

Postural Muscle Dyscoordination in Children with Cerebral Palsy

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ABSTRACT

The present paper gives an overview of the knowledge currently available on muscular dyscoordination underlying postural problems in children with cerebral palsy (CP). Such information is a prerequisite for developing successful therapeutic interventions in children with CP. Until now, three children with CP functioning at GMFCS (Gross Motor Function Classification System) level V have been documented. The children totally or partially lacked direction specificity in their postural adjustments and could not sit independently for more than 3 seconds. Some children functioning at GMFCS level IV have intact direction-specific adjustments, whereas others have problems in generating consistently direction-specific adjustments. Children at GMFCS levels I to III have an intact basic level of control but have difficulties in fine-tuning the degree of postural muscle contraction to the task-specific conditions, a dysfunction more prominently present in children with bilateral spastic CP than in children with spastic hemiplegia. The problems in the adaptation of the degree of muscle contraction might be the reason that children with CP, more often than typically developing children, show an excess of antagonistic co-activation during difficult balancing tasks and a preference for cranial-caudal recruitment during

during reaching. This might imply that both stereotypies might be regarded as functional strategies to compensate for the dysfunctional capacity to modulate subtly postural activity.

KEYWORDS

spastic hemiplegia, motor development, spastic diplegia, EMG

INTRODUCTION

Children with cerebral palsy (CP) are often hampered by dysfunctional postural control (Hadders-Algra et al., 1999b; Brogren et al., 2001; Van der Heide et al., 2004). Postural control is a prerequisite for activities in daily life. In the neural control of postural adjustments two functional levels can be distinguished (Forssberg & Hirschfeld, 1994). The first level consists of a direction-specific adjustment when equilibrium of the body is endangered. In the case of reaching, this adjustment means that the muscles on the dorsal side of the body are primarily activated when the body sways forward. The second level is involved in the fine-tuning of the direction-specific adjustment based on multisensorial afferent input from somatosensory, visual, and vestibular systems. This modulation can be achieved in various ways, for instance, by changing the order in which the agonist muscles are recruited (e.g., in a caudal-to-cranial sequence or in reverse order), by modifying the size of the muscle contraction, which is reflected by the EMG-amplitude, or by altering the

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degree of antagonist activation.

Children with CP are often treated for their postural problems, but the effects of therapy are largely unknown and only partly successful or not successful at all (Mayston, 2001; Bower et al., 2001; Cioni, 2002; Washington et al., 2002). Developing successful therapeutic interventions in children with CP requires a better understanding of the underlying mechanisms of postural control in children with CP. The present paper aims at giving an overview of the knowledge currently available on the muscular dyscoordination underlying postural problems in children with CP. Special attention is paid to postural dysfunction during reaching in a sitting position.

POSTURAL CONTROL IN TYPICALLY DEVELOPING CHILDREN

The majority of studies on postural adjustments in typically developing children have been performed using external perturbations, and relatively few studies addressed postural control during self-initiated movements like reaching and walking. The studies indicated that postural adjustments during different tasks and postures, such as sitting and stance, are direction specific and variable. External perturbation experiments in a sitting position demonstrated that direction-specific postural muscle activity can already be found at the age of 1 month (Hedberg et al., 2004). Direction-specific adjustments during reaching while lying supine or sitting are present from the age at which reaching ends in successful grasping (Van der Fits et al., 1999a).

Modulation of the EMG-amplitude of the basic direction-specific adjustment in sitting emerges soon after the child has developed the skill of sitting independently and is present from 9 to 10 months onwards (Hadders-Algra et al., 1996). When the child has developed the ability to stand and walk, the capacity to modulate postural adjust-

ments continues to develop, meaning that children gradually develop the ability to adapt postural activity in a subtle and energy efficient way to task-specific circumstances. One way in which the child can adapt his/her posture to the situation is by selecting from the repertoire of direction-specific adjustments the so-called *en bloc* adjustment (i.e., the adjustment during which all direction-specific neck and trunk muscles are activated in concert) when the risk of losing balance is high. This explains why the *en bloc* strategy dominates postural control during external perturbations in sitting until the age of 2½ to 3 years (Hadders-Algra et al., 1998) and during walking until 7 years of age (Assaiante & Amblard 1993; Assaiante, 1998), whereas this strategy is infrequently used during reaching in a sitting position (Van der Heide et al., 2003; Hadders-Algra, this issue).

The participation of antagonists—muscles that antagonize the function of the primarily activated muscles—in the postural adjustment mainly occurs when postural balance is at stake, for instance when children learn a new skill such as standing or walking independently (Forssberg & Nashner 1982; Berger et al., 1984). In general, antagonistic postural muscles are rarely recruited during sitting tasks. There are two transient exceptions to this rule. First, infants aged 8 to 18 months show a high rate of neck flexor activation during reaching—a finding that underscores the need for head stabilization in space for such individuals during this task (Van der Fits et al., 1999b). Second, children aged 9 months to 2 years frequently recruit antagonistic, dorsally located neck, trunk, and leg muscles during perturbations inducing a backward body sway, a situation which really challenges balance (Hadders-Algra et al., 1998). In standing, antagonistic activation is present at least until the age of 5 years (Forssberg & Nashner, 1982). When brought into play, the antagonists usually are not activated synchronously with the agonistic muscle but rather only after a delay of at least 40 ms.

During infancy, the temporal organization of muscle activity within direction-specific adjustments is highly variable (Hirschfeld & Forssberg, 1994. Hadders-Algra et al., 1996. Van der Fits et al., 1999b. Hedberg et al., unpublished; Washington et al., 2004). Nevertheless, during early infancy a mild preference for a top-down recruitment order can be observed (Hadders-Algra et al., 1996). In postural adjustments during external perturbations in sitting, the mild dominance of top-down recruitment changes around the end of the first year into a bottom-up recruitment (Hadders-Algra et al., 1996. Washington et al., 2004). The latter can be observed particularly when there is a high risk of losing balance, i.e., during perturbations in stance (Shumway-Cook & Woollacott, 1985. Sundermier et al., 2001). The recruitment order of direction-specific muscles during reaching while sitting remains highly variable throughout childhood. Also here general developmental trends can be distinguished: at early sitting age, postural muscles are most often recruited in a bottom-up fashion, whereas from 5 years onwards a mild preference for top-down recruitment emerges (Van der Fits et al., 1999a. Van der Heide et al., 2003).

The presence of anticipatory postural activity—defined as postural activity preceding the focal, voluntary movement—is dependent on task, position, and age. Anticipatory postural activity during reaching while sitting occurs consistently in infants only of 15 to 18 months (Van der Fits et al., 1999b. Van der Heide et al., 2003), but during most standing and walking, tasks anticipatory postural adjustments are consistently present beyond the age of 18 months (Forssberg & Nashner, 1982. Haas et al., 1989. Assaiante et al., 2000). A task during which no consistent anticipatory postural adjustments have been found in children aged 4 to 14 years was an arm-raising task during stance (Riach & Hayes, 1990).

The development of the subtle modulation of EMG amplitude shows a protracted course. The capacity to modulate EMG amplitude based on

proprioceptive information emerges around 9 to 10 months (Hadders-Algra et al., 1996. Van der Fits et al., 1999b). The postural muscle that forms the focus of modulation—the postural muscle showing the most marked amplitude modulation—varies with age and task. For instance, in adults who reach while sitting, the neck muscles are the focus of amplitude modulation. During childhood, however, none of the postural muscles has the primacy for amplitude modulation during reaching in sitting (Van der Heide et al., 2003). In stance, caudally located muscles usually are the focus of task-dependent modulation (Woollacott et al., 1987. Berger et al., 1995).

POSTURAL DYSCOORDINATION IN CHILDREN WITH CEREBRAL PALSY

In the majority of children with CP, the basic level of postural control is intact. Only children with severe forms of CP—children functioning at levels IV or V of the GMFCS (Gross Motor Function Classification System. Palisano et al., 1997)—have problems in generating direction-specific adjustments (Hadders-Algra et al., 1999a. Brogren et al., 2001). Postural abilities in these severely affected children have been tested in a sitting position only. Until now, three children with CP functioning at GMFCS level V have been documented (Hadders-Algra et al., 1999a,b. Van der Heide et al., 2004). Two totally lacked direction specificity in their postural adjustments and were unable to sit independently at the age of 4 years. The third child had direction-specific activity in neck and trunk muscles but was unable to generate consistently direction-specific activity in the leg muscles. At the age of 8 years, she could sit without help for less than 3 seconds. Data on postural adjustments in children with CP functioning at GMFCS level IV are available for eight children. Five had difficulties in producing consistently direction specific activity at the level

of the neck or leg muscles. The other three children were able to generate consistently direction specific adjustments (Brogren et al., 2001. Van der Heide et al., 2004).

All children with CP show alterations in the second level of postural control—in the recruitment of antagonistic postural muscles, in the temporal organization and EMG-amplitude modulation. Most studies addressing postural control in children with CP used the external perturbation paradigm. These studies showed that children with CP, aged 1½ to 11 years, show differences in recruitment order, differences in latencies to onset of postural muscle activation, and a higher level of antagonistic co-activation than typically developing children do (Nashner et al., 1983. Brogren et al., 1996. Woollacott et al., 1998). Children with CP also have deviances in the modulation of EMG-amplitude to task-specific circumstances (Brogren et al., 2001). A remarkable finding was that this deficit in EMG-amplitude modulation was attenuated when the children were allowed to sit in their usual crouched sitting position (Brogren et al., 2001).

In the following section, we will zoom in on our own research on postural control during reaching in a sitting position in children with CP.

Postural adjustments during reaching while sitting

Hadders-Algra et al. (1999b) and Van der Heide et al. (2004) focused on the development of postural adjustments during voluntary reaching in children with CP. Postural control during reaching was studied longitudinally in 5 infants with spastic hemiplegia (SH) and in 2 infants with severe bilateral CP (Bi-CP) between the ages of 4 and 18 months (Hadders-Algra et al., 1999b) and cross-sectionally in 34 children with SH and 24 children with Bi-CP, aged 2 to 11 years (Van der Heide et al., 2004).

The results of the studies indicated that most children with CP showed variable postural muscle

activity at all ages. This variability was reflected by the virtual absence of the *en bloc* pattern from the age of 2 years onwards. In only some children with severe CP, reaching movements were accompanied consistently by slow and weak modulations of tonic activity of the postural muscles, whereas a few others with severe CP strongly and consistently activated most postural muscles during reaching. The abnormalities in the postural activation patterns of children with severe CP corresponded with the muscle tone of their neck and trunk muscles. Children with variable postural muscle activation had a normal tone of neck and trunk muscles, whereas children with consistently weak or consistently strong postural activity had hypotonia and hypertonia of their neck and trunk muscles, respectively.

Our studies also demonstrated that children with CP, who are able to reach, have difficulties mainly at the second level of postural control during reaching in a sitting position. The children had a temporal organization of the adjustments that differed from that of typically developing children and had dysfunctions in the ability to modulate EMG-amplitude to task-specific circumstances. Remarkably, children with CP, just like typically developing children, show hardly any antagonistic co-activation in postural muscles during reaching in a sitting position. Thus, children with CP do not exhibit an excess of antagonistic co-activation during this postural task, whereas they do in conditions in which balance is more threatened, such as during external perturbations. This means that antagonistic co-activation in children with CP is not a hard-wired deficit but rather can be regarded as a functional adaptation to, for instance, tasks with a high degree of balancing difficulty.

In contrast to typically developing children, children with CP showed a strong preference for a cranial-caudal recruitment order of the direction-specific postural muscles (Fig. 1). The dominance for top-down recruitment was brought about by a

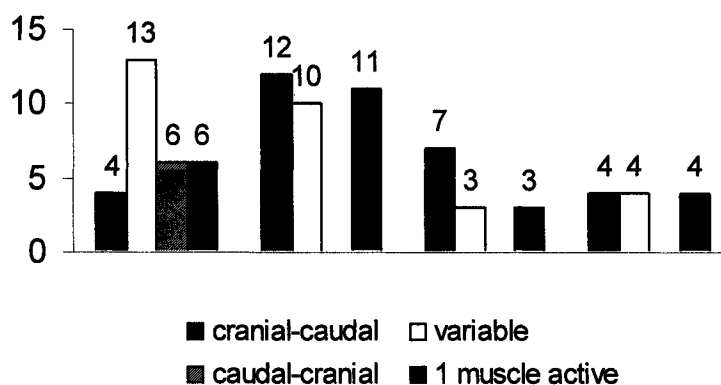


Fig. 1: Recruitment order of direction specific muscles in typically developing children and children with mild, moderate, or severe forms of CP. The severity of the motor disorder was determined during a neurological examination. Prevailing recruitment order was determined based on the mean latencies after prime mover onset per child. Crania-caudal recruitment: trunk muscle recruited > 100 ms later than neck muscle. caudal-cranial recruitment: neck muscle recruited > 100 ms later than trunk muscle. variable recruitment order: neck and trunk muscles recruited with a mean delay of ≤ 100 ms. 1 muscle active: either neck extensor or trunk extensor was activated in isolation precluding the calculation of a recruitment order.

slow recruitment of the trunk muscles and a fast recruitment of the neck muscles. The latter was true in particular for children with a mild or moderate form of CP. We wondered whether the prominent preference for top-down recruitment could be regarded as a dysfunction or as a functional strategy to cope with task-specific circumstances (*cf.* Latash & Anson, 1996).

Arguments in favor of both explanations are present. Arguments for the assumption that the dominance of top-down recruitment can be regarded as a sign of dysfunction are the findings that the preference for cranio-caudal muscle activation was related to a worse mobility score on the Pediatric Evaluation of Disability Inventory (PEDI, Custers et al., 2002), and to the presence of a severe brain lesion on the neonatal ultrasound scan in the children with SH. The argument that the prominent presence of top-down recruitment can be regarded as a functional strategy is the

finding that this strategy was more often seen in children with mild or moderate CP than in children with severe CP. The top-down organization of the postural adjustments might be a reflection that head stabilization in space is a major goal of postural control (*cf.* Pozzo et al., 1990).

The difficulties in EMG-amplitude modulation of the children with CP consisted of problems in adapting the EMG amplitude according to task-specific circumstances, such as arm movement velocity, initial head, trunk and pelvis position, and the presence of a heavy bracelet. These deficits were more profound in children with Bi-CP than in children with SH. An inability to modulate EMG amplitude was associated with a significantly worse quality of reaching movements (Van der Heide et al., under review) and—particularly in children with Bi-CP—to somewhat worse scores on the PEDI, i.e., the capacity to perform activities of daily life.

CONCLUDING REMARKS

Conceivably, in children functioning at GMFCS level V, the basic level of postural control is lacking totally or partially, meaning that the management of these children should focus on the provision of adequate postural support and not on the achievement of postural milestones. Children functioning at GMFCS level IV have a totally or partially intact basic level of control, and children at GMFCS levels I to III all have an appropriate access to direction-specific postural adjustments.

Children with CP, in particular, have difficulties in fine-tuning the degree of postural muscle contraction to the task specific conditions, a dysfunction that is more prominently present in children with bilateral spastic CP than in children with spastic hemiplegia. The problems in the adaptation of the degree of muscle contraction might be the reason that children with CP, more often than typically developing children, show an excess of antagonistic co-activation during difficult balancing tasks and a preference for cranial-caudal recruitment during reaching. This situation might imply that both stereotypies might be regarded as functional strategies to compensate for the dys-functional capacity to modulate postural activity subtly. This in turn, might suggest that guidance of children with mild to moderate forms of CP should not focus on the reduction of co-activation or top-down recruitment but rather on balancing exercises, in which children can practice varying degrees of postural control.

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