Best seating condition in children with spastic cerebral palsy

Angsupaisal, Mattana; Dijkstra, Linze-Jaap; la Bastide-van Gemert, Sacha; van Hoorn, Jessika F.; Burger, Karine; Maathuis, Carel G. B.; Hadders-Algra, Mijna

Published in:
Research in Developmental Disabilities

DOI:
10.1016/j.ridd.2017.09.016

Research in Developmental Disabilities 71 (2017) 42–52

Contents lists available at ScienceDirect

Research in Developmental Disabilities

journal homepage: www.elsevier.com/locate/redevdis

Best seating condition in children with spastic cerebral palsy: One type does not fit all

Mattana Angsupaisal[a], Linze-Jaap Dijkstra[a], Sacha la Bastide-van Gemert[b], Jessika F. van Hoorn[c], Karine Burger[d], Carel G.B. Maathuis[c], Mijna Hadders-Algra[a,*]

[a] *University of Groningen, University Medical Center Groningen, Department of Paediatrics – Division of Developmental Neurology, Groningen, The Netherlands*
[b] *University of Groningen, University Medical Center Groningen, Department of Epidemiology, Groningen, The Netherlands*
[c] *University of Groningen, University Medical Center Groningen, Department of Rehabilitation Medicine, Center for Rehabilitation, Groningen, The Netherlands*
[d] *Vogellanden Rehabilitation Center, Zwolle, The Netherlands*

ARTICLE INFO

Number of reviews completed is 3

Keywords:
Cerebral palsy
Seating inclination
Foot-support
Head stability
Reaching movement
Kinematics

ABSTRACT

Background: The effect of forward-tilting of the seat surface and foot-support in children with spastic cerebral palsy (CP) is debated.
Aim: To assess the effect of forward-tilting of the seat surface and foot-support in children with CP on kinematic head stability and reaching.
Methods: Nineteen children functioning at Gross Motor Function Classification System levels I–III participated [range 6–12y; ten unilateral spastic CP (US-CP) and nine bilateral spastic CP (BS-CP)]. Kinematic data were recorded of head sway and reaching with the dominant arm in four sitting conditions: a horizontal and a 15° forward (FW) tilted seat surface, each with and without foot-support.
Results: Seating condition did not affect head stability during reaching, but did affect kinematic reaching quality. The major reaching parameters, i.e., the proportion of reaches with one movement unit (MU) and the size of the transport MU, were not affected by foot-support. Forward-tilting had a positive effect on these parameters in children with US-CP, whereas the horizontal condition had this effect in children with BS-CP.
Implications: A 15° forward-tilted seating and foot-support do not affect head stability. Reaching in children with US-CP profits from forward-tilting; in children with BS-CP forward-tilting worsens reaching − effects that are independent of foot-support.

What this paper adds?

The nature of the best seating condition in children with cerebral palsy (CP) is debated due to conflicting study results. The latter is presumably due to the mixed composition of the study groups, the specifics of the seating conditions and the measurement methods We studied the contribution of seat surface forward tilting, foot support and the type and severity of CP on the kinematics of head stability and reaching of children with spastic CP. The study showed that in school-age children with spastic CP (6–12 years) functioning at Gross Motor Function Classification System level I to III, a 15° forward-tilted seating with or without foot-support did not affect head stability during reaching. Seat surface tilting did however affect the kinematic quality of reaching. In children with

* Corresponding author at: Departments of Paediatrics—Developmental Neurology, University Medical Center Groningen, Hanzeplein 1, 9713 GZ Groningen, The Netherlands.
E-mail address: m.hadders-algra@umcg.nl (M. Hadders-Algra).

http://dx.doi.org/10.1016/j.ridd.2017.09.016
Received 17 February 2017; Received in revised form 11 September 2017; Accepted 24 September 2017
Available online 05 October 2017
0891-4222/

unilateral spastic CP forward-tilting of the seat surface resulted in the best reaching quality, in children with bilateral spastic CP a horizontal seat surface was associated with best reaching performance. The effect of seating adaptation did not depend on severity of CP (GMFCS level I to III). However, the latter conclusion should be interpreted with caution, as the severity subgroups were small. Foot support affected reaching to a minor extent only.

1. Introduction

Dysfunctional postural control is one of the major impairments in children with cerebral palsy (CP) (Hadders-Algra & Carlberg, 2008). The dysfunction directly influences daily activities, such as sitting and reaching (Hadders-Algra & Carlberg, 2008). On the impairment level, dysfunctional postural control may result in a larger sway of the head (Sochaniwskyj, Koheil, Bablich, Milner, & Lotto, 1991), and a worse quality of reaching movements during sitting (van der Heide, Fock, Otten, Stremmelaar, & Hadders-Algra, 2005a). The stability of the head in space is considered to be a major goal of postural control during dynamic activities, such as reaching while sitting (Assaiante and Amblard 1993; Pozzo, Berthoz, & Lefort 1990), as the head functions as the base for the visual and vestibular systems (Assaiante and Amblard 1993).

Children with CP also demonstrate upper limb motor deficits, such as impaired reaching, grasping and manipulation (Schneiberg, McKinley, Sveistrup et al., 2010). In terms of kinematics, reaching quality may be described with the help of movement units. Movement units (MUs) are submovements of the reaching movement (van der Heide et al., 2005a; von Hofsten, 1991). Typical reaching movements of adults consist of one MU, reflecting the feedforward control of the movement (von Hofsten, 1991). Less well programmed reaching movements, for instance of infants (Fallang, Saugstad, & Hadders-Algra, 2000; von Hofsten, 1991) or children with CP (van der Heide, Fock, Otten, Stremmelaar, & Hadders-Algra, 2005b), consist of multiple MUs. In movements with multiple MUs, the relative part of the movement covered by the first MU, i.e., the transport MU, reflects the contribution of preprogrammed control (van der Heide et al., 2005b).

To improve activities and participation of school-age children with CP often seating adaptations are used (Hadders-Algra & Carlberg, 2008; ICF-CY, WHO 2007; McNamara & Casey 2007; Stavness, 2006). From a theoretical perspective, the position of the pelvis is considered to be a crucial factor to achieve a seating position that is optimal for upper extremity function (Green and Nelham, 1991; McNamara & Casey 2007; Pope, 2002; Reid, Sochaniwskyj & Milner, 1992; Stavness, 2006). The idea is to achieve a seating position in which the line of gravity of the child's trunk and pelvis is close to the ischial tuberosities. The mechanical effects of this position are considered to improve stabilization of the proximal body segments (pelvis, trunk, or head), which in turn is associated with increased freedom to move and functional effectiveness of the distal parts (upper extremities) (Green & Nelham, 1991; Pope, 2002). Notwithstanding these theoretical considerations, the nature of optimal seating is debated, especially during an activity that is associated with a subtle shift in the centre of gravity of the body segments, such as reaching (Angsupaisal, Maathuis & Hadders-Algra, 2015; Chung et al., 2008; McNamara & Casey, 2007; Ryan, 2016; Stavness, 2006).

In the present paper, we focus on children with CP who are ambulatory. It is common practice to provide these children, just as children with Developmental Coordination Disorder, with adaptive seating, to enhance their functional performance in daily life activities (Case-Smith & Clifford O'Brien, 2015; Ryan, 2012). In ambulatory children with CP, i.e., children who are able to sit independently and who function at Gross Motor Function Classification System (GMFCS) levels I to III (Palisano, Rosenbaum, Bartlett, & Livingston, 2007), focus of research on adaptive seating is on the potential effect of seat inclination (McNamara & Casey, 2007; Reid et al., 1992; Sochaniwskyj et al., 1991; Stavness, 2006). This implies that the focus of research in these children differs from that in children with severe CP in whom focus is on adaptive seating systems (Angsupaisal et al., 2015; Chung et al., 2008; McNamara & Casey, 2007; Stavness, 2006).

For the potential effect of seat inclination, evidence is emerging that backward tilting of the seat surface is associated with worse functional performance in children with GMFCS levels I–III (Nwaobi (1986): only children with GMFCS levels I-III; Hadders-Algra et al. (2007): including also some children with GMFCS level IV). Nevertheless, studies disagreed on the effect of forward (FW) tilting, due to the use of different methodology, outcome parameters, and differences in the nature of the CP of study participants. One point of variance was the seat angle which varied from 5° (Cherng, Lin, Ju, & Ho, 2009; McClenaghan, Thombs, & Milner, 1992), 10° (Cherng et al., 2009; Reid et al., 1992; Sochaniwskyj et al., 1991), to 15° (Cherng et al., 2009; Hadders-Algra et al., 2007; McClenaghan et al., 1992; Reid, 1996; Sochaniwskyj et al., 1991; Tsai, Yu, Huang, & Cheng, 2014). The studies did not reveal one consistently best seating angle, both with respect to head stability and reaching activities. Yet, in children functioning at GMFCS levels I–III, the 10° and 15° FW tilt were most frequently associated with functional improvement postural control (Cherng et al., 2009; Reid, 1996; Sochaniwskyj et al., 1991) and reaching (Cherng et al., 2009; Hadders-Algra et al., 2007). As the study of Cherng et al. indicated that a 15° FW-tilt was associated with a slightly better effect than a 10° FW-tilt, we opted to evaluate the effect of a 15° FW-tilt.

The evidence about the influence of the nature of the CP is illustrated by the study of Hadders-Algra et al. (2007) that evaluated the effect of seat inclination in a relatively large sample of children with bilateral (BS-CP) or unilateral spastic CP (US-CP), functioning at GMFCS levels I–IV. The results showed that in children with BS-CP, 15° FW-tilting resulted in a larger head sway, i.e., worse head control, and had no effect on the kinematics of reaching. In children with US-CP, 15° FW-tilting did not affect head sway, but it was associated with better reaching movements, i.e., with movements in which the transport MU covered a larger part of the reaching movement. However, the majority of participants did not receive foot support (Hadders-Algra et al., 2007) which differs from daily life situations (Angsupaisal et al., 2015; Ryan, Rigby, & Campbell, 2010).

Therefore, the aim of the present study is to explore the immediate effect of 15° FW-tilting in combination with the effect of foot-support in school-age children with spastic forms of CP, i.e. spastic unilateral and bilateral CP (US-CP and BS-CP) functioning at

GMFCS levels I–III on kinematics of head stability and reaching during the everyday activity of reaching at arm length distance. Our primary outcome parameter is head stability in space, as stability of the head in space is considered to be the primary aim of postural control (Hadders-Algra & Brogren Carlberg, 2008; Massion, 1998). We opted to focus on children who are able to sit independently, i.e., children functioning at GMFCS levels I–III, as their functional performance in sitting presumably may be facilitated by the simple type of adjustments we intended to investigate. In order to reduce heterogeneity in the study sample we restricted ourselves to school-age children with spastic CP. Spastic CP is the most common type of CP (Sellier et al., 2016). We reduced heterogeneity in the study sample by excluding children with dyskinetic or ataxic types of CP. Our secondary outcomes are the kinematic parameters of reaching that inform us about the extent of feedforward programming (number of MUs, percentage of reaches with one MU, size of the transport MU, and curvature index), whereas path length, movement duration, and average speed of reaching are considered tertiary outcomes. Previous studies showed that the reaching movements of children with CP consist less often of 1 MU, have a smaller transport MU, a less favorable curvature index, have a longer trajectory and take more time than those of typically developing children (Chang, Wu, Wu, & Su, 2005; Ju, You, & Cherng, 2010; van der Heide et al., 2004).

In the present study we address the following questions: 1) Does additional foot-support have an immediate effect on the kinematics of head stability and reaching in children with spastic CP during sitting on a horizontal or 15° FW-tilted seat surface; 2) Does the putative effect depend on the type of CP (US-CP versus BS-CP), or the severity of CP (GMFCS levels I–III)? We hypothesize that the immediate effect of additional foot-support is a better head stability, i.e., a smaller angular sway of the head, and a better reaching quality, e.g. larger transport MUs. As postural instability during reaching in sitting is larger in children with BS-CP than in children with US-CP (Hadders-Algra et al., 2007), we expect that children with BS-CP will profit more from foot-support.

2. Methods

2.1. Study design

A repeated-measures design was applied. To prevent fatigue effects, seating conditions were randomly applied with a balanced incomplete-block design (ABCD/CADB/BDAC/DCAB).

2.2. Participants

Nineteen children with spastic CP participated; ten with US-CP and nine with BS-CP (seven boys, 12 girls; 6–12 years old [median: 8 years 9 months]) diagnosed according to the Surveillance of Cerebral Palsy in Europe guideline (SCPE, 2000) and functioning at GMFCS levels I–III. We aimed to have an equal number of children with US-CP and BS-CP. However, a twentieth child with BS-CP had been invited to participate in the study, but he could not cope with the testing condition due to insufficient attention. The children were recruited at the outpatient clinic of the department of Rehabilitation Medicine, University Medical Center Xx (masked), and two schools for special education. Children were excluded if they functioned at GMFCS levels IV–V, had a dyskinetic or ataxic movement disorder, diagnosed behavioural disorders, severe visual impairment, or reaching inability. Parents signed an informed consent. The Central Committee on Research involving Human Subjects (CCMO;NL39267.000.12) approved the study.

2.3. Sample size calculation

Postural control studies are typically carried out with sample sizes of about ten children. These sample sizes allowed for conclusions on the effect of different seating conditions on capacity to adapt kinematics of posture and reaching (see e.g. Hadders-Algra, van der Fits, Stremmelaar, & Touwen, 1999; Van der Fits, Flikweert, Stremmelaar, Martijn, & Hadders-Algra, 1999). In the present study, power calculation was based on the results of the Hadders-Algra et al. (2007) study that revealed that group sizes of 10 subjects allow with a power of 90% ($\alpha = 0.05$; two tailed testing) for the detection of 5° difference in head sway (SD 3°). Five degrees of head sway is considered as clinically meaningful (Hadders-Algra et al., 2007; van der Heide et al., 2004; van der Heide et al., 2005a).

2.4. Assessments

All participants were randomly assessed in four seating conditions: horizontal seat surface without (a) and with (b) foot-support, and 15° FW-tilted seat surface without (c) and with (d) foot-support. The four seating conditions are schematically represented in Fig. 1. The horizontal seating condition consisted of sitting on a smooth, wooden horizontal surface mounted on a table, without additional neck-, trunk-, posterior pelvic, or arm support. The seat surface supported the child's buttocks and major part of the upper legs, while allowing for comfortable knee flexion. The feet could dangle freely. The seat surface could be tilted to a 15° FW-tilt, thereby creating the 15° FW-tilted condition. For the conditions with foot-support, a firm box with a horizontal surface with an adjustable height was placed below the child's feet. The height of the foot support surface was adjusted to the size of the child's (lower) legs, allowing full weight bearing by the feet while sitting. The feet were not strapped to the foot support surface. In each condition, a horizontal pelvis strap consisting of soft fabric was put around the participant's pelvis to prevent the child from slipping from the seat surface. Between the four testing conditions, the child had a 3-to-5-min break during which the examiner adjusted seating condition.

At the end of each test condition, we evaluated the child's perception of the seating condition in terms of pleasantness. The pleasantness score indicated the child's overall impression of comfort and functionality of the seating situation. To this end, a 'smiley-

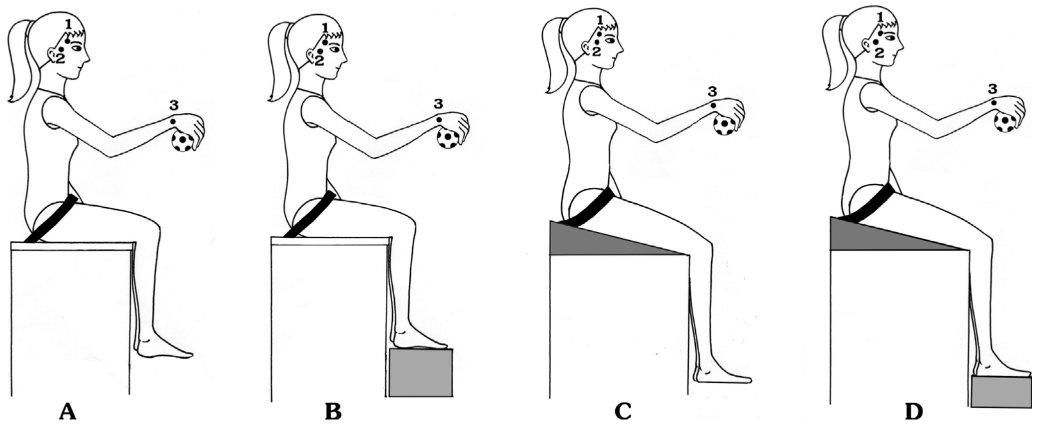

Fig. 1. Schematic representation of the seating conditions.
(A) the horizontal sitting condition without foot-support, (B) the horizontal sitting condition with foot-support, (C) the 15° FW-tilted sitting condition without foot-support, (D) the 15° FW-tilted sitting condition with foot-support. The numbered dots denote the position of the markers for the kinematic recordings.

scale' was designed on which the children could grade their impression of pleasantness on a Likert scale from 1 to 5, where 5 denoted 'very pleasant' and 1 'very unpleasant'. The pleasantness scale was not further validated. The assessments were performed either at the Institute of Developmental Neurology (UMCG), or at the special school, depending on the family's wishes.

Our research team has adopted the ecological task-oriented approach for children with CP (Ekstorm Ahl, Granat, & Brogren-Carlsberg, 2005; Ketelaar, Vermeer, Hart, van Petegem-van Beek, Helders, 2001). We therefore chose to use a simple reaching task during which the child reached at its own self-paced speed at arm- length distance (Hadders-Algra et al., 2007; Schneiberg, McKinley, Gisel, Sveistrup, & Levin, 2010; van der Heide et al., 2004; van der Heide et al., 2005a). The reaching movements were elicited by presenting the child a small attractive object at arm length distance in front of the child, in midline position at a height that corresponded to the child's nipple line (see Fig. 1). The instruction was to reach and grasp the object at self-paced speed with the dominant hand, i.e., the hand with which the child preferred to write. A trial ended when the child had grasped the toy. Ten to 20 trials were performed in each condition. In order to deal with the variation that characterizes children's motor behaviour (Hadders-Algra, 2010; Hadders-Algra, 2013), the minimum number of reaching movements was ten. We preferred, however, to have some extra reaches in order to cope with loss of data due to technical artefacts; cf. Hadders-Algra et al. (2007). Practice trials were carried out before testing.

Reaching movements were continuously recorded kinematically with a sampling rate of 50 Hz using the video, two-camera configuration of the SIMI Motion System (SIMI Reality Motion Systems GmbH, Unterschleissheim, Germany). Two reflective markers were placed on the head: laterally of the lateral epicanthus (marker 1) and 1 cm in front of the angle of mandible (marker 2). The arm movements were recorded with a marker on the radial styloid process of the wrist. Additionally, postural control was assessed with multiple surface electromyograms. The latter data are not included in this study.

After the reaching session, gross motor ability was assessed using the Gross Motor Function Measure 66-item version (GMFM-66) (Russell, Rosenbaum, Avery, & Lane, 2002). Reliability and validity of the GMFM-66 have been well established (Russell et al., 2002). Finally, the degree of spasticity of the biceps brachii of the dominant arm was assessed using the modified Tardieu Scale (Boyd & Graham, 1999). The psychometric properties of the scale are considered to be sufficient (Boyd & Graham, 1999).

2.5. Kinematic analysis

Kinematic analysis was carried out with the PedEMG software (van Balen, Dijkstra, & Hadders-Algra, 2012). First, the video-recordings were used to select reaching movements that ended in successful grasping (van der Heide et al., 2005b; van Balen et al., 2012) with the child devoting its attention to the task. Next, arm movement onset was determined from the video-recording as the moment when the wrist marker started to move.

To determine head stability in space, the behaviour of the vector between marker 1 and 2 was used, i.e. the angle of the head in space. Head sway was defined as the total travel of the vector angle during the reaching movement (see supplementary Fig. S1 (online)). To describe the reaching movements, four main outcome parameters were addressed: (i) the number of MUs where a MU was defined as the presence of one acceleration followed by a deceleration in the velocity profile of the wrist marker (van der Heide et al., 2005b) (Supplemental Fig. S1 (online)); (ii) proportion of trials during which the reaching movement consisted of one MU; (iii) the transport MU, i.e., the proportional length of the first MU relative to total reaching movement path length; and (iv) index of curvature, i.e. the ratio of the length of the straight line between starting and stopping position and the actual length of the reaching path (%) (van der Heide et al., 2005b). In addition, we determined the average wrist speed during reaching; total path length; and the duration of reaching.

Table 1
Clinical characteristics of participants.

Clinical information	Children with US-CP n = 10	Children with BS-CP n = 9
Age (y, mo; median and range)	10y 6mo (6y 3mo–12y 11mo)	8y 6mo (6y 2mo–12y 7mo)
Sex	5 females, 5 males	7 females, 2 males
Height (cm; median and range)	145 (116–165)	127 (124–155)
Weight (kg; median and range)	35 (21–76)	26 (23–39)
Body Mass Index (median and range)	16.7 (15.3–27.9)	16.3 (14.4–19.2)
GMFCS (n)		
- level I	6	6
- level II	3	1
- level III	1	2
GMFM – 66 total scores (median and range)[a]	77.9 (52.3–92.1)	76.8 (50.1–100)
Modified Tardieu (Bicep brachii) (n)[b]		
- grade 0	8	7
- grade 1	2	1
- grade 2	–	1
Head sway, number of valid trials (median, range)		
- horizontal without foot support	13 (3–22)	12.5 (11–15)
- horizontal with foot support	14 (11–16)	13 (11–15)
- FW without foot support	13 (3–16)	13 (11–17)
- FW with foot support	13 (10–17)	13 (7–14)
Reaching, number of valid trials (median, range)		
- horizontal without foot support	13 (10–18)	12 (9–14)
- horizontal with foot support	13.5 (9–15)	13 (11–15)
- FW without foot support	13 (12–16)	13 (11–17)
- FW with foot support	14.5 (10–16)	13 (7–14)
Smiley pleasantness rating (median, range)[c]		
- horizontal without foot support	3.5 (1–5)	4 (3–5)
- horizontal with foot support	3 (1–5)	4 (3–5)
- FW without foot support	4.5 (2–5)	4 (1–5)
- FW with foot support	3.5 (1–5)	4 (1–5)

BS-CP = children with bilateral spastic CP; cm = centimeters; FW = forward-tilted; GMFCS, = Gross Motor Function Classification System level I to III; GMFM–66 = Gross Motor Function Measure-66 version; kg = kg; mo = months; US-CP = children with unilateral spastic CP; y = years

[a] GMFM-66: BS-CP vs US-CP: Mann-Whitney *U* test, $p = 0.744$.

[b] Modified Tardieu's scale (of the dominant arm): Grade 0, no resistance throughout the course of the passive movement; Grade 1, slight resistance; and Grade 2, clear catch at precise angle interrupting the passive movement.

[c] Smiley pleasantness ratings of the seating conditions, from 5 (very good) to 1 (not very good): Friedman test, $p = 0.346$.

2.6. Statistics

The clinical characteristics, including the pleasantness scores were analysed with descriptive statistics and univariate non-parametric statistics, such as the Friedman test. The kinematic data were analysed with (generalized) linear mixed-effects models (MIXED; SPSS version 23.0, Chicago, IL, USA). Fixed-effects were determined as seating (horizontal vs FW-tilting), foot-support (with or without), and their interaction. Clustering of observations was accounted for by incorporating random-effects to model the correlation between the measurements within children. For each kinematic parameter, three models were tested: model 1, unadjusted estimates with fixed-effects of seating conditions only; models 2 and 3 were models additionally corrected for type of CP, its interaction with seating conditions, and for age and anthropometry. In addition, model 3 was also adjusted for GMFCS-level. Estimated marginal means for each of the seating positions were calculated based on these models and presented with their 95% confidence interval (CI). Lastly, post-hoc analyses were carried out to explore the most relevant clinical contrasts.

3. Results

Nineteen children completed the study. The clinical characteristics, the distribution across GMFCS-levels, and the number of trials the children completed per condition are presented in Table 1. The 19 participants produced a total of 1023 reaches in the four conditions. No adverse effect of the seating conditions was reported. The pleasantness ratings of the seating conditions were not significantly different (Friedman test, $p = 0.346$). The GMFM-66 scores of both subgroups of CP were similar (Mann-Whitney test, $p = 0.744$). The modified Tardieu Scale revealed that only a minority of children had some spasticity in the biceps brachii muscle of the dominant arm.

The adjusted analyses indicated that the type of CP affected the effect of seating condition and that GMFCS (level I–III) did not modify the effects (data not shown).

The unadjusted and the adjusted analyses showed that head sway was not affected by seating conditions (Fig. 2 ; Table 2). For reaching performance, the unadjusted analyses indicated that seating condition did not affect the main kinematic reaching parameters (number of MUs, % of reaches with 1 MU, transport MU and index of curvature). However, the adjusted analyses suggested that for the transport MU an interaction existed for seating condition and type of CP (Table 2). The analyses also suggested that foot-

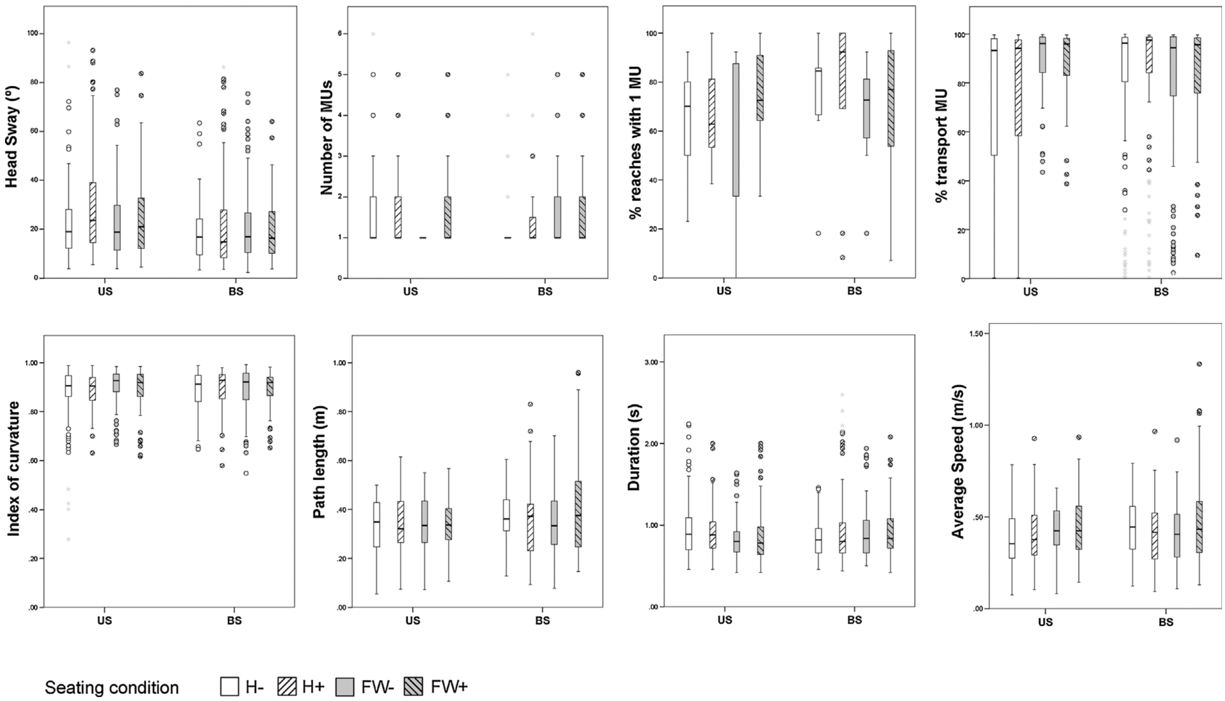

Fig. 2. Head sway and kinematic parameters of reaching in four seating conditions.
The horizontal bars indicate the median values, the boxes the interquartile ranges, the whiskers the range and the circles and stars extreme values. US = children with spastic unilateral CP; BS = children with spastic bilateral CP. H- = horizontal seat-surface without foot support; H+ = horizontal seat-surface with foot support; FW- = forward tilted seat-surface without foot support; FW+ = forward tilted seat-surface with foot support.

support did not affect these four reaching parameters. Therefore, we performed post-hoc analyses in which we pooled both foot-support conditions. These explorative analyses indicated significant interactions between seating condition (horizontal or FW-tilt) and type of CP for the number of MUs, the percentage of trials with 1 MU and the transport MU. In children with US-CP, FW-tilting was associated with better reaching performance, i.e., a lower number of MUs, a higher proportion of reaches consisting of 1 MU, and a larger transport MU, whereas in children with BS-CP the horizontal seating condition resulted in a better performance on these reaching parameters (Table 3).

For the tertiary outcomes, the unadjusted analyses indicated a significant effect of seating conditions on total path length and average reaching speed, whereas the adjusted analyses suggested that the effect of seating condition on all tertiary outcomes was affected by the type of CP (Table 2). Post-hoc analyses (Table 3) revealed that in children with BS-CP, FW-tilting with foot-support was associated with a significantly longer total path length and longer reaching duration, whereas in children with US-CP FW-tilting with foot-support did not affect total path length and was associated with a shorter duration of reaching. In all children with CP, FW-tilting with foot-support was associated with a faster average speed of reaching.

4. Discussion

Our exploratory study indicated that seating condition did not have a significant effect on head sway, but did affect the kinematics of reaching. The latter effect was however not a uniform effect, as it differed significantly for the two types of CP. The post-hoc analyses suggested that the FW-tilted condition was associated with better reaching in ambulatory children with US-CP, while horizontal seating resulted in better kinematics of reaching in ambulatory children with BS-CP. Foot-support in either horizontal or FW-tilted seating did not affect head stability or reaching parameters that largely rely on feedforward control. Foot-support in the FW-tilting was, however, associated with a higher reaching speed in all children, and affected path length and movement duration — an effect that differed for the two subgroups of CP.

The absent effect of seating conditions on head stability in space during reaching contrasts with the findings of Hadders-Algra et al. (2007) who found that in children with BS-CP reaching while sitting on a horizontal seating resulted in significantly less head sway than reaching while sitting on a FW-tilted seat. The seemingly conflicting results are most likely caused by the inclusion of children with GMFCS level IV in the previous study (Hadders-Algra et al., 2007), i.e., children with severe CP whom we excluded. Two other studies (Sochaniwskyj et al., 1991; Tsai et al., 2014) evaluated the effect of 15° FW-tilting on postural stability in children with mild to moderately severe forms of BS-CP, be it during functional tasks that differed from our reaching task. Sochaniwskyj et al. (1991) reported that postural sway of head and trunk during quiet sitting on a FW-tilted surface with foot-support was less than on a horizontal seat surface with foot-support. Tsai et al. (2014) reported that FW-tilting during ball throwing was associated with better

Research in Developmental Disabilities 71 (2017) 42–52

Table 2
Seating effects on head sway and kinematic quality of reaching: Unadjusted and Adjusted Analyses.

Unadjusted analyses						Adjusted analyses					
Response variable	Horizontal seating		FW-Tilted seating		P-value[a]	Type of CP	Horizontal seating		FW-Tilted seating		P-value[a]
	Without foot support	With foot support	Without foot support	With foot support			Without foot support	With foot support	Without foot support	With foot support	
Head sway (degrees; median and CI)	17.39 [14.07–21.48]	19.39 [15.72–23.95]	18.30 [14.81–22.60]	18.23 [14.81–22.58]	0.154	US-CP	19.63 [14.31–26.90]	22.99 [16.76–31.44]	19.30 [14.03–26.52]	19.85 [14.48–27.19]	0.178 (0.070)
						BS-CP	15.09 [10.73–21.24]	15.96 [11.37–22.42]	16.98 [12.10–23.83]	16.76 [11.92–23.57]	
Number of MUs (mean count and CI)	1.47 [1.30–1.64]	1.44 [1.25–1.64]	1.36 [1.22–1.52]	1.50 [1.30–1.73]	0.135	US-CP	1.56 [1.32–1.83]	1.45 [1.29–1.63]	1.30 [1.15–1.47]	1.48 [1.26–1.73]	0.178 (0.066)
						BS-CP	1.36 [1.12–1.66]	1.44 [1.08–1.91]	1.47 [1.20–1.79]	1.55 [1.20–2.00]	
% Trials with 1 MU (% and CI)	70.05 [58.87–79.27]	69.38 [56.24–79.98]	72.86 [62.81–81.02]	70.13 [57.75–80.13]	0.903	US-CP	66.50 [52.00–78.50]	66.50 [54.50–76.70]	79.60 [65.80–88.80]	74.00 [61.00–83.80]	0.871 (0.075)
						BS-CP	74.90 [55.70–87.60]	73.00 [46.50–89.40]	65.80 [50.00–78.80]	65.60 [43.60–82.50]	
Transport MU (%; median and CI)	91.46 [87.07–94.48]	92.45 [88.50–95.15]	93.38 [89.85–95.79]	92.85 [89.09–95.42]	0.221	US-CP	90.30 [82.00–95.00]	91.00 [83.20–95.40]	94.20 [88.90–97.20]	92.80 [86.50–96.40]	0.260 **(0.049)***
						BS-CP	92.60 [85.40–96.50]	93.80 [87.60–97.10]	92.50 [85.10–96.40]	92.80 [85.70–96.60]	
Index of curvature (median and CI)	0.91 [0.89–0.93]	0.91 [0.89–0.93]	0.92 [0.90–0.94]	0.92 [0.90–0.93]	0.119	US-CP	0.91 [0.88–0.94]	0.91 [0.87–0.94]	0.92 [0.89–0.95]	0.92 [0.89–0.94]	0.131 (0.570)
						BS-CP	0.91 [0.88–0.94]	0.92 [0.88–0.94]	0.92 [0.89–0.94]	0.91 [0.88–0.94]	
Total path length (m; mean and CI)	0.34 [0.29–0.39]	0.35 [0.30–0.40]	0.35 [0.29–0.39]	0.37 [0.32–0.42]	< **0.001***	US-CP	0.34 [0.26–0.41]	0.35 [0.27–0.42]	0.34 [0.27–0.42]	0.34 [0.27–0.42]	< **0.001***
						BS-CP	0.35 [0.27–0.43]	0.36 [0.28–0.44]	0.35 [0.27–0.43]	0.41 [0.33–0.49]	**(< 0.001)***
Duration of reach (s; median and CI)	0.86 [0.80–0.94]	0.87 [0.80–0.94]	0.84 [0.77–0.91]	0.84 [0.80–0.92]	0.368	US-CP	0.90 [0.80–9.99]	0.86 [0.77–0.96]	0.81 [0.72–0.91]	0.81 [0.73–0.91]	0.456 **(0.001)***
						BS-CP	0.82 [0.72–0.93]	0.88 [0.78–1.00]	0.87 [0.77–0.98]	0.88 [0.78–1.00]	
Average speed (m/s; mean and CI)	0.41 [0.35–0.47]	0.41 [0.35–0.47]	0.42 [0.36–0.47]	0.45 [0.39–0.50]	**0.001***	US-CP	0.39 [0.31–0.47]	0.41 [0.33–0.49]	0.43 [0.35–0.51]	0.44 [0.36–0.52]	**0.001 (0.005)***
						BS-CP	0.44 [0.35–0.52]	0.40 [0.32–0.49]	0.40 [0.32–0.49]	0.46 [0.37–0.55]	

Presented are the estimated marginal means based on the results from the (generalized) mixed effects models. The covariates included in the adjusted analyses are age (in months), height (in centimeters), body mass index (BMI), and type of CP.

*(Generalized) linear mixed-effects models; $p < 0.05$.

[a] The p-values in the unadjusted analyses and the first p-values in the adjusted analyses are the values of the type III test of the fixed effects of the four seating positions. The second p-values (in brackets) in the adjusted analyses are those of the interaction term of seating position with CP-type.

BS-CP = children with bilateral spastic CP; CI, 95% confidence intervals (the values in square brackets); m, meters; m/s, meters/second; MUs, movement units; s, second; US-CP = children with unilateral spastic CP. Note that participants functioned at GMFCS Level I (12/19), Level II (4/19), and Level III (3/19).

Table 3
Seating effects on kinematic quality of reaching: post-hoc analyses.

Horizontal vs FW-tilted seating			
Kinematics of reaching Secondary outcomes	Horizontal seating	FW-tilted seating	P-value[a]
Number of MUs (mean count and CI)			0.912
US-CP	1.50 [1.34–1.69]	1.39 [1.21–1.61]	**(0.016)***
BS-CP	1.40 [1.14–1.72]	1.51 [1.21–1.88]	
% Trials with 1 MU (% and CI)			0.851
US-CP	66.54 [55.40–76.20]	76.62 [63.80–85.90]	**(0.012)***
BS-CP	73.87 [53.90–87.20]	65.62 [49.10–79.10]	
Transport MU (median and CI)			0.115
US-CP	90.66 [82.88–95.10]	93.50 [87.85–96.72]	**(0.010)***
BS-CP	93.23 [86.78–96.76]	92.61 [85.64–96.41]	
Index of curvature (median and CI)			**0.036***
US-CP	0.91 [0.88 – 0.94]	0.92 [0.89 – 0.94]	(0.310)
BS-CP	0.91 [0.88 – 0.94]	0.92 [0.88 – 0.94]	

FW-tilted with foot-support vs all other seating conditions			
Tertiary outcomes	FW-tilted with foot-support	Other seating positions	P-value[b]
Total path length (m; mean and CI)			< **0.001***
US-CP	0.34 [0.27–0.42]	0.34 [0.27–0.42]	**(< 0.001)***
BS-CP	0.41 [0.33–0.49]	0.35 [0.27–0.43]	
Duration Movement (s; median and CI)			0.611
US-CP	0.81 [0.73–0.91]	0.86 [0.77–0.96]	**(0.033)***
BS-CP	0.88 [0.78–0.99]	0.86 [0.76–0.96]	
Average speed of wrist (m/s; mean and CI)			< **0.001***
US-CP	0.44 [0.36–0.52]	0.41 [0.33–0.49]	(0.342)
BS-CP	0.46 [0.37–0.55]	0.42 [0.37–0.55]	

Presented are the estimated marginal means based on the results from the (generalized) mixed effects models. The covariates included in the adjusted post-hoc analyses are age (in months), height (in centimeters) and body mass index (BMI). In the upper half of the table the post-hoc contrast focusses on the difference between the horizontal and the forward-tilted seating position (irrespective of foot support), in the lower half of the table the post-hoc contrast addresses the difference between the forward-tilted condition with foot-support and the other seating conditions.
*(Generalized) linear mixed-effects models; $p < 0.05$[a] and [b] The first p-values are the values the type III test of the fixed effects of seating condition ([a] = horizontal vs FW-tilted.[b] = forward tilted with foot-support vs other seating positions respectively). The second p-values (in brackets) are those of the interaction term of seating position with CP-type.

stability expressed in terms of Centre-of-Pressure behaviour than sitting on a horizontal seat surface. The studies show that the effect of FW-tilting on postural stability may not only depend on the type of CP, but also on the nature of the task and that of the stability parameters.

A priori we had distinguished two categories of reaching parameters: those that primarily provide information about the feed-forward control of the reaching movement (number of MUs, percentage of trials with one MU, size of the transport MU, and index of curvature) and those being brought about by a mix of feedforward- and feedback-mechanisms (total path length, movement duration and average speed). The post-hoc analyses suggested that three of the four feedforward parameters (number of MU units, percentage of trials with one MU, relative size of the transport MU) were affected by FW-tilting, irrespective of foot-support. In children with US-CP, FW-tilting was associated with movements with a larger feedforward control component, whereas in children with BS-CP the horizontal seat was associated with this effect. In other words, the data suggest that in these seating conditions, which were specific for the type of CP, children needed less feedback corrections (van der Heide et al., 2005b; von Hofsten, 1991). The findings are in line with those of Hadders-Algra et al. (2007), and complement the latter study by the indication that the results are independent of foot-support. Reid (1996) studied the effect of 15° FW-tilting with foot-support in six children with BS-CP but was not able to demonstrate a statistically significant effect of FW-tiling on the number of MU, presumably because the study lacked statistical power.

Our study indicated that FW-tilting with foot-support was associated with a higher average velocity of reaching in all children with CP. Two other studies (Hadders-Algra et al., 2007; Reid Sochaniwskyj & Milner, 1992) evaluated the effect of FW-tilting on reaching velocity. Reid et al. (1992) was unable to demonstrate an effect of 10° FW-tilting with foot-support on reaching velocity in four children with CP. Hadders-Algra et al. (2007) did not find an effect of FW-tilting on reaching velocity, but recall that most children in this study did not receive foot-support. It is well known that during sitting with foot-support the lower limbs play a substantial role in postural stability as more than half of the body weight support is shifted to the lower limbs (Cherng et al., 2009; Dean, Shepherd, & Adams, 1999). The combination of FW-tilting and foot-support induces a forward shift of the body's Centre-of-Pressure, thereby generating kinetic energy that may be expressed in a higher velocity of reaching (Cherng et al., 2009).

In children with BS-CP, 15° FW-tilting with foot-support was associated with reaching movements with a longer total path length and a longer duration. In the children with US-CP a similar effect was absent (total path length) or reverse, i.e., FW-tilting was associated with a shorter movement duration. Reid and colleagues (Reid et al., 1992; Reid, 1996) were the only other ones who evaluated the effect of FW-tilting on path length; their underpowered studies did not find a statistically significant effect. Four other studies addressed the effect of 15° FW-tilting on movement duration (Cherng et al., 2009; Hadders-Algra et al., 2007; Reid, 1996; Tsai et al., 2014). Three of them did not find an effect of FW-tilting on movement duration: the study of Reid (1996) was underpowered; Hadders-Algra et al. (2007) did not use foot-support; and Tsai et al. (2014) assessed movement duration during ball throwing. Cherng et al. (2009) reported a shorter duration of reaching during 15° of FW-tilting, an effect that may be explained by the type of CP (unknown) and their challenging reaching task, i.e., to a target beyond arm length distance.

The strength of this study is the detailed kinematic assessment of head sway and reaching in children with CP being randomly assessed in four seating conditions. Another strength is the presence of two subgroups of children with CP (BS-CP and US-CP) that were similar in age, body proportions, GMFCS-level and GMFM-66 scores, and muscle tone of the reaching arm. A third strength is the application of mixed-effect model analyses, allowing for the correction of the confounding effects of age and body proportions. These analyses demonstrated that the effect of the type of CP was not modified by GMFCS-level. Caution is however warranted for the latter conclusion as the proportion GMFC-level I participants was relatively high (12/19), which may have obscured a potential severity effect. The relatively high proportion corresponds however to the prevalence of GMFCS-level I reported in the literature (Østenjø, Carlberg & Vøllestad, 2004; Østenjø, Carlberg & Vøllestad, 2005).

However, the study has some limitations. First, our findings cannot be generalized to all children with CP, as we only studied ambulatory children with spastic CP and functioning at GMFCS levels I to III, within a specific age range (6–12 years), without significant co-morbidity in terms of severe visual impairment, dyskinesia or ataxia. In addition, the proportion of children with US-CP and BS-CP in our study differed from that of groups of children with spastic CP reported in the literature (about 1:1 in our study versus 1:2 to 2:3 in the literature (Benfer et al., 2014; Krägeloh-Mann & Cans, 2009; SCPE, 2002). Second, the small sizes of the subgroups are additional limitations, implying that the analyses on the effect of severity of CP should be interpreted with caution. A third limitation is that we studied the effect of seating only once in a laboratory setting, i.e., during reaching at arm-length distance, which precludes direct generalization to all everyday activities in everyday environments, that also include reaches beyond arm-length distance. This indicates that our findings should be interpreted with caution and that the study begs for future replication in larger groups and including the measurements of performance outcomes across all domains of the ICF-CY (Ryan, 2012; WHO, 2007).

5. Conclusion

In conclusion, our study indicated that FW-tilting of the seat surface with or without foot-support did not affect head stability during reaching in ambulatory children with spastic CP functioning at GMFCS levels I to III. Our study suggested also that seat surface tilting did affect the kinematics of reaching at arm-length distance. This effect differed for the two types of CP. The study suggested that ambulatory children with US-CP profited from FW-tilting, which resulted – irrespective of foot-support – in less MUs and a larger transport MU. Children with BS-CP were worse off during FW-tilting which was – irrespective of foot-support – associated with more MUs and a smaller transport MU; and – with foot-support – with reaches with a longer path and duration. Thus, – according to our study – children with ambulatory BS-CP have better reaches when they sit on a horizontal seat surface.

Funding

This work was supported financially by the Naresuan University, Phitsanulok, Thailand and the Graduate School for Behavioural and Cognitive Neurosciences, University of Groningen, The Netherlands.

Acknowledgements

We gratefully acknowledge the support of Tjitske Hielkema, MD, in subject recruitment and Siebrigje Hooijsma, MD, for retrieval of clinical information of the children recruited at the special schools. We also acknowledge the hospitality of the schools for special education (the Prins Johan Friso Mytylschool, Haren and De Twijn, Zwolle) and the skillful assistance during data collection of Anneke Kracht-Tilman, Iris Jager, MSc, Gerdien ten Brinke, MSc, Fran Leijten, MSc, Baudina Visser, PT, and Rivka Toonen, OT.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ridd.2017.09.016.

References

Angsupaisal, M., Maathuis, C. G. B., & Hadders Algra, M. (2015). Adaptive seating systems in children with severe cerebral palsy across International Classification of Functioning, Disability and Health for Children and Youth version domains: A systematic review. *Developmental Medicine & Child Neurology, 57*(10), 919–931.

Assaiante, C., & Amblard, B. (1993). Ontogenesis of head stabilization in space during locomotion in children: Influence of visual cues. *Experimental Brain Research, 93*(3), 499–515.

Benfer, K. A., Jordan, R., Bandaranayake, S., Finn, C., Ware, R. S., & Boyd, R. N. (2014). Motor severity in children with cerebral palsy studied in a high-resource and low-resource country. *Pediatrics, 134*(6), e1594–e1602.

Boyd, R., & Graham, H. (1999). Objective measurement of clinical findings in the use of botulinum toxin type A in the management of children with cerebral palsy. *European Journal of Neurology, 6*(Suppl. 4), S23–S35.

Case-Smith, J., & Clifford O'Brien, J. (2015). *Occupational Therapy for Children and Adolescents* (7th ed.). St. Louis: Elsevier.

Chang, J. J., Wu, T. I., Wu, W. L., & Su, F. C. (2005). Kinematical measure for spastic reaching in children with cerebral palsy. *Clinical Biomechanics, 20*(4), 381–388.

Cherng, R., Lin, H., Ju, Y., & Ho, C. (2009). Effect of seat surface inclination on postural stability and forward reaching efficiency in children with spastic cerebral palsy. *Research in Developmental Disabilities, 30*(6), 1420–1427.

Chung, J., Evans, J., Lee, C., Lee, J., Rabbani, Y., Roxborough, L., et al. (2008). Effectiveness of adaptive seating on sitting posture and postural control in children with cerebral palsy. *Pediatric Physical Therapy, 20*(4), 303–317.

Dean, C., Shepherd, R., & Adams, R. (1999). Sitting balance I: Trunk-arm coordination and the contribution of the lower limbs during self-paced reaching in sitting. *Gait and Posture, 10*(2), 135–146.

Ekstorm Ahl, J. E., Granat, T., & Brogren-Carlsberg, E. (2005). Functional therapy for children with cerebral palsy: An ecological approach. *Developmental Medicine & Child Neurology, 47*(9), 613–619.

Fallang, B., Saugstad, O., & Hadders-Algra, M. (2000). Goal directed reaching and postural control in supine position in healthy infants. *Behavioural Brain Research, 115*(1), 9–18.

Green, E. M., & Nelham, R. L. (1991). Development of sitting ability, assessment of children with a motor handicap and prescription of appropriate seating systems. *Prosthetics and Orthotics International, 15*(3), 203–216.

Hadders-Algra, M., & Carlberg, E. B. (2008). *Postural control: A key issue in developmental disorders. Clinics in developmental medicine no. 179*. London: Mac Keith Press.

Hadders-Algra, M., van der Fits, I. B. M., Stremmelaar, E. F., & Touwen, B. C. L. (1999). Development of postural adjustments during reaching in infants with cerebral palsy. *Developmental Medicine & Child Neurology, 41*(11), 766–776.

Hadders-Algra, M., van der Heide, J., Fock, J., Stremmelaar, E., van Eykern, L., & Otten, B. (2007). Effect of seat surface inclination on postural control during reaching in preterm children with cerebral palsy. *Physical Therapy, 87*(7), 861–871.

Hadders-Algra, M. (2010). Variation and variability: Key words in human motor development? *Physical Therapy, 90*(12), 1823–1837.

Hadders-Algra, M. (2013). Typical and atypical development of reaching and postural control in infancy. *Developmental Medicine and Child Neurology, 55*(4), 5–8.

Ju, Y. H., You, J. Y., & Cherng, R. J. (2010). Effect of task constraint on reaching performance in children with spastic diplegic cerebral palsy? *Research in Developmental Disabilities, 31*(5), 1076–1082.

Ketelaar, M., Vermeer, A., Hart, H., van Petegem-van Beek, E., & Helders, P. J. M. (2001). Effects of a functional therapy program on motor abilities of children with cerebral palsy. *Physical Therapy, 81*(9), 1535–1545.

Krägeloh-Mann, I., & Cans, C. (2009). Cerebral palsy update? *Brain Development, 31*(7), 537–544.

Massion, J. (1998). Postural control systems in developmental perspective. *Neuroscience & Biobehavioral Review, 22*(4), 465–472.

McClenaghan, B. A., Thombs, L., & Milner, M. (1992). Effect of seat-surface inclination on postural stability and function of the upper extremities of children with cerebral palsy. *Developmental Medicine & Child Neurology, 34*(1), 40–48.

McNamara, L., & Casey, J. (2007). Seat inclinations affect the function of children with cerebral palsy. A review of the effect of different seat inclines. *Disability and Rehabilitation: Assistive Technology, 2*(6), 309–318.

Nwaobi, O. M. (1986). Effects of body orientation in space on tonic muscle activity of patients with cerebral palsy. *Developmental Medicine & Child Neurology, 28*(1), 41–44.

Østenjø, S., Carlberg, E. B., & Vøllestad, N. K. (2004). Motor impairments in young children with cerebral palsy: Relationship to gross motor function and everyday activities? *Developmental Medicine & Child Neurology, 46*(9), 580–589.

Østenjø, S., Carlberg, E. B., & Vøllestad, N. K. (2005). The use and impact of assistive devices and other environmental modifications on everyday activities and care in young children with cerebral palsy? *Disability and Rehabilitation, 27*(14), 849–861.

Palisano, R., Rosenbaum, P., Bartlett, D., & Livingston, M. (2007). *Canchild Centre for childhood disability research – The gross motor function classification system – Expanded and revised.* http://www.canchild.ca/en/measures/gmfcs_expanded_revised.asp./. [Accessed 9 April 2013].

Pope, P. (2002). Posture management and special seating. In S. Edwards (Ed.). *Neurological physiotherapy*. London: Churchill Livingstone.

Pozzo, T., Berthoz, A., & Lefort, L. (1990). Head stabilization during various locomotor tasks in humans. I. normal subjects. *Experimental Brain Research, 82*(1), 97–106.

Reid, D., Sochaniwskyj, A., & Milner, M. (1992). Instrumentation and a protocol for quantification of upper-limb movement of children with and without cerebral palsy in two sitting positions. *Neurorehabilitation & Neural Repair, 6*(1), 25–34.

Reid, D. T. (1996). The effects of the saddle seat on seated postural control and upper-extremity movement in children with cerebral palsy. *Developmental Medicine & Child Neurology, 38*(9), 805–815.

Russell, D., Rosenbaum, P., Avery, L., & Lane, M. (2002). *Gross motor function measure (GMFM-66 & GMFM-88): User's manual. Clinics in developmental medicine No.159.* London: Mac Keith Press.

Ryan, S., Rigby, P., & Campbell, K. (2010). Randomised controlled trial comparing two school furniture configurations in the printing performance of young children with cerebral palsy. *Australian Occupational Therapy Journal, 57*(4), 239–245.

Ryan, S. (2012). An overview of systematic reviews of adaptive seating interventions for children with cerebral palsy: Where do we go from here? *Disability and Rehabilitation: Assistive Technology, 7*(2), 104–111.

Ryan, S. (2016). Lessons learned from studying the functional impact of adaptive seating interventions for children with cerebral palsy. *Developmental Medicine & Child Neurology, 58*(Suppl. 4), 78–82.

Surveillance of Cerebral Palsy in Europe (SCPE) (2000). A collaboration of cerebral palsy surveys and registers. *Developmental Medicine & Child Neurology, 12*(42), 816–824.

Surveillance of Cerebral Palsy in Europe (SCPE) (2002). Prevalence and characteristics of children with cerebral palsy in Europe. *Developmental Medicine & Child Neurology, 9*(44), 633–640.

Stavness, C. (2006). The effect of positioning for children with cerebral palsy on upper-extremity function: A review of the evidence. *Physical & Occupational Therapy in Pediatrics, 6*(3), 39–48.

Schneiberg, S., McKinley, P. A., Sveistrup, H., Gisel, E., Mayo, N. E., & Levin, M. F. (2010). The effectiveness of task-oriented intervention and trunk restraint on upper limb movement quality in children with cerebral palsy. *Developmental Medicine & Child Neurology, 52*(11), e245–53.

Schneiberg, S., McKinley, P. A., Gisel, E., Sveistrup, H., & Levin, M. F. (2010). Reliability of kinematic measures of functional reaching in children with cerebral palsy.

Developmental Medicine & Child Neurology, 52(11), e167–73.
Sellier, E., Platt, M. J., Andersen, G. L., Krägeloh-Mann, I., De La Cruz, J., Cans, C., et al. (2016). Decreasing prevalence in cerebral palsy: A multi-site European population-based study, 1980–2003. *Developmental Medicine & Child Neurology, 58*(1), 85–92.
Sochaniwskyj, A., Koheil, R., Bablich, K., Milner, M., & Lotto, W. (1991). Dynamic monitoring of sitting posture for children with spastic cerebral palsy. *Clinical Biomechanics, 6*(3), 161–167.
Tsai, Y., Yu, Y., Huang, P., & Cheng, H. (2014). Seat surface inclination may affect postural stability during boccia ball throwing in children with cerebral palsy. *Research in Developmental Disabilities, 35*(12), 3568–3573.
Van der Fits, I. B. M., Flikweert, E. R., Stremmelaar, E. F., Martijn, A., & Hadders-Algra, M. (1999). Development of postural adjustments during reaching in preterm infants. *Pediatric Research, 46*(1), 1–7.
van Balen, L., Dijkstra, L., & Hadders-Algra, M. (2012). Development of postural adjustments during reaching in typically developing infants from 4 to 18 months? *Experimental Brain Research, 220*(2), 109–119.
van der Heide, J. C., Begeer, C., Fock, J. M., Otten, B., Stremmelaar, E., van Eykern, L. A., et al. (2004). Postural control during reaching in preterm children with cerebral palsy. *Developmental Medicine & Child Neurology, 46*(4), 253–266.
van der Heide, J., Fock, J., Otten, B., Stremmelaar, E., & Hadders-Algra, M. (2005a). Kinematic characteristics of postural control during reaching in preterm children with cerebral palsy. *Pediatric Research, 58*(3), 586–593.
van der Heide, J., Fock, J., Otten, B., Stremmelaar, E., & Hadders-Algra, M. (2005b). Kinematic characteristics of reaching movements in preterm children with cerebral palsy? *Pediatric Research, 57*(6), 883–889.
von Hofsten, C. (1991). Structuring of early reaching movements: A longitudinal study. *Journal of Motor Behavior, 23*(4), 280–292.
World Health Organization (2007). *International classification of functioning disability and health – children and youth version (ICF-CY)*. http://apps.who.int/iris/bitstream/10665/43737/1/9789241547321_eng.pdf?ua=1/. [Accessed 9 April 2013].