their repertoire beyond a static posture by developing stability and freedom of movement according to the new affordances offered by the position. For example, once an infant achieves upright sitting, their hands are free to reach out and interact with objects. This requires adaptation of postural muscle forces as the configuration of the body changes when the arms reach away from the trunk in different directions and distances. Adjustments must be made in the postural muscles before and during reaching in order to stay upright throughout the activity. In addition, our musculoskeletal system also affects the potential for postural control. As infants and children grow into adult size bodies, they must constantly adapt their postural responses to accommodate changes in the distribution of body weight and increasing length of bones and muscles. The complexity of sensorimotor control for posture is phenomenal, yet typically developing infants master the basics of this control during the span of a mere 6–9 months. Beyond 9 months of age, trunk control is so efficient that it is often modeled as a single link in postural control research (Goodworth and Peterka 2012).

Neuroscience research has demonstrated that the neural structures involved in motor control are highly plastic at birth and are molded by the child's interactions with their environment. Infants are born with an abundance of neural connections and during the first years of life the nervous system goes through a period of rapid change based on the child's interactions with the environment. These changes influence the refinement of sensory structures and strengthen sensorimotor connections for muscle synergies. From a maturational theory of motor development, the severity of the neural lesion would form an impenetrable barrier to behavior change in children with moderate to severe disability. A more current approach to motor development, **systems theory** is consistent with current neuroscience research and considers behavioral outcomes to be flexible, emergent properties that result from interaction of anatomical, physiological, and neurological components within specific task and environmental contexts. We use the general definition of systems theory (as described by Shumway-Cook & Woollcott (Shumway-Cook and Woollacott 2016)) which was first introduced by Bernstein in 1967. According to this theory, patterns of movement self-organize within the environmental and task conditions, based on the body systems and characteristics of the individual. In other words, changes in a subsystem underlying postural control and changes in the environment can enable or constrain a child from achieving postural control (Spencer et al. 2000). It is this systems perspective that we take to explore postural control in children with cerebral palsy.

Categorizing and Testing Posture

Postural control can be categorized in several ways (Fig. 2) (Shumway-Cook and Woollacott 2016). *Static control* refers to the ability to achieve and maintain an upright position within the gravitational field. While muscle strength plays an important role in static control, it should be noted that complex neural processes also underlie static control. For static control, postural stability in quiet sitting or standing is measured. Even during quiet sitting, our bodies are constantly moving with very small oscillations that are referred to as postural sway. As the amplitude or velocity of sway increases, a child will visibly wobble. If the child wobbles far enough that their center of mass approaches the edge of their base of support, the child will need to take a step or reach out to secure their balance or they may fall.

Active or Anticipatory control refers to the ability to adjust the postural muscles before or during a movement in anticipation of the expected perturbation. Expected perturbations can include internal (self-initiated motion that perturbs the posture system, such as reaching, walking, and even breathing) or external (predictable forces from the surrounding, such as anticipating a slippery surface or anticipating the forces to pick up an object). Anticipatory responses are learned over time and require practice. Active control is evaluated by examining the child's ability to prepare in advance for a planned movement. This might include weight shift or activation of muscles prior to the onset of a task like stepping or reaching. Examination of reaching activities is a common method used in both laboratory and clinical tests.

Reactive control refers to the ability to respond to an unexpected threat to balance. For example, if an infant is accidentally bumped or jostled, the postural control system must quickly select and activate the correct muscles in a coordinated manner in order to return the body to an upright balanced position before a fall occurs, or if an older child slips or trips, he/she must alter his/her stepping pattern to prevent a fall. The underlying premise of reactive testing is that the participant must first achieve a position of balance either standing or sitting and then an unexpected external perturbation will challenge balance. The movement distance, recovery of position, change in ground reaction forces, or muscle activation patterns are examined and compared across different types and directions of perturbation and between children with typical development and children with cerebral palsy.

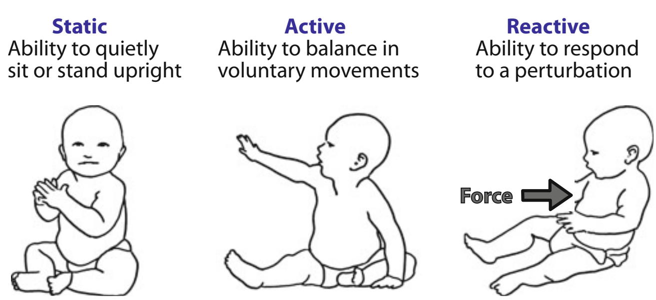

Fig. 2 Postural control can be subdivided as the ability to maintain static, active/anticipatory, and reactive control

For posture testing, environments can be altered to assess the impact of sensory systems. Visual contributions to posture are assessed by comparing balance during different visual conditions such as eyes closed or moving visual surround. Altering the type of support surface or placing vibration on muscles can be used to assess contributions of cutaneous touch and pressure sensors or muscles sensors. Vestibular input to posture is usually assessed by tipping the child sideways and observing if the child corrects their alignment.

Deficits in Posture in Cerebral Palsy

Postural deficits in children with CP vary widely based on the level of severity. Therefore, it is helpful to categorize CP across severity. The Gross Motor Function Classification System (Palisano et al. 2008) (GMFCS) was developed as a method of classifying children with CP on the basis of functional abilities and limitations. Since the original publication in 1997, the GMFCS has become widely used around the world as way to describe gross motor function of children with CP. The GMFCS includes five levels of gross motor function across 5 age bands that span from birth through 18 years. In general, children who are in Level I demonstrate relatively "good" postural control and walk without limitations. Children in Level II walk independently but have some limitations based on environmental conditions that present heightened challenges to posture. Children who are in Level III have noticeably impaired postural control and therefore walk using a hand-held mobility device like a walker, cane, or crutches and have self-mobility through crawling or scooting while sitting on the floor. Those children who are classified as Level IV have impairments in trunk postural control. Their limitations typically exhibit impairments in self-mobility and they may use power mobility for function. Children who are in Level V are transported in a manual chair and are unable to accomplish self-mobility. Posture deficits in children at Level V are severe with very little trunk postural control with frequent deficits in their control of head position. For those in Levels III–V, there is similarity in postural control between level of severity of CP and typically development infants, where Level V is associated with head control only (similar to 2–3 month old infant) and Level III may have independent sitting but not walking (similar to 7–8 month old infants) (Saavedra and Woollacott 2015).

With the advent of motion analysis and computer processing in the last 30 years, research has given more detail into differences in static, active, and reactive postural control in CP compared to typically developing peers (Shumway-Cook and Woollacott 2016). The majority of research has been completed with subjects who can stand and walk independently (typically GMFCS levels I and II) (Woollacott and Shumway-Cook 2005). In these studies, CP is associated with larger sway in static posture, abnormal sensory integration of vision and vestibular cues (more often in spastic diplegia and ataxia compared to hemiplegia), and different patterns of muscle activation. Active posture associated with voluntary reaching has fairly typical anticipatory posture adjustments but have slower and shorter reaches. Reactive postural control is associated with different and delayed functional muscle activations and more stepping or falling. During gait, many of the movement patterns associated with CP pose a heightened challenge to postural control, such as tripping or instability due to deficits in lower extremity alignment, strength or coordination.

Impairments in trunk and head control are also present in CP. Trunk control is important because it creates the foundation for most functional skills and is critical for production of speech as well as swallowing, eating (Redstone and West 2004; Stevenson 1995), and reaching (Santamaria et al. 2016). Reactive trunk posture impairments are evident as high co-activation of muscles, poor modulation of posture responses, and different timing patterns of muscles: with a top-down sequence of activation compared to typical development where a bottom-up pattern is prevalent (Brogren et al. 1998). This difference implies that children with CP may prioritize head stability. For those with moderate-to-severe CP (GMFCS levels III–V), impaired trunk posture is a major factor limiting independent standing and walking. These children exhibit delays in static, active, and reactive control. For children who are able to sit independently (typically GMFCS level III), ability to align vertically, especially during hands free sitting can be challenging. Static posture typically exhibits a posterior tilt of the pelvis and kyphotic trunk with forward head position when sitting and an anterior tilt with excess lumbar lordosis during standing. These classic postures are likely adopted as compensation to limit the number of degrees of freedom that need to be balanced against gravity (i.e., reducing the available movement in head and spinal segments).

For those who cannot sit independently (GMFCS levels IV–V), it is nearly impossible to describe static, active, and reactive postural control using conventional methods. Historically, researchers and clinicians have investigated the trunk as a single unit, typically describing a child as either exhibiting independent sitting or not. This “all or nothing” approach does not capture the segmental developmental spectrum and is not informative for understanding populations with underdeveloped or impaired sitting. Until recently we did not have tools to adequately study posture in those with severe impairments. However, recent research is investigating trunk and head posture using a segmental approach, where external trunk support is provided and postural control is described in body segments above the support. While this is a new area of research, the segmental approach paired with modern technology is opening opportunities to understand postural control in children who face severe motor control challenges (Goodworth et al. 2017).

Goals and Environment

Postural control serves as the foundation for all motor skills (Shumway-Cook and Woollacott 2016). As such, posture impacts every aspect of function, encompassing all four components of the World Health Organization’s International Classification of Functioning, Disability and Health (ICF). The impact on (1) body function and structure, (2) activities and participation, (3) personal and (4) environmental factors depend on the severity of the child’s cerebral palsy. If a child is ambulatory, improved postural control might make them safer in complex environments but may not have a distinct impact on their potential for participation. Whereas for a non-ambulatory child who lacks head control, improved postural control may not alter mobility but could improve participation by improving head stability for better visual interaction with the environment and allowing the child to make eye contact and observe facial gestures for increased social interaction. The burden of care and challenges faced by families of children with CP are directly related to the child’s level of postural control.

Children at GMFCS levels I and II have deficits in postural control that may interfere with speed, stability, or agility when walking or running, or cause challenges to safety and attention in complex environments or on uneven surfaces. Children with this level of severity gain independent ambulation before 6 years of age (Palisano et al. 2008). Postural deficits contribute to poor alignment or difficulty coordinating balance responses and this can lead to clumsiness, decreased energy efficiency, and increased fatigue. These challenges can lead to difficulty participating in age-related physical activity on the playground or during sports related activities especially as children reach adolescence and performance requirements for the activities become more demanding. Children who are classified at GMFCS level II may require adaptations to enable participation in physical activities or sports. Nevertheless, deficits are minimal enough to allow children with these levels of severity to move freely in their home and community and to practice postural control throughout their day.

Children classified at GMFCS level III learn to sit by 2–4 years of age, frequently using “W-sitting,” and learn to walk using a hand-held mobility device by 6 years of age (Palisano et al. 2008). Deficits in postural control limit the child’s activity and participation not only in the community but also within their homes. These children need to hold on to a person or a support surface if they want to transfer from sit to stand or from the floor to stand. The child often must choose between task performance and postural control. For example, the “W-sit” position reduces the degrees of freedom for the lumbar spine and pelvis thus reducing the demand for postural control. This allows the child more freedom for upright head and upper body movement including having at least one hand free to play with toys. Unfortunately, while this helps the child with the current task performance, it is a compensatory strategy that locks the posture system in such a way that the child is not practicing active postural control when reaching. That is, the child is not learning to coordinate posture with voluntary activities. Children with this level of severity often need additional pelvic or trunk support in order to free both hands for bilateral hand activities. Postural deficits also lead to body structure and functional limitations. Muscle imbalance and altered bone growth can arise from abnormal posture alignment, minimal time in standing and walking, and movement patterns used to compensate for inadequate postural control. These secondary deficits restrict the child's ability to achieve good postural alignment and increase the risk for hip dysplasia, lower extremity surgeries, and medications or injections for muscle tone management. For these reasons, the burden of care is higher for parents of children at GMFCS level III. These children do, however, have adequate postural control and self-mobility for some level of autonomy and independence. They need adaptations (hand-held mobility device, manual or power wheel chair) to enable physical activities and sports in the community. Context modifications can be used in the home or school settings to increase the options for the child to practice active postural control without having to choose between posture or task performance. One example of a home-based contextual modification is the sit-to-stand device shown in Fig. 3 that allows the child to spontaneously practice weight shifts, reaching, sitting, and standing for postural control while engaged in eye-head-hand coordination and mobility skills.

For children who are classified at GMFCS level IV, deficits in posture interfere with development of adequate trunk control for independent sitting. The child may be able to floor sit, when placed, but is not able to sit erect and needs to use hands for balance, thus limiting the ability to reach for and interact with toys. Children with this level of severity are able to assist with sit to stand when an adult helps them. They may be able to walk short distances with a walker with close adult supervision; however, they have limited self-mobility. Poor sitting balance contributes to delays in mastering skills such as eating, object manipulation, and eye-head-hand coordination for reaching (Redstone and West 2004; Santamaria et al. 2016). With age, these children spend increasingly more of their day in a wheelchair. Community mobility requires adaptations including power wheelchair and/or physical assistance. These children face similar or greater risks for muscle imbalance and boney deformities as those at GMFCS level III. Positioning devices for children with this level of severity are often geared toward ease of care and propping the child upright but are usually not adjusted with the intent of offering the opportunity for practice of postural control. As in the case of children at GMFCS level III, deficits in postural control for children at GMFCS level IV have a significant effect on body structure and function, activity and participation and contribute to a high burden of care for the family. More importantly, children with this level of severity are dependent on others to help set up the context and offer assistance for any opportunity to practice postural control. Figure 4 shows a modification to the home-based sit to stand device that can be used by children at GMFCS level IV or V. The modification includes a sit-to-stand box surrounding the child that allows unlimited practice with sit to stand, weight bearing, and weight shift and can offer the parent some respite. One parent using this device reported "this is the first time since my child was born that I have been able to relax and take time for self-care. I can put him in this device and he is happy to play for 20–25 minutes without needing input from me." Unlike the child at GMFCS level III, the sit-to-stand box does not allow the child with more severe posture problems to explore postural control. With this modification, children often use excessive trunk stiffness, a compensatory strategy to allow upright alignment that limits variations in posture. Children often need to hold on to a support bar or lean against the box to remain upright and the ability to turn and look around or reach in different directions is limited. To practice posture with variable movements and

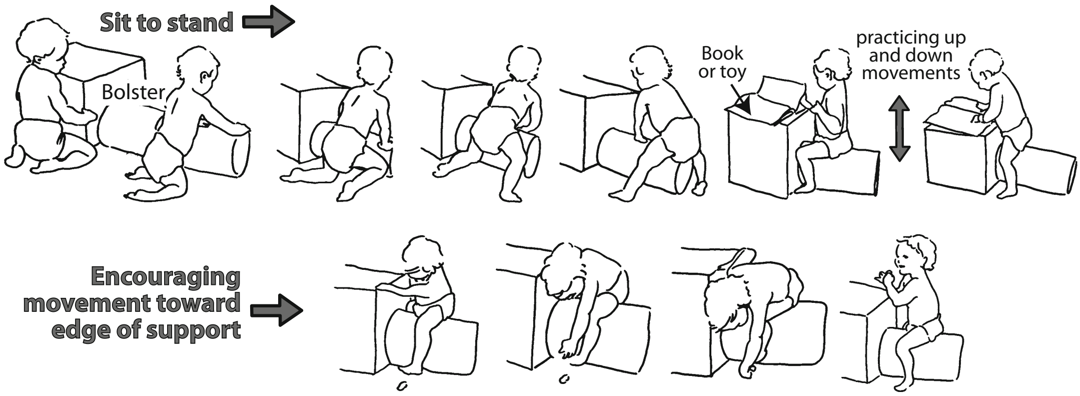

Fig. 3 Example of a context modification in a sit-to-stand device for a child at GMFCS level III. A firm bolster with diameter approximately the length of the child's lower leg and long enough to extend through both sides of the box and still provide space outside the box for the child to sit. The bolster is secured by cutting holes to allow it to be inserted through the bottom of a large box. The box serves to stabilize the bolster, provide a play surface for the child, and provide a stable surface the child can use to assist with sit to stand. The bolster encourages sitting with legs abducted and feet on the floor. Sitting or standing with legs straddled across the bolster provides pelvic stability while still allowing freedom of movement for the lower trunk. In this way, the child can practice reaching and playing with toys with bilateral hands free while also practicing postural control. Weight shift and transfers can be promoted as the child gets on and off of the bolster. The child can continuously practice sit to stand easily and spontaneously throughout the day without requiring parental assistance. The child can move toward the edge of his/her base of support and weight shift laterally by reaching for objects on the floor on either side of the bolster

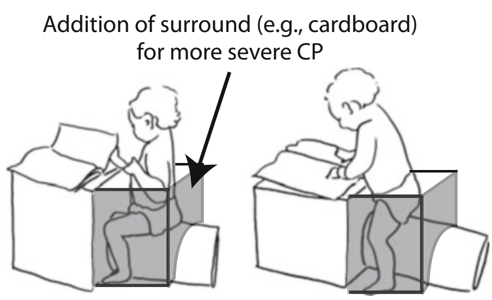

Fig. 4 Example of a modification of a sit to stand device to allow children at GMFCS level IV or V to spontaneously practice sit to stand. A box is placed around the child to offer additional support for safety and to allow independence

control, the child would need external support to the level where postural control is challenged (usually thoracic region for GMFCS level IV) and opportunity to practice active postural control, coordinating head and arm movements in an upright vertical alignment. Another option would be to adjust the trunk support on a gait trainer to allow the child to practice upright control when stepping or standing. This requires attention to height and firmness of support for optimal upright position. If the support is not high enough or firm enough, the child will have to compromise either posture or stepping.

Children at GMFCS level V have the most severe postural deficits with the greatest impact on body structure and function, activity, and participation and the burden of care for families is highest. These children are limited in their ability to achieve or maintain upright head or trunk postures. All mobility and transitions are dependent on caregivers (Palisano et al. 2008). These children require support devices (e.g., wheelchairs, seating systems, standers, gait trainers) for sitting, standing, bathing, and eating and often for communication (Ostensjo et al. 2005). Mobility and functional limitations are not fully compensated by equipment. These children require assistance from others for most functional tasks. Participation in physical activities or sports necessitates physical assistance and/or use of power mobility. Opportunities for practice of postural control are the most limited for children at GMFCS level V and require custom adaptations of equipment specifically for the purposes of allowing upright vertical practice. The effort needed to provide this type of opportunity can be rewarding because even small improvements in head control can lead to increase in active participation. If a child gains head control, the potential for eye contact and interaction with others is improved. This can dramatically change the child's potential for social interaction and communication through facial gestures. It can change participation from the child being "present" to being "actively engaged" with other people. Not only are children at GMFCS level V limited in their ability to practice upright control but they also miss the activity-dependent integration of sensory systems that support the development and control of posture. The biggest changes in visual and vestibular systems occur in typically developing infants during the first 6 months of life, and many of these changes appear to be facilitated and integrated through emergence of active antigravity control of the head and trunk. Children at GMFCS level V often use compensatory strategies for head and trunk posture in order to stabilize their head for visual interaction. For example, one 12-year-old child we worked with had poor head control that resulted in variable movements when trying to keep his head vertical. During our laboratory posture tests, we allow participants to watch a movie and we found this particular child regularly dropped his head to his shoulder in order to stabilize his visual feedback. This compensation unfortunately eliminates any active postural control of the head. Interestingly, when his vision was occluded with a blindfold, he lifted his head up more vertically and was thus practicing postural control of his head. Ideally, he could be encouraged to combine practicing vertical head control during engaging visual tasks. This can be accomplished by offering him a flat surface behind his head. The surface guides him with respect to where vertical is and allows him to press into a stable surface to help stabilize his head upright. An example of this type of positioning is shown in the case study at the end of this chapter.

Technique

Physical therapy interventions for deficits in postural control begin with meaningful assessments, followed by activities to improve function and/or promote motor learning. Therefore, we begin this section by summarizing commonly used posture assessments for various functional levels, then review motor learning principles, and then describe common interventions for postural control for children with CP.

Assessments

Figure 5 shows several of the posture assessments that have adequate research support covering a range of static, active, and reactive control for children with CP. Other posture assessments exist with variable levels of research support (Bañas and Gorgon 2014; Saether et al. 2013). The clinical assessments listed here are geared towards quantification of (1) alignment and stability for static control, (2) movement distance and stability using reaching, stepping or turning to assess active control, and (3) responses to brief nudges or being tipped sideways, forward or backward to document reactive control. Another way to document changes in posture is by examining change in motor skills that reflect underlying improvement in posture. The most commonly used global assessment that infers changes in postural control in children with CP is the Gross Motor Function Measure, however the Bruininks Oseretsky Test of Motor Performance (BOT-2) validated in typically developing children, is also used for the higher functioning children with CP (GMFCS levels I–II) and the Alberta Infant Motor Scales (AIMS) or Peabody Developmental Motor Scales 2nd edition (PDMS-2) may be used for younger children with CP.

The first two measures listed in Fig. 5 (gray shading) allow evaluation of children across all GMFCS levels because they do not require the ability to sit independently. The *Segmental Assessment of Trunk Control (SATCo)* is measured during sitting and with arms lifted. External

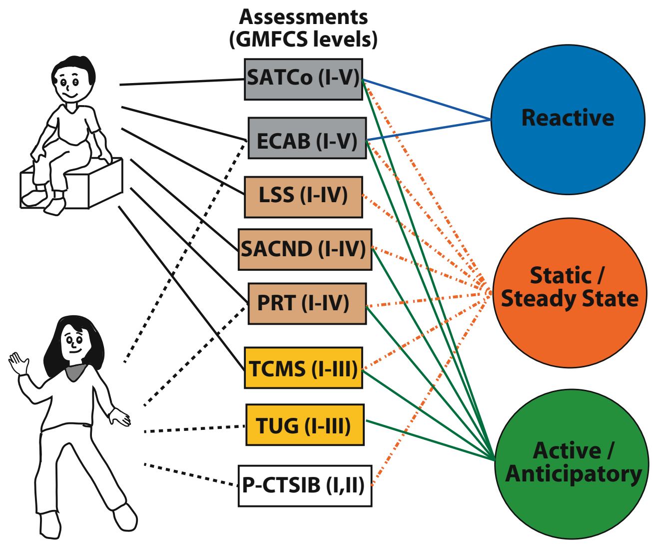

Fig. 5 Assessment tools used to measure postural control in children with cerebral palsy. Some assessments are performed sitting, standing, or both. Each assessment has research support across specific GMFCS levels and focuses on one or more aspect of postural control

support is initially provided high on the trunk where static, active, and reactive control is evaluated in body segments above the level of support. Support is gradually lowered until the patient no longer demonstrates control. Performance is rated on an ordinal scale. A strapping system is required to secure the pelvis and assistance is required to apply the nudges. Test time is about 10–15 min. The Early Clinical Assessment of Balance *(ECAB)* (Mccoy et al. 2014) was designed as a broad, comprehensive observational measure of overall postural stability in young children with CP less than 7 years of age. It includes a head/trunk control section that measures head and trunk righting responses for children with more severe CP and incorporates sitting, standing, walking, and turning items for children classified at GMFCS I–III. Performance is a numeric total. Test time is about 15 min.

The next group of posture assessments (Fig. 5 tan shading) require that the child be able to safely maintain a sitting position when placed on a bench or stool and thus cannot be used for children at GMFCS level V and may be difficult for those at GMFCS level IV. The *Level of Sitting Scale (LSS)* rates sitting ability based on amount of manual support required to maintain a sitting position. Performance is rated on an 8-point ordinal scale ranging from "unplaceable" to ability to sit with hands free and reach laterally. No special equipment is needed. Test time is about 5–10 min. The *Sitting Assessment of Children with Neuromotor Dysfunction (SACND)* is an assessment of static and anticipatory trunk control. Sitting posture is videotaped during 5 min of quiet sitting and during 5 min when the child is encouraged to point forward at different objects. Scores are rated on a 4 point ordinal scale for categories of postural tone, alignment, balance, and stability. A Plexiglas board with toy attachments is required. Test time is about 10–15 min. The *Pediatric Reach Test (PRT)* is a modification of the adult Functional Reach Test incorporating sitting and standing positions and side reaching as far as possible without moving the base of support. Performance is based on reaching in all three directions and measured as a distance. No special equipment is needed. Test time is less than 15 min. Children at GMFCS level IV can be included in the sitting but not the standing portion.

For children who are at GMFCS levels I–III, the *Trunk Control Measurement Scale (TCMS)* can be used to assess static and anticipatory trunk control. This test requires that the child have stable independent sitting on a bench or table with feet unsupported. Performance of sitting is measured while children complete a series of reaches, within and outside their base of support and attempt to remain stable while completing leg movements. Performance is rated on 2, 3, or 4 point ordinal scale. No special equipment is required. Test time is about 15 min. The TCMS has been used to help differentiate the effect of trunk postural control on gait in higher functioning children with CP. The *Timed Up and Go (TUG)* assesses the speed with which a child stands up from a chair, walks three meters, turns, walks back to the chair, and sits down. No physical assistance is given, but an assistive device can be used by the child so this can be used for children at GMFCS levels I–III. No special equipment is required. Test time is about 5–10 min. The *Pediatric Clinical Test of Sensory Interaction and Balance (P-CTSIB)* focuses on standing posture and the ability to incorporate information from vision, vestibular, and somatosensory feedback. Children with adequate standing balance (GMFCS levels I–II) stand in eyes open or eyes closed, on a firm or foam surface, and with or without looking into a visual dome attached to the head. Each condition modifies the type of sensory feedback available to the child. Performance is rated on an ordinal scale. A foam pad and visual dome is required. Test time is about 5–10 min.

While most of these assessments have been tested for reliability (*consistency within and between different testers*) and validity (*results accurately reflect constructs of postural control*), there is sparse evidence for responsiveness (*sensitivity to changes in postural control*). More research is necessary to document this aspect of currently available posture assessments (Saether et al. 2013).

Principles of Motor Learning

Activities that elicit the highest levels of motor learning include activities with cognitive and motivational factors that help solidify learning (Magill and Anderson 2014). For example, it is best to use activities that are engaging to the individual child, and novel or variable. Children involved with age appropriate problem solving tend to be more engaged. Tasks that are relevant to a child's everyday life will increase motivation and focus. In these activities, it is typically best for the child's focus to be on the external result of their action as opposed to the details of how their movement or posture was carried out. Finally, because most activities need to be carried out in a range of different contexts, and because children with CP have reduced adaptive responses, it is important to generalize learning through variable practice.

Four hallmarks of motor learning include: improvement, adaptability, consistency, and retention (Magill and Anderson 2014). For postural control, improvement must be evident in a meaningful outcome measure. Outcome measures include several of the assessments noted above along with more mechanistic findings like quantification of alignment, postural sway, or muscle activation patterns that can be obtained in a research laboratory. After a child achieves improved postural control in a specific situation, adaptability is needed to transfer the improved control into new situations, such as a new environments (e.g., clinic and school; on a smooth and rough surface) or modified movements (e.g., maintain posture with voluntary reaching in multiple directions for different objects). Consistency refers to the child's ability to maintain adequate performance with posture when repeating an activity, where neither fatigue nor distractions significantly degrade performance. Retention refers to the child's ability to maintain performance goals weeks, months, and years after the intervention. Retention is particularly difficult to assess in research because longitudinal studies are logistically complex and numerous factors vary across months and years that can influence outcome measures.

Interventions

Research studies exploring interventions for postural control in CP are minimal; however, the variety and quality of studies has increased over the past 20 years (Dewar et al. 2015). Techniques reported include biomechanical approaches, strength or muscle facilitation techniques, massed practice, techniques to enhance feedback, and perturbation-based approaches. Any of these approaches can

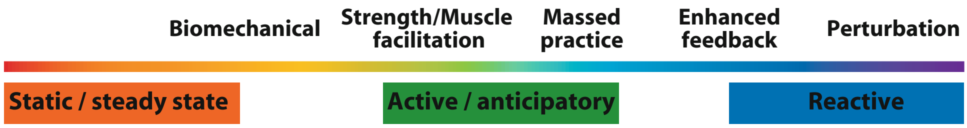

Fig. 6 Summary of posture interventions aligned by type of control, for children with cerebral palsy

potentially influence static, active, or reactive postural control. However, most approaches tend to emphasize one more than the other (Fig. 6).

Biomechanical

One approach to improving static control and alignment is to provide biomechanical support to the postural control system. A number of studies have evaluated the effects of seating systems on alignment and the effects of external support on posture and upper extremity skills. Methods that abduct the legs and help the pelvis to tilt anteriorly tend to help children align more vertically (Harris and Roxborough 2005; Roxborough 1995). External trunk support improves reach and alignment for young children with mild CP (Saavedra et al. 2009) and children of any age with more severe CP (van der Heide et al. 2004; Saavedra and Woollacott 2015; Santamaria et al. 2016).

The immediate change in alignment and upper extremity function due to changes in biomechanical context is important for considering contextual adaptations or positioning devices for children with partial trunk control. However, the most pertinent question is whether or not biomechanical approaches can also be used to promote improved postural control. Butler (1998) (Butler 1998) took the biomechanical approach to the next level when she provided a custom seating or standing device on a rocking base and added home exercises for active and reactive training. The device was adjusted based on the child's level of trunk control such that the child was working on the edge of where they were gaining postural control and the support was gradually lowered over time as each child gained control. Families used the custom device and completed posture training activities at home 5–7 days per week, 20 min up to 2 h 30 min per day for 12–25 weeks. All 6 children (aged 2–7 years, GMFCS levels III–IV) gained independent sitting and increased their segmental level of trunk control. Improvements were retained in 2 children who had follow-up testing at 20 weeks and 1 year post-intervention. This protocol was repeated in a recent randomized controlled trial in which 28 children (aged 2–14 years, GMFCS levels III–V) were randomized into intervention or control group. The children trained in the support device either at home or at school for an average of 84 min per week for 6 months and showed significant improvements in head and trunk control, but the improvement was not maintained at follow-up 6 months post-intervention (Curtis et al. 2016). Because of the importance of helping children with severe impairment acquire basic components of postural control (head and trunk control), similar studies are on-going.

Biomechanical approaches for the lower extremities for children who are ambulatory most often include the use of an ankle foot orthosis (AFOs) to prevent excessive plantar flexion and control spasticity. AFOs can be solid or flexible. By preventing plantar flexion, the AFO may lessen certain types of tripping, but an AFO also limits mobility in the ankle and therefore limits the repertoire of reactive postural control strategies (Burtner et al. 1999). Overall, there are mixed results with respect to improvement of alignment and balance in children with CP through use of AFOs (Butler et al. 1992; Harris and Roxborough 2005).

Strength or Muscle Facilitation

Interventions that focus on muscle strength or muscle facilitation techniques have the potential to improve alignment and static control of posture while also contributing to improvements in muscle activation and timing for better active control.

Motor impairments for children with CP include (1) coordination issues related to co-activation of postural muscles, (2) poor modulation of posture responses, (3) different timing patterns of muscle recruitment, and (4) weakness that can prevent the child from achieving and sustaining upright alignment. Classic strength training and task repetition techniques similar to those used in adults with increasing difficulty and/or repetitions over time have been used for children at GMFCS levels I–III. Protocols varying from 10 to 30 min sessions, 2–5 days per week for 4–12 weeks have shown variable results, some have shown increase in strength but no change in standing balance, while others have shown improvements in standing and walking or in alignment during sitting (Dewar et al. 2015). Very few of these studies have done follow-up testing for retention; one study that used a home-based strengthening program showed results that were maintained at 6-week follow-up.

Kinesiotape is often used in sports training to improve muscle performance. Recent randomized controlled studies using this technique have yielded encouraging results for children with CP. Two studies applied kinesiotape, 6 days per week for 12 weeks while attending traditional therapy sessions two or three times per week. Running speed, strength, and balance improved significantly in the study for children at GMFCS levels I–II (Kaya Kara et al. 2015). Children at GMFCS levels III–V, in the other study, showed significant improvements in sitting balance and hand function, but no changes in gross motor function (Şşimşşek et al. 2011). Functional electrical stimulation is used for rehabilitation in adults and a few cases have been reported in children with CP as an aid to specific task practice. Two recent studies have reported improved alignment and sitting control for young children with CP when 30 min of electrical stimulation was administered to trunk muscles 5 days per week during a 6 week in-patient rehabilitation protocol (Dewar et al. 2015). None of the studies with kinesiotape and electrical stimulation included follow-up examinations for retention.

Massed Practice

Intensive massed practice has been effective for upper extremity constraint induced therapy or bilateral arm movement training for children with CP and for lower extremity balance in adults post-CVA. The concept of massed practice applied to postural control has not been explored very extensively. Treadmill training for children with CP is usually focused on improving gait speed or fitness; however, there have also been reports of improved standing balance for children at GMFCS levels I–III (Dewar et al. 2015). One interesting study focused more directly on massed practice of reactive posture to a predictable perturbation in standing conditions. Researchers gave a group of 6 children (age 7–12 years, GMFCS levels I–II) 100 perturbations/day for 5 days on a moveable platform (Dewar et al. 2015). This study showed improved ability to recover stability and the reduced time to recover. The improvements remained 30 days after completion of training.

Enhanced Feedback

Techniques that provide enhanced feedback include studies with virtual reality, video/computer games, or visual feedback. Engagement and enjoyment is typically increased in children when gaming is coupled to rehabilitation. However, improvements in postural control are less well documented. Five studies were reviewed by Dewar (Dewar et al. 2015). A total of 52 children were included. Four of the five studies included only GMFCS levels I–II. In these three studies, interventions included use of a Nintendo Wii fit balance board (3–5 weeks of 30 min of practice per session), a virtual reality program (5 days with 90 min of practice), and a balance training protocol with visual feedback of the child's center of pressure (6 weeks with training 3 times per week). The Nintendo Wii studies showed mixed results. The virtual reality and visual feedback programs both reported improvements in standing balance and mobility scores, with retention 1 month later. One of the five studies included subjects with more severe CP. Children played a computer game in their wheelchair that aimed to improve trunk control and smoothness of movements (4–5 sessions over 1 week). No significant changes were found.

Perturbation Training

We considered hippotherapy (individualized therapy by PT, OT, or Speech therapist using horse riding), therapeutic horse riding (program designed and implemented by a therapeutic riding instructor), and equine simulators to be perturbation approaches. The movements of the horse, while repetitive and reasonably consistent, offer greater variability than the massed practice from a moveable platform or treadmill. Two recent reviews of the effects of hippotherapy for children with CP (Zadnikar and Kastrin 2011; Tseng et al. 2013) along with the reviews listed above (Dewar et al. 2015; Harris and Roxborough 2005) yielded 12 studies that examined the effect of equine seated perturbation training on postural control in children with CP. Across the three studies using therapeutic riding, a total of 27 children (2–12 years, GMFCS levels I–IV) were included. One study involved riding 60 min 2x per week for 10 weeks and showed improved balance for all 11 children. The other two studies involving (1) 60 min 1x per week for 26 weeks and (2) a single session of before and after riding found that 50% of the children improved and 50% did not improve in balance measures and/or alignment. Across the six studies using hippotherapy, a total of 38 children (2–17 years, GMFCS levels I–V) were included. Duration varied from 20 to 50 min per session, 1 or 2x per week for 8–12 weeks. Posture and functional balance improved for children in the five studies who were at GMFCS levels I–II or I–IV and did not improve in the study that was limited to three children who were at GMFCS level V. Across the four studies using hippotherapy simulators, 77 children (3–18 years, GMFCS levels I–V) received 10–40 min simulated riding 1–2 times per week for 4–12 weeks. Posture improved as measured by postural sway tests for children in 3 of the studies. The 4th study showed significant improvements in GMFM Dim B with those children at GMFCS level V showing the strongest response. These results were not maintained at 12 week follow-up. Overall, these type of approaches offer some of the strongest evidence for improved balance in children with CP; however, only one study included follow-up and the results were not maintained at 12 weeks post-intervention (Dewar et al. 2015).

Evidence of Effectiveness

In this section, we first review the strength of evidence from published research studies. However, because research is limited, we also apply theoretic concepts into suggested approaches for interventions across GMFCS levels as a guide for families and clinicians.

Evaluation of Research

Overall, the research evidence for effectiveness of interventions that directly target postural control for children with CP is limited. As indicated in the previous section, a variety of methods have been created and explored for improving postural control in small numbers of children, but no single approach has risen to the top and more extensive exploration is warranted. For children who have already achieved sitting and standing balance, there are a variety of interventions that have been researched: muscle facilitation techniques (strengthening exercises and kinesiotape), massed practice (treadmill, and standing platform perturbations), perturbation techniques (therapeutic riding, hippotherapy, and riding simulators), and enhanced feedback through video games. In children with the most severe CP (GMFCS levels IV–V), there is sparse but encouraging evidence from a few randomized controlled trials, segmental training (biomechanical approach) resulted in improved head and trunk control, hippotherapy simulator (perturbation approach) showed improved performance on sitting tasks, and kinesiotape and electrical stimulation to trunk muscles (muscle facilitation approach) resulted in improved sitting alignment.

The four hallmarks of motor learning (sensitive measures of improvement, adaptability, retention, consistency) provide a means to discuss areas that could be improved in research studies.

Improvement

Most studies evaluated children before and after intervention for signs of improvement. However, measuring improvements of postural control in and of itself is challenging because most laboratory and clinical measures, while reliable and valid, have not been tested for responsivity. Moreover, children with CP can sometimes have "good" or "bad" days where emotional or behavior factors can interfere with performance measures. Identifying responsive outcome measures is particularly challenging for more severely involved children. The SATCo offers one potential measure; however, responsiveness to change has not yet been established for children with CP. Changes in gross motor function may not be adequate to document changes related to improvement of head or upper thoracic control. Posture studies for children with more severe disability should explore measures that are aligned with development of head and upper trunk control such as "social looking," eye-head coordination for gaze control, look duration, eating and drinking skills, eye-head-hand coordination during reaching, frequency and coordination of uni-manual or bimanual reaching activities, and wheel chair driving or propulsion.

Adaptability

In general, the question of adaptability has been addressed by most researchers at a macroscopic level through evaluating carry-over in terms of improvements in functional activities assessed with standardized motor tests. Further studies that explore adaptability as an outcome measure at a micro level are warranted. For example, a number of studies have demonstrated that children with CP show less variability of postural sway (da Costa et al. 2017; Kyvelidou et al. 2013) and less adaptability to changes in perturbation amplitude (Brogren et al. 1998; Hadders-Algra 2008; Carlberg and Hadders-Algra 2005). Thus, interventions that help the posture system to adapt more robustly to contextual changes would be an important step forward.

Retention

In contrast to improvement and adaptability, retention was not tested for most interventions. There have been very few postural intervention studies that include follow-up evaluations to assess for retention. Some of the studies with the positive improvements were not retained. For example, retention tested at 12 weeks for hippotherapy simulator and at 6 months for segmental training did not yield a positive outcome. This is an important area for future work.

Consistency

While consistency has been studied for anticipatory reactions and reaching performance during a single session of postural testing, we are not aware of any studies that used measures of consistency to document the trajectory of motor learning for postural control in an intervention across hours and days in children with CP. It is expected that when an improvement in postural control is first achieved, it will fluctuate over time, with plateaus and setbacks (especially in a growing child). But eventually the improvement should solidify and become consistent.

Theoretical Concepts

Posture is usually controlled at a subconscious level. We only notice our posture if it interferes with a task we hope to accomplish or if someone draws our attention to our alignment. Children are even less disposed to pay attention to posture. They are driven to move and explore their environments. These reasons likely underlie the challenges in studying interventions intended to improve postural control. Therefore, we suggest therapist should treat posture by combining an engaging task with posture demands. We do not suggest practicing posture in isolation in youth and children.

When combined with a task, postural control can be "built in" to daily function. This could be accomplished by creating goal-directed assessments and adapting the posture programs with specific emphasis on the child or family's goals. If the new skills can be incorporated into the child's daily activities, it is likely to be more effective in the long term. This requires some level of individualization with respect to activities that have meaning to the child and family and matching of the intervention to the type of postural control that is most needed by the child.

Our proposed model for engaging children in posture training is shown in Fig. 7. Children at GMFCS levels I and II, on the left side of the plot, spontaneously develop upright trunk control for independent sitting and standing. Some care and attention may be needed to adjust the activity for more variability and challenge for postural improvement, but these children have the potential to engage spontaneously and further refine their postural control. For example, a child who wants to play on the local soccer team would benefit from a more perturbation and repetition based balance approach like treadmill training or video games that require lots of leg movements or stepping. A child who seeks improved balance to be able to stand and play drums in the band might need more strengthening and static balance activities like playing video games while standing in one place.

Children at GMFCS level III are at a pivotal location. These children face situations where they have inadequate postural control to accomplish many tasks. If environmental supports or contexts can be created that allow the child to actively use postural control, there is potential that posture and task performance could simultaneously improve. However, if contextual support is not available, the child will need to alter the task or their position to stabilize the postural component. This can be placing one hand down at all times during sitting or collapsing the trunk into kyphosis. Using external trunk support can bring the child into a range where they have the potential for successful active postural responses while also practicing new functional tasks.

For those with more severe CP, one of the major challenges for gaining postural control is the child's level of trunk control. The lack of control interferes with the child's freedom to spontaneously practice head and trunk posture during skill performance. A therapist must focus on significant modifications to the context so these children have the opportunity to practice upright postural control. For these children, training posture must often take the form of simplifying the postural control tasks by reducing the degrees of freedom involved (providing trunk or partial head support) or providing additional avenues of support (hand rail). After the simplified posture is achieved, additional challenges can be introduced (lessening support and adding perturbations or larger voluntary movements). In this way, posture is developed incrementally, similar to the typical

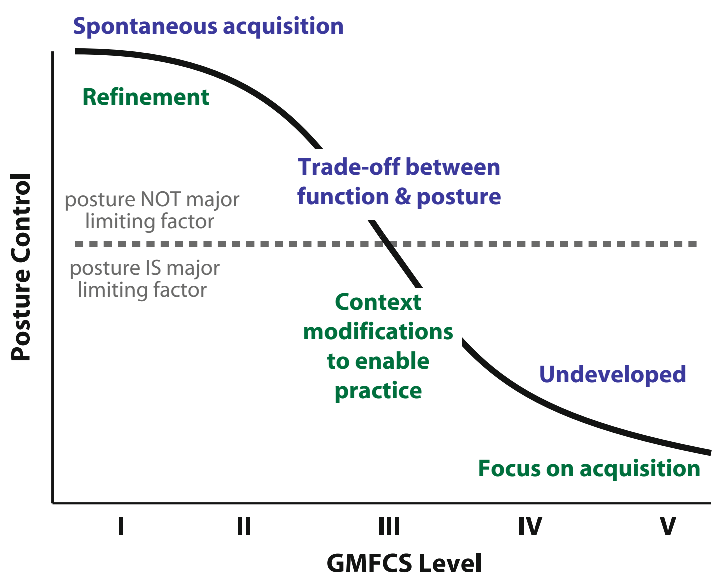

Fig. 7 Schematic of patient behavior and intervention focus across levels of severity in cerebral palsy. GMFCS is the Gross Motor Function Classification System

developmental pattern. Even in the more severe children, it is still recommended to keep posture as the underlying focus while the child is interacting with a different functional task.

This approach is consistent with a recent systematic review of interventions for children with cerebral palsy. In this review, three types of training topped the list of effective methods for general functional skill performance across subgroups of children with cerebral palsy. These were goal-directed training, home programs, and context-focused therapy (Novak 2014). Goal-directed training is defined as "child-active" repetitive and structured training in self-care tasks, e.g., dressing, designed to meet a goal meaningful to the child. In goal-directed training, the tasks and the environment are also changed to promote skill acquisition (Ahl et al. 2005). Home programs are defined as "evidence-based home programs of child-active repetitive and structured home-based practice of tasks that are meaningful to the child and their family" (Novak 2014). Context-focused therapy is a compensatory/environmental approach where the environment is adapted to promote successful task performance (Law et al. 2011). However, for children who do not spontaneously develop independent sitting, we advocate for creating an environmental approach that also specifically allows children the opportunity to practice postural control with support optimized based on the child's segmental level of control.

Case Example

We provide an example to demonstrate the concepts for promoting opportunity to practice postural control for a child with severe CP (GMFCS level V). Much more research is needed to determine if this approach can alter the course of postural development in children with CP, but the immediate improvement in functional skills and opportunity to actively engage in practicing postural control make it a better option than the traditional care that positions these children passively throughout most of the day.

History

JAS was born prematurely at 24 weeks gestation, weighing just 1 pound 13 ounces and in his mother's words "survived a harrowing five months in the NICU." His mother reported that "Although he didn't have any brain bleeds and as a family, we had no indication he might have cerebral palsy, at 17 months actual (13 adjusted) he is unable to sit, roll, or crawl. He has high tone on his right side and very low tone in his core. He falls over when propped in a sitting position and can't handle sitting in a high chair because he's very wobbly."

Examination and Evaluation

On evaluation for our research study at 14 months corrected age, we observed that JAS is an enthusiastic and engaging child whose fine motor skills (5% on Peabody Developmental Motor Scales, Edition 2, PDMS-2, fine motor subtests) were markedly better than his gross motor skills (<1% for Alberta Infant Motor Scales and PDMS-2, gross motor subtests). During the Segmental Assessment of Trunk Control (*Figure A right side*), he demonstrated loss of static and active posture at the level of Head Control. Reactive control was not assessed since he was unable to achieve static control at the upper thoracic region. His parents reported that he is happiest and most functional when being held. Figure 8a shows his mother supporting him during part of his evaluation. Note that she has stabilized his pelvis by having him straddle her leg and by pulling him up against her

(continued)

body. She is providing firm support to his trunk at the level of the axillae and JAS consistently kept his head pressed backwards against his mother. On the few times when he pulled his head away from his mother's body it fell forward rapidly.

Intervention

1. Equipment and positioning devices for participation:

JAS is enrolled in a pilot study that explores options for providing segmentally appropriate equipment across as many activities as possible as a supplement to other interventions. Since JAS was more than a year of age and did not yet have any self-mobility, we created a custom seating system for an electronic car. He controls "when" the car stops and goes. His parents control "where" it goes by using a rope and pulley steering mechanism (Fig. 8b, *right*). We adapted a commercially available Firefly GoTo seat (https://www.fireflyfriends.com/us/goto-seat) by adding a pelvic strapping system (Butler et al. 2010) to stabilize his pelvis. Without the additional pelvic strapping system, he tended to extend his trunk and legs making it difficult to maintain a vertical sitting position. Car adaptations included a large push button switch and modifications for seat installation. He was able to operate the switch immediately. His parents were instructed in how to strap him into the seat and how to remove it from the car if they wanted to use it in other places during his daily routine. While this seat allows JAS to have upright experience in a variety of environments and the opportunity for upright eye-head-hand coordination, it does not

(continued)

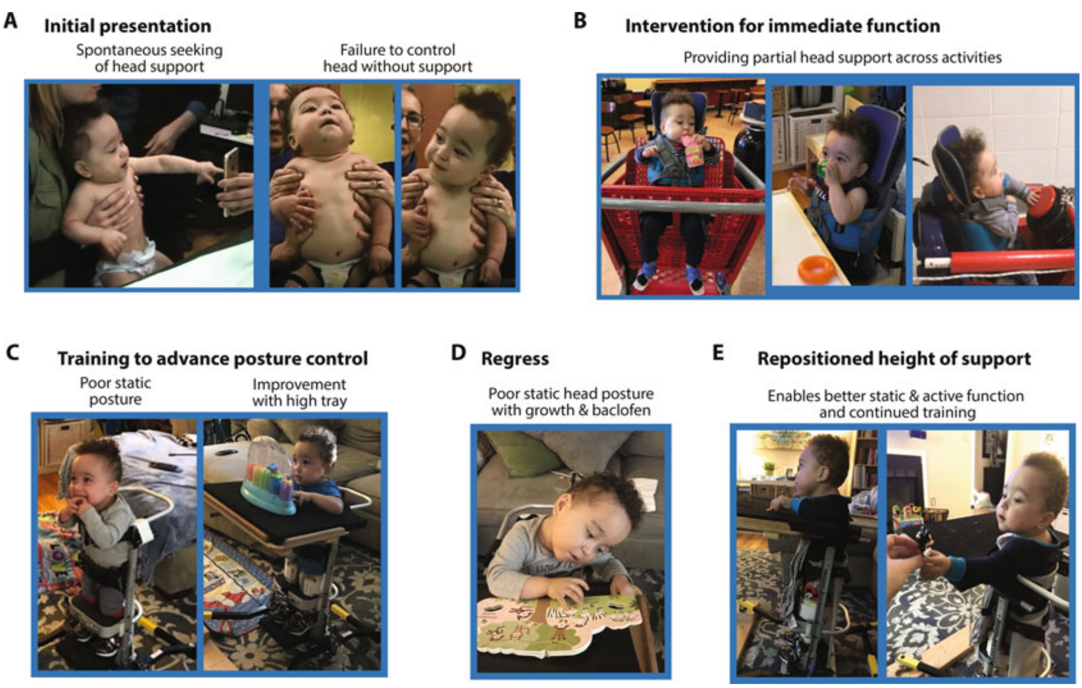

Fig. 8 Case example of a young child with cerebral palsy at GMFCS level V, showing rationale and adjustments made to equipment to promote opportunities for the child to practice vertical upright postural control

challenge or allow him to train new levels of trunk posture control.

2. Targeted Training and motor learning for postural control:

For posture training, we used the Targeted Training approach (Butler 1998; Curtis et al. 2016) and created a custom stander to hold him in vertical alignment with very firm support to the axillae and a tray at shoulder height (Fig. 8c). With axillae support but no tray we found that he tended to collapse forward into the front band and did not achieve active vertical alignment. With the tray added at shoulder height JAS was able to raise his head and hold it upright for more than 10 s and turn to look to either side. If his head started to fall backward, he was able to recover quickly and efficiently so we did not need to use a head rest. He trained in this device beginning with 5 min per day and progressing to 20–30 min per day 5–6 days per week. We noticed a fairly immediate increase in bilateral hand activities and he has continued to use both hands when in the stander. After 4 months of training, he was able to pass the SATCo at the level of head control and progressed to activities that involved raising his arms up off the tray to begin working on upper thoracic control. At that time he was also started on Baclofen. Within 1 month, his parents reported that he was developing a habit of dropping his head to one side or the other and it was difficult to get him to hold his head upright especially when working on refined activities that required visual-motor precision. When he came for his device fitting, we found that he had grown so the support level had shifted down towards the mid thoracic region and he was unable to attain and hold vertical head alignment for more than a few seconds (Fig. 8d). The device was adjusted to reposition the support at the axillae for upper thoracic training and his activities were advanced for reaching further to each side. He was able to accomplish this with good head control during approximately 5 out of 8 attempts and his parents were instructed in how to entice this by alignment of the toy or snack they were offering him.

Outcomes

1. Participation in environment – Family and Community

The adapted Firefly seat with pelvic strapping was very successful for the family as it allowed him to be placed in a grocery cart (Fig. 8b, *left*), in high chairs when eating out and in his toddler chair and table set (Fig. 8b, *center*). This device reduced the burden of care for his family, allowed better social interaction with his parents because they could interact face to face with him during activities instead of always having to sit behind him, and increased his ability to participate in more community activities. His mother reported that it made shopping for shoes to go over his braces extremely easy. Previously when he needed to be held in parent's arms, it had been nearly impossible to try shoes on over his AFO's. JAS recently started preschool and his parents are promoting conversations between his local physical therapist and our research team to explore options for adapting his school equipment to allow him to continue practicing upright control within that environment. These adaptations mostly involve creating firmer support, higher on his trunk and in more vertical alignment. Based on these results, future studies may

(continued)

benefit from formal participation outcome measures.

2. Structure and Function Measures

We used SATCo to monitor segmental improvements in posture control and adjusted the devices based on improved posture and function in the devices. Traditional global outcome measures were used to monitor fine and gross motor changes (e.g., PDMS-2, GMFM) and laboratory posture tests (kinematics with various types of perturbation) are being used to assess changes in posture for the research study. There is a need, especially for children who are at GMFCS levels IV and V, to develop or validate more clinical outcome measures that reflect the effects of improved posture for head and/or thoracic control, for example, assessments of eye-head-hand coordination, social interaction, communication or feeding. Typical infants do not gain independent sitting until they achieve trunk control in the lower lumbar or pelvic regions (Saavedra et al. 2012); thus, posture measures of sitting balance will not be sensitive to improvements at higher segments of the trunk.

Professional Practice Reflections with Respect to Device Modifications

For children at GMFCS levels III–V, we have made suggestions for modifying equipment to allow combined practice of posture and functional tasks. For physical therapists in the USA, the Federation of State Boards of Physical Therapy Model Practice Act definition for "practice of physical therapy" includes *prescription, application and as appropriate, fabrication of assistive, adaptive, orthotic, prosthetic, protective and supportive devices and equipment (The Model Practice Act for Physical Therapy. A Tool for Public Protection and Legislative Change, 5th edition, 2011).* However, practice acts are determined by each state individually. Therapists are encouraged to assume responsibility to review the practice acts and regulations in the state or country where they are licensed to determine if there are conflicts that limit their ability to make these type of modifications. As with all professional practice, therapists must use caution and care to assure the safety of the child and take responsibility to train the caregivers in proper use of the equipment. The modifications we have suggested for the most part increase the firmness or height of postural support. We are not recommending structural changes to manufactured equipment. A number of manufacturers have begun to recognize and respond to therapists' requests for seated and standing devices that allow firmer, more specific, segmentally adjustable trunk support (e.g., Leckey, R82, Rifton). Clinicians and families who find modifications to be helpful should continue to share with manufacturers.

Cross-References

▶ Cerebral Palsy Prognosis Based on the Physical and Neurologic Examination
▶ Gaming Technologies for Children and Youth with Cerebral Palsy
▶ Seating and Positioning Approaches for Children and Youth with Cerebral Palsy
▶ Selective Voluntary Motor Control in Children and Youth with Spastic Cerebral Palsy
▶ Treadmill Training for Children and Youth with Cerebral Palsy
▶ Using Hippotherapy Strategies for Children and Youth with Cerebral Palsy

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