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Reviews/Short communication

The Reactive Postural Control in Spastic Cerebral Palsy Children

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Objectives: Postural control deficit is one of the most important problems in children with spastic cerebral palsy (CP). The purpose of this paper is to review the reactive postural control in spastic children with CP.

Methods: Researches on development of reactive postural control in typically developing (TD) children and children with Cerebral Palsy (CP) were analyzed.

Results: The results of this review revealed at least three main systems of reactive postural control, including: sensory, motor, and cognitive systems. These systems develop in a nonlinear mode. Maturation of postural control depends on the reach of each system to an adequate threshold of development and organization.

Conclusion: limited data indicated the development of reactive postural control in children with CP occur similar to TD children but with limitation in motor function and sensory organization.

Key words: reactive postural control, balance, adjustment postural control, child, cerebral palsy

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Introduction

Cerebral palsy is described as a general term for a syndrome of non progressive disturbances in the developing fetal or infant's brain. It is designated as a group of permanent disorders and dysfunctions of the sensory, motor and posture systems (1). There are many categories and types of CP. The spastic type is the most prevalent type of CP (2). It is characterized by an increase muscle tone, pathological reflexes and exaggerated deep tendon reflexes that causes developmental abnormality in motor function and postural control (3). Postural control deficits are the major causes of long-term disability in these children. The postural control problems lead to the child's activity and participation restrictions (4). This article aimed at: 1) to describe postural control and its model 2) explain systems for reactive postural control and their development and 3) review available researches on the reactive postural control in children with spastic CP.

The postural control and models

Postural control as an important part of motor development, is defined as controlling the body`s position in space in order to obtain stability and orientation (5). Postural orientation is the ability to control the relationship between the body segments, between the body and the environment while doing a task. Postural stability (balance) is defined as the ability to control center of body mass (COM) in the stability limits (5). Postural control includes three types including: steady state (static), reactive (adjustment) and anticipatory (proactive).

Static refers to control of the COM relative to the base of support (BOS) under unperturbed conditions. Reactive is the ability to recover postural control after an unexpected perturbation and anticipatory refers to ability to modify postural control prior to a potentially destabilizing movement in order to avoid instability (6). Postural control is described in a variety of models such as reflex model, hierarchical model, systems model and ecological model (5).

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Recent models of postural control show that development of postural control not only depends on the sensory or musculoskeletal system, but also engages other systems' interactions. According to the systems theory, postural control is complex and context-depended (5). It is created by the interaction of individual, task demands and environment constraints (5).

Task demands can impress on the neural organization of postural control. The nature of the task determines the type of movement required action. There are many functional categories for grouping tasks such as; stability and mobility tasks, bed or transfer tasks, hierarchy of stability demands, and movement variability (open-close) (5).

Environment constraints have effect on postural control via two features (including regulatory and non-regulatory). Regulatory features consist of size, shape and weight. Non- regulatory features are background noise, light and presence of distractions (5).

In individual, postural control emerges through the interaction of multiple brain structures and processes such as: Musculoskeletal, neural, cognition, and perception system.

Systems for reactive postural control

Produce effective postural control related to the organization of several systems. At least three systems play the main role in generating and coordinating postural control (7). They are sensory, motor, and cognitive systems that reviewed as below.

Sensory System: Sensory system consists of vision, somatosensory and vestibular components. The central nervous system (CNS) organizes outputs from these senses for controlling posture.

The visual component: provides an illustration of the vertical plane depended on the objects in the visual field. Vision is essential for postural control. Visual inputs can influence postural control via focal system (for object identification) and ambient system (for movement control). Visual inputs provide information regarding the position and motion of the head. It occurs by reacting to motion as a relative image shift on the retina, and stimulates the muscle activation needed for postural recoveries (8-10). Development and maturation of visual component in infants and children for postural orientation recoveries occurs as: for head control during birth to two months, for sitting balance during birth to one year, and for independent standing to early walking during 13-16 months of age. Children show adult -like ability to use vision as primary information for controlling their posture during 2-10 years old (11, 12). The efficiency of vision in postural control depends on: mutually inputs coordination from other information sources (vestibular- somatosensory inputs), visual acuity, object distances (the optimal distance is less than 2 m), visual contrast and light. (7).

The somatosensory component: Proprioceptors and exteroceptive receptors provide information about limb position and support surface characteristics for somatosensory component. Information related to limb, body position and the distension of the respective muscles, are generated by the proprioceptive receptors. Proprioceptors are enriched in muscle spindles (type Ia and II), Golgi tendon organs (Ib) and joint receptors. Exteroceptive receptors are located in the cutaneous and subcutaneous tissues. The most important types of cutaneous receptors are Meissner corpuscles and Merkel disks (located closest to the skin surface) and Ruffini ending and Pacinian corpuscles (in deeper in the skin) .These receptors are also in joint capsules, generate information about the movements and positions of the body parts (their roles in postural control have not been fully determined yet). The pressoreceptors determine the body sway; the mechanoreceptors can detect both the location and velocity of the skin stimulation, as well as acceleration and pressure changes. The proprioceptors generate some critical inputs for postural control during stance: First, they recognize the ankle joint's inputs in order to detect the movement of the center of gravity. Second, they generate the neck muscle's inputs in order to give important references concerning head movement in relation to the trunk. And third, they provide input from the eye muscles to reproduce the eye position in relation to the head. Somatosensory processing occurs in the parietal lobe of cerebral cortex (8, 9, 13). The age of maturation of using somatosensory inputs in infant and children in postural control: for head competency responses and maintenance of sitting balance is 6 months of age or greater, for sensory conflict declaration is 4-6 years old and showing adult –like ability is 7-10 years old (14, 15).

The vestibular component (system) is one of the most important parts of central nervous system

(CNS) for postural control. The vestibular system works as both sensory and motor systems. As a sensory system, it provides information about the position and motion of the head and the direction of gravity. The CNS combines this information with information from other sensory system. Then it provides a schema or a map of the position and movement of the entire body (sensing and perceiving self-motion) in the surrounding environment (orienting vertical). As a motor system, provides necessary information in order to control center of mass, and stabilize the head (16).

The motion sensors of this system are: 1) The semicircular canals (SCCs) sense movement's velocity changes with 0.2 to 10 Hz frequencies, and they have been active at the beginning and the end of rotational movement. 2) The otholiths sense movements with low frequencies (less than 5 Hz) and provide information of linear acceleration, e.g. gravity (16, 17). The vestibular system output also contributes directly to motor control via three main reflexes. The Vestibulo-Ocular Reflex (VOR) generates eye movement. The vestibulo-ocular reflex produces eye movements that compensate for head motion; it provides clear vision when the head is in motion. The Vestibulo-Spinal Reflex (VSR) is to stabilize the head and the body, also it generates positional movements. The vestibule-colic reflex (VCR) works on the neck muscles to stabilize the head (13, 16). There is controversy idea about the roles of vestibular to the perception of body orientation and the perception of sway during normal quiet stance (18, 19). Nevertheless vestibular function is responsive during 6 to 12 months of age, it is gradually maturing as children can use vestibular inputs around 15 years old as a reference system as an adult (20).

Motor system: Motor system plays main roles in developing postural control, by an organization sufficient activation of muscles in maintaining stability of the neck, trunk and legs. It consists of two subsystems: musculoskeletal including: strength, ROM, muscle tone, body geometry, alignment and neuromuscular consist of: postural tone, force generation, coordination of muscle activity and timing) (21, 22). To understanding the role of the motor system in postural control, we must keep in mind some terms such as: synergy, strategy and co activation.

Synergy results from production of unnecessary movements in joints and muscles that generates mass and stereotypical patterns of movements. These movements are not changed and adapted to changes in task or environmental demands (21, 22)."A synergy is defined as the functional coupling of groups of muscles that are constrained to act together as a unit; this simplifies the control demands on the CNS" (23;p:172).

Strategy is defined as a plan for action, in which organized individual elements into a jointed structure. Strategies contributing to postural action are: postural control strategies as defined the organization of suitable movements for controlling the body's position in space (24). Sensory strategies are the organization of sensory information from visual, somatosensory and vestibular components for postural control. Sensorymotor strategies are coordination of sensory and motor aspects of postural control (25). Attention strategies determine the degree of attention provided to the pastoral task when doing other tasks at the same time (26).

Co activation is one of the findings in early stages of learning a skilled movement, during early stages of postural development in a healthy infant, or a result of functional impairments. It is defined as activation of both the agonist and the antagonist muscles simultaneously and coordinately during functional movements (22, 23)

Neuromuscular subsystem: The roles of neuromuscular subsystem in postural control happen through motor process and involve components in high level planning, coordination, and force generation. Planning is being processed in frontal and motor cortex. Coordination is being processed in brainstem and spinal networks where coordinated muscle response synergies. Process of force generation occurs in motor neurons and muscles (8).

After body perturbation, we must get postural stability .It occurs by three motor reactions: reflex, automatic and voluntary reactions. Reflex reactions don't play a directive role in balance recovery. This response regulates muscle force by generation stretch reflex through spinal pathways. Automatic reactions coordinate the contraction of all muscles of legs, neck, and trunk via sub cortical and brainstem pathways. Voluntary reactions take place through cortical pathways. These responses are variable and generate purposeful movements. Development of muscle coordination pattern is organized for head control, sitting balance and standing balance.(9) According to Electromyography (EMG) recording for head control, activation of neck muscles starts through active head turning during 0-7 week's age. Head control is completed during 2-4 months of infants' age. Infants present group activation of anti gravity extensor and flexor muscles during 3-5 months in porn and supine position (27). For sitting, infants are able to sit with arm support during 5-6 months of age. At this time muscle coordination patterns are activated but co contractions and reversal of proximal to distal pattern are displayed in variable timing and , the adaptation to task specific condition are poor. During 7-10 months of age, infants can sit with decreased timing variability and activations of leg, trunk and head muscles. From 9 months to 3 years old, children show invariant of directionally specific muscle coordination patterns and good modulation of base of support for adaptation to task specific condition. Children show muscle coordination patterns in less co-contraction and variability direction similar to adult after 3 years old (28-30). For standing, infants who pull to stand, display beginning of ankle strategies during 7-8 months age. They stand independently with grossly directionally specific muscle coordination patterns from distal to proximal during 10-12 months. Stepping strategies are presented with variability of directionally specific muscle coordination patterns from 4 to 6 years old, and children can stand like adult during 7-10 years old (27, 31-33).

Musculoskeletal subsystems: Musculoskeletal subsystems contribute in coordinating postural activity via many components such as: Rang of Motion (ROM), muscle strength, muscle tone and body geometry (9, 23).

This system generates necessary force for producing muscle activity. Force generation can be shown in neck muscles against gravity at 2 months. Infants produce adequate force to maintain body weight at 6 months. Children show overall torque generation to recover balance after sudden distribution during 9 months to 10 years. Postural capacity to control balance with leg muscles may be complete after 4 or 5 years of walking experience (32, 34). Development and maturation age of ROM occurs through the teen years. Body geometry develops at different ages and related to gender and hormonal conditions. Children display kinematics of body sway similar to adult approximately at 4-6 years old and decrease sway velocities through 12-15 years old (27).

Cognitive (cortical) system: Postural control is not automatic, but requires some amount of attention or information recourses. There are significant attention requirements for postural control as called dual tasks. Dual tasks can refer to the simultaneous challenge changes in postural control and completion of another attention demanding tasks (23). The role of cognitional tasks on postural control is not constant, but depends on:

1) The age: clearly that in normal children, as the age increased, attention capacity are increased (35, 36).
2) Voluntary attention focuses on postural control: when voluntary attention focuses on the movements or on body sway, the neuromuscular activity improves. It means that the recruitment of additional motor units improves and the muscular force generation increases. So that postural control is regulated better (37, 38).
3) The sensory information.
4) The children's previous experiences.
5) The complexity level of the task: as the level of complexity of cognitive tasks is being more, the ability of children under 7 years old to perform pastoral tasks is being less. But the reaction of the older children in these situations is recruitment different postural strategies to keep stability (39, 40).

The role of cognition in developmental postural control has not been studied in depth, but many scientists confirm that cognitive processing plays the important role in the development of postural control.

Reactive Postural Control in Children with CP

As motioned many systems play a role in reactive postural control. Disruption in these systems due to delay or diseases will result in inadequate postural control strategies.

The postural control is the basis to support the primary movement. It is necessary for the emergence of psycho motor skills (head control, sitting, crawling, independent standing and walking) in children. Understanding the pastoral substrate for these skills, and the knowledge of constraints in their postural abilities is the first step in determining the best therapeutic interventions. There are few studies about the development of postural control of children with CP during infancy. Most studies are about postural muscle activities, assessment of postural control in children with CP, or explaining the differences between CP and normal children in postural control. In this review, we have reported current knowledge about contributing systems in children with CP's Reactive Postural Control (RPA). This is outlined below:

Sensory system in RPA of children with CP

Studies show sensory system deficits in spastic children with CP can be affected on organization sensory inputs to changes in tasks and environmental demands. Also they can be caused to provide an inaccurate schema for RAP. Typically developing (**TD**) children are dependent on the visual component of sensory system to controlling their posture aged 4 months to 2 years. They start to use somatosensory information appropriately during 3 to 6 even 11 years of age. The vestibular function gradually improves children's RAP in sensory conflict conditions at birth to 15 years of age (20). Investigators indicated spastic children with CP depend on the visual information on the RAP after 2 years old (41). They have difficulty in using somatosensory information. The development of the vestibular component in RAP isn't clear yet (42). It may be related to the low level cooperation of infants and children in testing of this system and unavailability tests of vestibular function in this group (43).

One of the ways for measuring the influence of vision, somatosensory and vestibular inputs on RPA is "Sensory Organization Test "(SOT) which developed by Nashner and colleagues. SOT has many versions as the Clinical Test of Sensory (CTSIB), or the Pediatric Clinical Test of Sensory Interaction and Balance (P-CTSIB). In all versions subject should stand quietly for 30 seconds in six different sensory environments and has measured her/his sway (43). The amount and frequency of sway indicate the sensory system's ability to organize sensory information (vestibular, vision and somatosensory) correctly. The conditions include: no sensory conflict (eyes open and surface is firm), no vision (eyes closed and surface is firm), inaccurate visual information (firm surface with visual surround sway referenced, inaccurate somatosensory information (eyes open with sway referenced surface), vestibular sensation only inaccurate visual and somatosensory information (eyes closed with sway referenced surface), and 6) vestibular sensation only with accurate visual and somatosensory information (visual surround and surface sway referenced) (25, 43, 44).

Nashner et al., (1983) analyzed sway response of 10 spastic (mild to severe) children CP aged between 7 and 9years and compared them with TD children .They suggested that children with CP have more sway than TD children in the six sensory conflict conditions. These results indicated children with CP have difficulty with organization of sensory inputs for controlling their balance in different sensory situations (45). Cherng et al., (1999) compared the sway index of 14TD children with seven mild spastic children with CP 7-8 years old in six sensory conflict conditions with SOT. They found the sway was not different in CP and TD children on conditions 1, 2, 3 on SOT. The results demonstrated children with CP can maintain stability when sensory information for RPA is consistent, and they are unstable when there is unreliable somatosensory information. The difference in stance stability between two groups was significantly greater in unreliable somatosensory situations than the unreliable visual situation (46) .Others reported similar results that Spastic children with CP have greater sway than normal children with different swayed surface conditions due to nature of CP condition and poor sensory organization and re-weighting sensory inputs coming the vestibular, vision and somatosensory recourse (47-53).

This review shows that the developmental changes in sensory organization strategies in children with CP are similar to TD children but with delay. This delay may be related to severity of sensory system impairments, its flexibility to the weighting of sensory inputs for orientation and difficulty in shifting from unreliable sensory inputs to another type of scenes.

Neuromuscular subsystem in RPA of children with CP

According to Forssberg and Hirschfeld (1994) there are two levels in neural development of postural control .The first level is defined as generation of basic direction-specific adjustments. The second level is fine-tuning as means involvement of multi-sensorial afferent inputs (from somatosensory, visual, and vestibular) to generate the basic postural pattern (54).

According to study of Nashner et al. (1983), the spastic children showed impairments in direction-specific responses, disproportionate amount of co-activation in the antagonistic leg muscles during forward displacement and a reversal of the normal bottom-up muscle recruitment (45).

Brogren et al., (1998) studied ten mild to severe type of spastic diplegia aged 4-11, and ten genders and age matched controls during sitting position. They recorded muscles activity from three the ventral body muscles (i.e., neck flexors, abdominal muscle, hip flexors) and four dorsal muscles (i.e., neck extensors, thoracic extensors, lumbar extensors, hip extensors). They analyzed postural responses based on direction specificity, temporal ordering and degree of co- activation at sitting position on a movable platform producing a random series of forward (FW) and backward (BW) translations. They indicated that in direction specificity, children with CP achieved basic muscle coordination pattern at the first level. Children with CP showed stereotyped activation in 3 ventral muscles whereas the controls responded with a variety of patterns on muscles. It can be due to the severity of the impairment and the excessive co- activation of muscles. However children with CP didn't show stereotyped activation during BW translations. Concerning the temporal order of muscle recruitment, children with CP began the response with neck flexors but control group started with abdominal muscle during FW translations. This difference could be due to deficits of the CNS in the generation of a mature response pattern. Both groups started in response with the most caudal muscle, hamstring muscle during BW translations. The difference between FW-BW translations may be related to the difference in stability limits in FW-BW direction and in neural mechanisms controlling the dorsal and ventral muscles. During co-activation of antagonistic muscles, children with CP showed co-activation of antagonistic neck and hip extensors muscles but control group had a reciprocal activation. Also the time relationship in antagonistic activation was different (55).

The study of Hadders-Algra et al., (1999) was only studying on the development of postural control of children with CP during infancy. They designed a longitudinal assessment of postural control in 6 children with CP with different severity during reaching between 4 and 18 months. The TD children showed direction-specific adjustment till 15 months of age but children with CP showed this after 18 months of age. Children with high severity lacked direction-specific postural adjustments and they could not adjust pastoral activity to task condition (56).

Ferdjallah et al (2002) described the postural control synergies and approximated the contribution of body transverse rotation using the weighted differential center of pressure signals during quiet standing in TD and children with CP (7-10 years old) using dual force platforms. They found that body transverse rotation contribution is significant in TD children and is critical for postural stability in children with CP They presented poor ankle control mechanisms so increased the hip protraction/retraction synergies (because it needs less muscle's efforts) and body transverse rotation for maintaining balance (57).

Van der Heide et al., (2004 & 2005) found top-down recruitment of postural muscles in children with CP in sitting, reaching in a sitting and standing position. They indicated that it was related to the severity of the impairment and child's efforts to cope with deficient postural control (58, 59).

Woolacott et al., (2005) stated that these children present a high degree of antagonistic co-activation in sitting position. This is high during backward body sway and low during the forward body sway. This could be related to the configuration of the sitting and to more experience of forward body sway during daily activity (60).

Peters et al., (2007) stated that development of postural control in children with CP is related to the severity of the impairment. Children with severe types of CP are confronted by serious dysfunction of the first level of postural control; they don't achieve the second level. Mild and moderate forms of children with CP are basically intact in the first level, but at the second level show problems in these areas: dominance of crania-caudal recruitment, the amount of antagonist co-activation and the degree of muscles contraction and spasticity in the specific situation (61).

As mentioned before there are many differences in the modulation of the response in children with CP excessive antagonistic muscle's co-activation, weakness and inappropriate timing of muscle activation, lack of voluntary movements and abnormal top-down muscle recruitment (55, 62-68). But investigators did not describe how these differences occurred, are there any differences in response between open and closed eye, or which neural mechanisms are involved in this.

Musculoskeletal subsystems in RPA of children with CP

It is clear that spasticity, hyperactive stretch reflexes and limited ROM in ankle, hip and knee contribute to RPA of children with CP. These decrease the sequencing, timing and amplitude of postural muscle activity (66, 68, 69). Abnormal postural alignments in sitting and standing can produce many contractures and involve muscles recruitment and coordination for RPA (69). Crouched posture has been most common mal –alignment which shown by children with CP for keeping balance following a perturbation.Crouched posture in sitting is characterized by excessive posterior tilt of the pelvic and shortened hamstring muscle. This position can be a solution to the instability on sitting (62, 70, 71). Crouched posture in standing is characterized by hip flexor tightness, knee flexion and shortened gastrocneminus muscle. It can decrease the leg and trunk muscles recruitment and coordination following balance perturbation (68, 72).

Cognitive (cortical) system in RPA of children with CP

Research on the role of cognition factors in the postural control in children with CP is a new and expanding area. However the authors found only one study about the relationship between cognition factors (as known dual tasks) and postural control in children with CP. Reilly et al;. (2008) investigated the relationship between postural task (the primary task) and a cognitive task (secondary task) in four groups in childrenfrom4 to 14 years old. The two groups were children with CP as both type spastic and ataxic aged 10-14 years and in level 1, 2, 3 of Gross Motor Function Classification System (GMFCS). The other groups were TD children as young TD children aged 4-6 years and older TD children aged 7-12 years. The postural tasks were two positions of stance: wide and narrow. The cognition task was a modified form a visual working memory. They found in dual task (narrow stance) spastic children with CP showed faster and greater sway than old TD children and similar to young TD children. They stated that this difference may be due to the slower reaction time of children with CP to conflicting stimuli and the constraint of executive attention capacity in children with CP (38).

It appears further studies with considering the equally difficult tasks between children and the equally children's experiences are needed.

Conclusion

According to this review, there is little study about the development of postural control in children with CP especially during infancy. Most studies in this area could be related to moderate to the mild type of disorder and to school aged children who have not the extent motor control or cognitive problems. Investigates the role of cognition and sensory factors in children with CP postural control is rare. However, recently studies have been investigated on motor system aspects of pastoral control. Despite many researchers have been done on postural control in cerebral palsy children, we still are dealing with limitation to full understanding of postural control systems, the effect of the feedback system, the environmental factors and the education on postural control. Hence, it is required further studies and much work on different approaches in this area.

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