Adaptive seating and adaptive riding in children with cerebral palsy

Angsupaisal, Mattana

Chapter 3

Effects of forward tilted seating and foot-support on postural adjustments in children withspastic cerebral palsy: an EMG-study

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

Submitted

ABSTRACT

Objective: To evaluate the effect of 15° forward (FW) seat inclination and foot-support in children with cerebral palsy (CP) on postural adjustments during reaching.
Design: Observational study repeated-measures design.
Setting: Laboratory unit within University Hospital and two special education schools.
Participants: 19 children (ten unilateral spastic CP (US-CP); nine bilateral spastic CP (BS-CP); Gross Motor Function Classification System levels I-III; 6–12 years old). Participants were able to take part for one, one-hour session.
Intervention: Reaching while sitting in four seating conditions (FW or horizontal seat; with or without foot-support) applied in randomized order.
Outcome measures: Simultaneously, surface electromyography (EMG) of neck, trunk and arm muscles (current Project II), and kinematics of head and reaching arm (previous Project I) were recorded. In Project II, primary outcome parameters were the ability to modulate EMG-amplitudes at baseline and during reaching (phasic muscle activity). Other EMG-parameters were direction-specificity (1st control level), and 2nd level of control parameters: recruitment order, and anticipatory postural activity. Motor behaviour measures: ability to modulate EMG-amplitudes to kinematic characteristics of reaching and head stability.
Results: Only foot-support was associated with increased tonic background EMG-amplitudes and decreased phasic EMG-amplitudes of the trunk extensors in children with US-CP and BS-CP (mixed-models analyses; p-values < 0.01). The foot-support effect was also associated with better kinematics of reaching (Spearman's Rho; p-values < 0.01).
Conclusion: In terms of postural adjustments during forward reaching, foot-support enhanced the children's capacity to modulate trunk extensor activity, which in turn improved reaching quality. FW-tilting did not affect postural muscle activity.

Contribution of the paper

- Seat forward-tilting does not affect postural muscle activity during reaching in children with spastic CP
- Foot-support is associated with increased tonic background activity of the trunk extensors
- Increased tonic background activity of trunk extensors was associated with better reaching kinematics
- Combining Project II with its twin Project I suggests: in children with unilateral CP best approach is forward-tilting with foot -support; in children with bilateral CP horizontal seating with foot-support

Key words:
Cerebral palsy; Seat inclination; Foot-support; Postural muscle activity; Reaching movement; Electromyography.

Introduction

Children with cerebral palsy (CP) often exhibit postural dysfunctions during reaching while sitting.[1,2] Adaptive seating is recommended to improve postural control.[3–6] In children with CP functioning at Gross Motor Function Classification System (GMFCS) level I-III[7] seat-surface inclination is often used[8,9] and debated.[10–17] Many factors may cause conflicting findings: different outcome measures[10,12,13,16,18–20], heterogeneity in CP, the degree of postural support, and variation in seat angle (5°[17,19], 10°[13,19], and 15°[12,13,17,19–21]). In children with GMFCS levels I-III, a 10° and 15° FW-tilting is recommended.[12,13,19] As the 15° FW-tilting showed better postural stability during forward reaching and better reaching kinematics than the 10°[19], we decided to further evaluate the 15° FW-tilting.

Previously, only the study of Hadders-Algra et al.[21] specified CP-subtypes. The study was conducted in 58 children with unilateral (US-CP) and bilateral spastic CP (BS-CP), functioning at GMFCS level I-IV. It demonstrated that in children with US-CP the 15° FW-tilting reduced phasic muscle activity of the postural muscles, which was associated with a better kinematic quality of reaching, whereas in children with BS-CP the horizontal seating was associated with better postural control.[21]

However, Hadders-Algra et al.[21] did not apply foot-support. Others evaluated the effect of seat inclinations in the presence of foot-support but did not address its contribution.[11–14,16,17,19,20] In the present project, we replicated the Hadders-Algra et al. study[21] while also evaluating the effect of foot-support as a possible factor affecting postural control. In the first part of the study (Project I) we reported the effect of the seating modifications on head stability in space and reaching quality.[22] We confirmed the differential effect on kinematic reaching quality: children with US-CP benefitted from FW-tilting, the children with BS-CP from a horizontal seat surface.[22] No effect of FW-tilting on head stability was found, presumably because the children in our project[22] are less severely affected than those in the Hadders-Algra study[21] (GMFCS levels I-III[22] versus levels I-IV[21]). Interestingly, in all children with spastic CP, foot-support in the FW-tilted position was associated with higher reaching velocity, whereas this effect was absent during horizontal seating. In children with US-CP, FW-tilting with foot-support also was associated with a shorter reaching duration. However, in children with BS-CP, FW-tilting with foot-support induced a longer total path length and a longer reaching duration.[22] In the current paper, Project II, we address the effect of the seating modifications on postural adjustments. To date, no studies have focused specifically on foot-support as a possible factor affecting postural muscular adjustments during forward reaching.

In the control of postural muscle activity, two functional levels may be distinguished.[23] The first level consists of direction-specificity, i.e., when balance is threatened by a forward sway of the body as in forward reaching, the dorsal postural muscles are primarily activated; whereas in a backward body sway the ventral postural muscles are primarily activated. The second level involves the fine-tuning of the direction-specific adjustments, for example by (a) selection of the order in which the agonist muscles are recruited (e.g., in top-down or bottom-up recruitment order); (b) presence of anticipatory postural activity[24–26]; and (c) modulation of the degree of postural muscle contraction which is reflected by the EMG-amplitude. The latter (c) is the most subtle form of postural fine-tuning.[1,23,26]

School-age children with CP, GMFCS level I-III, can generate the basic level of control during reaching but have impaired fine-tuning.[1] Presumably the children's major problem is their reduced capacity to modulate EMG-amplitude to the specifics of the task, e.g., reaching velocity.[2] This problem is more severe in children with BS-CP.[1,2]

The aim of the present exploratory study is to evaluate the effect of 15° FW-tilting of the seat surface in combination with the effect of foot-support in children with spastic CP, i.e. US-CP and BS-CP, GMFCS levels I-III, on postural adjustments while reaching. We address the following questions:

Does FW-tilting or horizontal seating, with or without foot-support affect EMG-parameters of postural control during reaching? The effect is studied at both levels of postural control, but we hypothesized that a potential effect is best expressed in the EMG-amplitudes, i.e., the amplitudes at baseline and during reaching. Therefore, the EMG-amplitudes are our primary outcome parameters.

1. Does seating condition affect the capacity to modulate EMG-amplitudes during reaching in terms of stronger correlations between EMG-amplitudes and kinematics of reaching and head stability?
2. Do the putative effects depend on the type of CP, or GMFCS levels?

Method

Study design

Repeated-measures design.

Participants

This observational study used data of the nineteen participants (seven boys, 12 girls; GMFCS levels I to III; 6 to 12 years old (median age: 8 years 9 months)), who also participated in Project I (see Angsupaisal et al., 2017[22]). Ten children were diagnosed with US-CP and nine with BS-CP.[27] The children were recruited at the outpatient clinic of the department of Rehabilitation Medicine, University Medical Center, and two special schools. Children were excluded if they functioned at GMFCS levels IV-V, had dyskinetic or ataxic movement disorders, distinct behavioural problems, severe visual impairment, or reaching inability. Parents signed an informed consent. Ethical approval was obtained.

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
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)
EMG outcome variables, number of valid trials (median, range)		
– horizontal without foot support	13.5 (12 – 16)	13 (11 – 15)
– horizontal with foot support	14.5 (11 – 16)	13 (11 – 15)
– FW without foot support	13 (13 – 16)	13 (10 – 16)
– FW with foot support	15 (10 – 17)	14 (7 – 14)

BS-CP = children with bilateral spastic CP; cm = centimetres; EMG = electromyography; FW = forward-tilted; GMFCS, = Gross Motor Function Classification System level I to III; GMFM-66 = Gross Motor Function Measure-66 version; kg = kilogram; 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, $p = 0.346$.

Measures

Reaching performance of all participants was randomly assessed in four seating conditions: horizontal seat surface without (a) and with (b) foot-support, and 15° FW-tilted without (c) and with (d) foot-support. Between conditions, the child had a 5-minute break during which the examiner adjusted the seating condition, and the child rated the pleasantness of the previous seating.[22] The assessments were performed at either the research institute or the special school, depending on the family's wishes.

Reaching movements were performed at arm-length distance. The instruction was to grasp the object at self-paced speed with the dominant hand, i.e., the hand with which the child preferred to write. As motor behaviour of children generally is characterized by variation,[25,28] and to deal with data loss due to technical artefacts, the children were asked to perform at least ten trials to a maximum of 20 trials in each condition. Practice trials were carried out before testing.[22]

Postural control was measured with surface EMGs. Simultaneously, kinematics of head stability in space and reaching quality was recorded (for details see Angsupaisal et al.[22]). The whole reaching session was recorded on video. Muscle activity of neck, trunk and arm muscles was measured with bipolar surface electrodes (interelectrode distance: 14 mm) that were applied to the reaching side of the body on five postural muscles (sternocleidomastoid or neck flexor (NF); neck extensor (NE); rectus abdominis (RA); thoracic extensor (TE); lumbar extensor (LE)) and four arm muscles (deltoid, pectoralis major, biceps and triceps brachii). The EMG signal was recorded at a sampling rate of 500 Hz with the Portilab software program (Twente Medical Systems International, Enschede, the Netherlands).

After the reaching session, gross motor ability was assessed using the Gross Motor Function Measure 66-version (GMFM-66).[29] Reliability and validity of the GMFM-66 have been well established.[29] Finally, the degree of spasticity of the biceps brachii of the dominant arm was assessed using the modified Tardieu Scale[30] that classifies spasticity grades ranging from 0 to 4. The psychometric properties of the scale are sufficient.[30]

EMG and kinematic analyses

Electromyographic and kinematic analyses were carried out by the first author and a medical master student with the PedEMG Program.[26] The kinematics of head stability in space and reaching were the focus of Project I.[22] Here, EMG-activity is evaluated. PedEMG allows for a synchronous analysis of EMG, kinematic and video data. The program uses the dynamic threshold statistical algorithm of Staude and Wolf (1999)[31] to determine onsets of phasic EMG-activity.[26] The activity of the postural muscles was considered to be related to the arm movement if increased muscle activity was found within a time window consisting of 100 milliseconds before activation of the "prime mover," that is, the arm muscle that was activated first, and the duration (the first 1,000 milliseconds) of the reaching movement.[32,33]

For each seating condition and each child, the following EMG-parameters were calculated: (1) the percentage of direction-specific trials at the neck or trunk level; a trial was direction-specific if the dorsal muscle was recruited before the antagonistic ventral muscle or without antagonistic activation.[26] The other EMG parameters were calculated only for trials in which direction-specificity at the trunk level was present: (2) the percentage of trials with top-down, or bottom-up order of recruitment.[1] The recruitment order could only be determined when at least two direction-specific muscles showed significant phasic activity; (3) percentage of trials with anticipatory postural activity at the neck or trunk level (i.e., activation starting within 100 milliseconds (ms) before activation of the "prime mover"); (4) relative mean amplitudes of NE, TE and LE in three different time intervals. The interval (I1) ranged from 100 ms before prime mover onset to prime mover start (T0). This interval covers anticipatory postural muscle activity. The second- and third-time intervals ranged from T0 to100 ms (I2) and from 100 to 1,000 ms after T0 (I3), respectively. I2 reflects a mix of anticipatory and compensatory postural control, whereas I3 reflects reactive, feedback activity.[2,21] The relative mean amplitude was the ratio between the absolute EMG-amplitude in a specific interval and the baseline amplitude (tonic background activity). The baseline was defined as the average amplitude during the period with lowest activity in the entire recording determined using the Staude and Wolf algorithms.[31]

Statistical Analysis

The study sample was based on the kinematic parameter head stability in space used in Project I.[22] The clinical characteristics, including the pleasantness scores were analysed with the Friedman's test. Relationships between EMG-amplitudes and the kinematic parameters were analysed with Spearman's Rho. To avoid a Type-I error in the many correlations, $p < 0.01$ was here regarded as statistical significant.

The EMG data were analysed with (generalized) linear mixed-effects models (MIXED; SPSS version 23.0.0.3., Chicago, IL, USA). The four seating positions were included as fixed effects for all EMG parameters and the analyses were adjusted for covariates which were age and anthropometry (height and body mass index), with additional corrections for the type of CP and its interaction with seating positions. The material did not allow an additional inclusion of GMFCS-level and GMFM-score, due to the relatively small number of events.

The EMG-amplitudes of NE, TE and LE were analysed with mixed-effects models. Clustering of observations was accounted for by incorporating a random subject effect to model the correlation between the measurements within children.

Generalized linear mixed models with the logit link function were used for the binary response variables, i.e. direction-specificity, 'complete pattern', recruitment order, and anticipatory postural activity. Estimation was performed with generalized estimating equations (GEE) and the cluster variable was determined by the child. Estimated marginal means for each of the seating positions were calculated based on these models and presented with their 95% confidence interval (CI). The *post hoc* Bonferroni tests were performed to explore the most relevant clinical contrasts.

Results

The clinical characteristics of the 19 participants, their distribution across GMFCS-levels, and the number of trials achieved per condition are shown in Table 1.[22] The participants generated 1,065 reaches with proper EMG-data in four seating conditions (approximately 56 observations per child). No adverse effects of the seating conditions were reported. The pleasantness ratings of the four seating conditions were similar (Friedman test, $p = 0.346$). The children with BS-CP and US-CP had similar GMFM-66 scores (median value [range]: 76.8 [50.1 -100] vs 77.9 [52.3–92.1]; 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.[22]

Seating condition and postural muscle activity

The adjusted analyses in the whole group of participants indicated that seating condition affected tonic background activity of TE and LE and phasic EMG-amplitudes of TE in intervals 1 and 3 (Table 2). The type of CP did not affect the effect of seating conditions (Table 2). The results suggested that the effect of seating was brought about by the effect of foot-support. Therefore, we performed *post hoc* Bonferroni analyses in which we pooled both seat surface conditions (FW and horizontal surface) and both types of CP. These explorative analyses suggested that the presence of foot-support was associated with higher tonic background activity in TE and LE, and with lower TE activity in the three phasic intervals (Table 3).

The adjusted analyses indicated that the seating conditions were not associated with significant changes in the following parameters: direction-specificity, recruitment order, and anticipatory postural activity (Supplementary Table 1).

Table 2 Seating effects on tonic background activity and phasic EMG (relative mean) amplitudes: adjusted analyses

	Horizontal seating		**FW Tilt seating**		
Response variable (NE, TE, LE)	**Without foot support (CI)**	**With foot support (CI)**	**Without foot support (CI)**	**With foot support (CI)**	**P-value[1]**
NE baseline					0.09
Type CP = US	1.49	1.63	1.55	1.46	(0.26)
	[1.05–2.12]	[1.14–2.31]	[1.08–2.24]	[1.03–2.07]	
Type CP = BS	1.51	2.58	1.47	1.76	
	[1.04–2.19]	[1.78–3.74]	[1.02–1.08]	[1.20–2.53]	
NE1					0.12
Type CP = US	2.80	2.49	2.50	2.73	(0.32)
	[2.19–3.58]	[1.95–3.18]	[1.94–3.24]	[2.14–3.49]	
Type CP = BS	2.53	1.73	2.49	2.06	
	[1.96–3.28]	[1.34–2.24]	[1.93–3.23]	[1.59–2.67]	
NE2					0.17
Type CP = US	3.15	3.19	2.96	3.22	(0.06)
	[2.40–3.13]	[2.44–4.18]	[2.24–3.92]	[2.46–4.22]	
Type CP = BS	2.96	1.83	2.84	2.33	
	[2.23–3.94]	[1.38–2.44]	[2.13–3.77]	[1.75–3.10]	
NE3					0.09
Type CP = US	3.19	1.86	2.86	2.28	(0.07)
	[2.41–4.22]	[1.40–2.46]	[2.16–3.74]	[1.72–3.02]	
Type CP = BS	3.48	3.36	3.15	3.49	
	[2.66–4.54]	[2.58–4.39]	[2.38–4.16]	[2.68–4.56]	
TE baseline					< 0.001**
Type CP = US	1.50	2.34	1.51	2.49	(0.92)
	[0.97–2.32]	[1.52–3.62]	[0.96–2.36]	[1.61–3.84]	
Type CP = BS	1.68	2.58	1.42	2.49	
	[1.05–2.70]	[1.63–4.08]	[0.90–2.25]	[1.57–3.94]	

	Horizontal seating		FW Tilt seating		
Response variable (NE, TE, LE)	**Without foot support (CI)**	**With foot support (CI)**	**Without foot support (CI)**	**With foot support (CI)**	**P-value[1]**
TE1					0.009**
Type CP = US	3.72	2.83	3.88	2.44	
	[2.39–5.78]	[1.82–4.40]	[2.47–6.12]	[1.57–3.79]	0.96
Type CP = BS	4.44	3.33	4.00	2.73	
	[2.74–7.19]	[2.09–5.30]	[2.51–6.39]	[1.71–4.35]	
TE2					0.05
Type CP = US	5.92	4.68	6.05	4.24	
	[3.72–9.40]	[2.95–7.44]	[3.75–9.76]	[2.67–6.73]	(0.98)
Type CP = BS	5.32	4.12	5.08	3.39	
	[3.21–8.83]	[2.52–6.71]	[3.11–8.28]	[2.08–5.53]	
TE3					0.011*
Type CP = US	7.13	5.05	7.81	4.76	
	[4.50–11.31]	[3.19–8.02]	[4.85–12.58]	[3.00–7.55]	(0.95)
Type CP = BS	6.16	4.23	5.70	4.01	
	[3.72–10.21]	[2.60–6.89]	[3.50–9.28]	[2.46–6.53]	
LE baseline					0.005**
Type CP = US	1.16	1.93	1.28	1.99	
	[0.69–1.95]	[1.15–3.23]	[0.75–2.19]	[1.19–3.34]	(0.92)
Type CP = BS	1.11	2.22	1.20	1.83	
	[0.64–1.91]	[1.29–3.83]	[0.69–2.07]	[1.06–3.16]	
LE1					0.36
Type CP = US	2.02	1.58	1.99	1.60	
	[1.16–3.51]	[0.91–2.75]	[1.13–3.52]	[0.92–2.78]	(0.92)
Type CP = BS	1.48	1.03	1.40	1.34	
	[0.82–2.65]	[0.57–1.84]	[0.78–2.50]	[0.75–2.40]	
LE2					0.46
Type CP = US	2.20	1.79	2.13	1.79	
	[1.23–3.92]	[1.00–3.20]	[1.17–3.86]	[1.01–3.21]	(0.94)
Type CP = BS	1.55	1.10	1.54	1.40	
	[0.84–2.86]	[0.60–2.04]	[0.84–2.85]	[0.76–2.59]	
LE3					0.59
Type CP = US	2.60	2.21	2.93	2.26	
	[1.38–4.91]	[1.17–4.17]	[1.52–5.64]	[4.26–1.02]	(0.84)
Type CP = BS	1.80	1.39	1.85	1.99	
	[0.92–3.51]	[0.71–2.72]	[0.95–3.62]	[1.02–3.90]	

Presented are the estimated marginal means expressed in the median [95% confidential interval; lower bound – upper bound] based on the results from the (generalized) mixed effects models. For the marginal means estimate, the covariates appearing in the model were evaluated at age = 110.89 months, height = 135.78 centimetres, and BMI = 17.353 kg/m², and type of CP. (Generalized) linear mixed-effects models: * = p-value < 0.05 and ** = p-value < 0.01.

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

CP: US-CP = children with unilateral spastic CP; BS-CP = children with bilateral spastic CP; CI, 95% confidence intervals (the values in square brackets); EMG relative mean amplitude of NE = neck extensor, TE = trunk extensor, LE = lumbar extensor at baseline (tonic background activity); and EMG relative mean amplitude during the intervals 1 = NE1, TE1, LE1, during interval 2 = NE2, TE2, LE2, and during interval 3 = NE3, TE3, LE3 (phasic activity).

Table 3 Foot-support effects on tonic background activity and phasic muscle activity: post-hoc analyses

Response variable (Whole group of participants)	Without foot-support	With foot-support	P-value[1]
TE baseline	1.52 [1.15–2.02]	2.47 [1.87–3.27]	< 0.001**
TE1	3.99 [3.00–5.31]	2.81 [2.12–3.74]	0.001**
TE2	5.57 [4.15–7.48]	4.08 [3.04–5.47]	0.007**
TE3	6.63 [4.93–8.92]	4.50 [3.35–6.03]	0.001**
LE baseline	1.18 [0.86–1.63]	1.99 [1.44–2.74]	< 0.001**

Presented are the estimated marginal means of the whole group of children with CP expressed in the median [95% confidential interval; lower bound – upper bound] based on the results from the (generalized) mixed effects models. The covariates appearing in the model were evaluated at age = 110.89 months, height = 135.78 centimetres, and BMI = 17.353 kg/m². The post-hoc contrast focuses on the difference between the sitting without foot-support and with foot-support condition (irrespective of seat surface tilting).
**(Generalized) linear mixed-effects models; p-value < 0.01.
[1] The p-values are the values of the Type III test of the fixed effects of two sitting conditions (without vs with foot-support).

Correlation between EMG-amplitudes and kinematic parameters

To evaluate research question 2, we correlated the relative mean amplitudes of TE and LE with the kinematic parameters[22] in each of the four seating conditions. None of the correlations reached statistical significance (Supplementary table S2), indicating that no signs of amplitude modulation in any of the seating conditions were found. The lack of significant correlations could be due to the limited number of observations per condition and the fact that the main effect of seating condition presumably was brought about by foot-support. Therefore, we analysed the correlations for the seating conditions with and without foot-support (i.e., with pooling of the FW and horizontal conditions). The data suggested that foot-support was associated with a modulating capacity of the tonic background activity in TE and LE: higher background activity was associated with better reaching kinematics, i.e., with larger transport MUs (Table 4).

Table 4 Correlations between tonic and phasic EMG activity, and kinematics of reaching movement, head stability in space

	Head sway		MUs		Transport MU		Index curvature		Reaching speed	
Response	without foot-support	with foot-support	without foot-support	with foot-support	without foot-support	with foot-support	without foot-support	with foot-support	without foot-support	with foot-support
TE baseline	-0.158	0.207	-0.528	-0.366	0.363	0.589**	-0.062	0.346	-0.013	0.364
TE1	0.146	0.147	0.083	-0.06	0.342	-0.091	0.456	-0.174	0.258	-0.185
TE2	0.274	-0.019	-0.038	-0.184	0.347	-0.168	0.550	0.073	0.414	-0.056
TE3	0.226	-0.033	0.006	-0.227	0.295	-0.161	0.521	-0.042	0.331	-0.089
LE baseline	0.139	0.247	-0.176	-0.496	0.407	0.611**	0.325	0.271	0.101	0.277

Presented are correlations between tonic background activity (baseline) of TE and LE, phasic EMG-activity (relative mean amplitudes) of TE in three intervals and the kinematics of the head stability in space (head sway) and reaching movement (Spearman's rank correlation coefficient; **p-value < 0.01). MUs = movement unit

Supplementary Table S1 (on-line version). Seating effects on the EMG parameters on the first and second level of postural control: adjusted analyses.

	Horizontal seating		Tilted seating		
Response variable	Without foot support [CI]	With foot support [CI]	Without foot support [CI]	With foot support [CI]	**P-value**[1]
Directional Specificity at the neck					0.35
Type CP = US	0.76 [0.60;0.87]	0.78 [0.69;0.85]	0.67 [0.48;0.82]	0.75 [0.67;0.82]	(0.58)
Type CP = BS	0.77 [0.60;0.87]	0.66 [0.55;0.76]	0.68 [0.52;0.81]	0.74 [0.57;0.85]	
Directional Specificity at the trunk					0.89
Type CP = US	0.90 [0.78;0.96]	0.94 [0.88;0.97]	0.96 [0.89;0.98]	0.96 [0.94;0.98]	(0.45)
Type CP = BS	0.89 [0.79;0.95]	0.93 [0.86;0.97]	0.94 [0.88;0.98]	0.96 [0.94;0.98]	
Top-down recruitment order					0.79
Type CP = US	0.38 [0.27;0.50]	0.32 [0.23;0.43]	0.33 [0.19;0.50]	0.33 [0.24;0.43]	(0.42)
Type CP = BS	0.39 [0.25;0.54]	0.43 [0.30;0.57]	0.42 [0.26;0.60]	0.32 [0.21;0.46]	
Bottom-up recruitment order					0.13
Type CP = US	0.31 [0.22;0.42]	0.20 [0.14;0.29]	0.13 [0.07;0.22]	0.22 [0.17;0.29]	(0.74)
Type CP = BS	0.27 [0.15;0.44]	0.19 [0.11;0.30]	0.16 [0.09;0.28]	0.17 [0.10;0.27]	
Anticipatory postural activity at the neck					0.47
Type CP = US	0.33 [0.25;0.43]	0.34 [0.27;0.42]	0.32 [0.23;0.43]	0.34 [0.23;0.46]	(0.63)
Type CP = BS	0.42 [0.36;0.48]	0.45 [0.38;0.52]	0.41 [0.30;0.52]	0.34 [0.23;0.46]	
Anticipatory postural activity at the trunk					0.15
Type CP = US	0.38 [0.27;0.50]	0.47 [0.34;0.61]	0.36 [0.26;0.47]	0.46 [0.38;0.54]	(0.93)
Type CP = BS	0.45 [0.31;0.61]	0.52 [0.40;0.61]	0.40 [0.25;0.58]	0.47 [0.29;0.66]	

Presented are the estimated marginal means expressed in the median [95% confidential interval; lower bound; upper bound] based on the results from the (generalized) mixed effects models. For the marginal means estimate, the covariates appearing in the model were evaluated at age = 110.89 months, height = 135.78 centimetres, and BMI = 17.353 kg/m², and type of CP.
* (generalized) mixed effects models; p-value < 0.05. [1] The first p-values in the adjusted analyses are the values of the Type III test of the fixed effects of four seating conditions. The second p-values (in brackets) in the adjusted analyses are those of the interaction term of seating position with CP-type. CI, 95% confidence intervals (the values in square brackets); Type CP: BS-CP = children with bilateral spastic CP; US-CP = children with unilateral spastic CP.

3

Supplementary Table S2 (on-line version): Correlations between tonic and phasic EMG activity and kinematics of reaching and head stability in space

	Head stability in space				Movement units (MU)				Transport MU				Index of curvature				Average speed of reaching movement			
	Horizontal seating		FW Tilt seating		Horizontal seating		FW Tilt seating		Horizontal seating		FW Tilt seating		Horizontal seating		FW Tilt seating		Horizontal seating		FW Tilt seating	
EMG ampli-tude	Without foot support	With foot support	Without foot support	With foot support	Without foot support	With foot support	Without foot support	With foot support	Without foot support	With foot support	Without foot support	With foot support	Without foot support	With foot support	Without foot support	With foot support	Without foot support	With foot support	Without foot support	With foot support
TE baseline	-0.226	0.009	0.342	0.304	-0.187	-0.212	-0.234	-0.306	-0.139	-0.012	0.253	0.116	0.255	0.153	0.044	0.319	0.195	0.212	0.222	0.232
TE1	-0.15	0.126	0.315	-0.046	-0.25	-0.165	-0.153	0.236	0.067	0.061	0.127	-0.165	0.191	-0.037	0.203	-0.293	-0.133	-0.251	0.032	-0.058
TE2	-0.249	-0.004	0.573*	-0.246	-0.294	-0.283	-0.259	0	0.026	-0.023	0.3	-0.181	0.24	0.16	0.278	-0.072	-0.158	-0.167	0.373	0.132
TE3	-0.265	-0.086	0.434	-0.207	-0.414	-0.236	-0.102	0	0.121	-0.098	0.154	-0.239	0.263	-0.06	0.296	-0.111	0.015	-0.291	0.232	0.04
LE baseline	0.074	0.109	0.224	0.349	0.054	-0.306	-0.085	-0.212	0.011	-0.058	0.063	-0.016	0.302	0.221	0.003	0.281	0.065	0.225	0.069	0.251

Presented are correlations between tonic background activity (baseline) of TE and LE and phasic EMG-activity (relative mean amplitudes) of TE in three intervals and the kinematics of the reaching movement, and the head stability in space (head sway). Spearman's rank correlation coefficient; * This correlation had a p-value of 0.013. MUs = movement units

Discussion

The present exploratory study suggested that in school-age children with CP a 15° FW-tilting was not associated with postural muscular adjustments during reaching. Yet, foot-support was associated with increased background EMG-amplitude of the trunk extensors, which in turn was associated with better reaching kinematics.

Our finding that FW-tilting did not affect postural muscle activity is at variance with two studies.[13,21] Sochaniwskyj et al. (1991)[13] reported that FW-tilting during quiet sitting in school-age children with BS-CP was associated with increased background EMG-amplitude of the trunk extensors. However, the authors only reported descriptive data without statistical analyses. Hadders-Algra et al. (2007)[21] indicated that in children with US-CP, FW-tilting during seated reaching was associated with statistically significantly lower phasic EMG-amplitudes in the trunk extensors. The differences between the latter study[21] and ours may be due to: (1) the number of participants and their age range differed[21]; (2) the latter study did not adjust for the confounding effects of anthropometrics and age.[21] We suggest that FW-tilting may influence postural muscular activity especially in children with US-CP, but presumably this effect is just a minor one.

The present data suggested that foot-support affected the fine-tuning of postural adjustments, i.e., it was associated with (a) increased background EMG-amplitude in the trunk extensors before the onset of reaching, and (b) decreased phasic amplitudes of TE during the reaching movement, irrespective of the seating inclination. The increased tonic activity in the trunk extensors, in turn, was associated with improved kinematics of reaching, i.e., increases in the transport MU – one of the parameters reflecting feedforward control of reaching.[22,33,34] Therefore, our results suggest that foot-support promotes postural adjustments that may be fine-tuned to the specifics of the reaching movement. This is in line with the suggestions provided by Myhr et al. 1995[18] and Hadders-Algra et al. 2007[21] – studies that were, however, not able to provide evidence on the effect of foot-support. No other studies systematically evaluated the effect of foot-support on muscle activity during activities in sitting.

Clinically, foot-support is regarded as an important component of adaptive seating that may influence postural control.[6,18,35,36] The idea is that foot-support decreases the degrees of freedom of the lower extremities, therewith enhancing stability.[1,18,35] Our findings are in line with clinical experience: foot-support may enhance the capacity to modulate postural activity needed for proper reaching.

On the basis of the combination of Projects I and II on the effect of FW-tilting and foot-support, we conclude the following. The kinematic part[22] indicated that children with US-CP benefit from FW-tilting in terms of better organized reaching movements. If foot-support was added to the FW-inclination, reaching velocity became higher and movement duration shorter.[22] The present EMG-study suggests that the better reaching kinematics in the foot-support condition in part may be mediated by a better capacity to modulate postural activity in the trunk extensors. The latter effect was found in all children with CP in both seat inclination conditions. However, in all children with CP foot-support in the horizontal situation was not associated with significant improvements in the kinematics of reaching – despite the positive effect of foot-support on the ability to modulate postural EMG activity. Nor, did children with BS-CP generally profit from foot-support in the FW-inclined situation: the velocity of their reaching movements was higher, but at the expense of increases in path-length and duration. Therefore, our previous[22] and present study suggest that for children with US-CP the FW-tilted seating with foot-support offers the best situation for optimal reaching movements. In children with BS-CP, the horizontal seating with foot-support presumably is best.

The strength of this study is the standardized measurement and analyses of EMG-recordings and the statistical analyses with mixed effect models, allowing to adjust for confounders such as age and anthropometrics while accounting for clustering in the data. Another strength is the composition of the study groups (US-CP and BS-CP) that were comparable in age, body proportions, GMFCS-level and GMFM-66 scores, and spasticity level of the reaching arm. However, the study has some limitations. Our findings cannot be generalized to all children with CP, as we only studied ambulatory, school-age children with spastic forms of CP. We could not address the effect of GMFCS-level due to the small number of children per subgroup. Future research should aim for replication in larger groups with equally sized subgroups per GMFCS level. Lastly, we used a laboratory setting precluding direct generalization to the variety of activities in everyday environments.

Conclusion

Foot-support enhanced the capacity of children with spastic CP to modulate trunk extensor activity, which was associated with improved reaching quality. FW-tilt did not affect postural muscle activity. Combining present and previous[22] results, we suggest that children with US-CP benefit most from FW-tilted seating with foot-support; in children with BS-CP the horizontal seating presumably is best, with a potentially minor positive effect of foot-support.

Ethical Approval

The Central Committee on Research involving Human Subjects, Den Haag (Ref. No.: CCMO;NL39267.000.12) approved the study.

Funding

This work was supported by funding from the Naresuan University, Phitsanulok, Thailand and the Graduate School for Behavioural and Cognitive Neurosciences, University of Groningen, The Netherlands. The funding sources had no role in the design, conduct, or reporting of this study.

Conflict of interest

The authors declare that they have no competing of interests.

Acknowledgements

We acknowledge the support of Tjitske Hielkema, MD, PhD, 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.

References

1. Hadders-Algra M, Carlberg EB, eds. *Postural control: a key issue in developmental disorders*. Clinics in Developmental Medicine No 179. London: Mac Keith Press 2008.
2. Van Der Heide JC, Begeer C, Fock JM, et al. Postural control during reaching in preterm children with cerebral palsy. *Dev Med Child Neurol.* 2004; **46**(4): 253–266.
3. Gericke T. Postural management for children with cerebral palsy: consensus statement. *Dev Med Child Neurol.* 2006; **48**(4): 244.
4. *International Classification of Functioning, Disability and Health: Children and Youth Version—ICF-CY.* Geneva, Switzerland: World Health Organization; 2007.
5. Ryan S. An overview of systematic reviews of adaptive seating interventions for children with cerebral palsy: where do we go from here? *Disabil Rehabil Assist Technol.* 2012; **7**(2):104–111.
6. Angsupaisal M, Maathuis CGB, Hadders-Algra M. 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. *Dev Med Child Neurol.* 2015; **57**(10):919–930.
7. Palisano RJ, Rosenbaum P, Bartlett D, et al. *The Gross Motor Function Classification System–Expanded and Revised (GMFCS-E & R).* Canchild Centre for Childhood Disability Research. Available: http://www.canchild.ca Accessed April 9, 2013.
8. Chung J, Evans J, Lee C, et al. Effectiveness of Adaptive seating on Sitting Posture and Postural Control in Children with Cerebral Palsy. *Pediatr Phys Ther.* 2008; **20**(4): 303–317.
9. McNamara L, Casey J. Seat inclinations affect the function of children with cerebral palsy: A review of the effect of different seat inclines. *Disabil Rehabil Assist Technol.* 2007; **2**(6): 309 – 318.
10. Myhr U, von Wendt L. Improvement of functional sitting positions for children with cerebral palsy. *Dev Med Child Neurol.* 1991; **33**(3): 246–256.
11. Pope PM, Bowes CE, Booth E. Postural control in sitting the SAM system: evaluation of use over three years. *Dev Med Child Neurol.* 1994; **36**(3): 241–252.
12. Reid DT. The effects of the saddle seat on seated postural control and upper-extremity movement in children with cerebral palsy. *Dev Med Child Neurol.* 1996; **38**(9): 805–815.
13. Sochaniwskyj A, Koheil R, Bablich K, et al. Dynamic monitoring of sitting posture for children with spastic cerebral palsy. *Clin Biomech*. 1991; **6**(3):161–167.
14. Miedaner J. The effects of sitting positions on trunk extension for children with motor impairment. *Pediatr Phys Ther.* 1990; **2**:11–14.
15. Nwaobi OM. Seating orientations and upper extremity function in children with cerebral palsy. *Phys Ther.* 1987; **67**(8): 1209–1212.
16. Nwaobi OM, Brubaker CE, Cusick B, et al. Electromyographic investigation of extensor activity in cerebral-palsied children in different seating positions. *Dev Med Child Neurol.* 1983; **25**(2): 175–183.
17. McClenaghan BA, Thombs L, Milner M. Effect of seat-surface inclination on postural stability and function of the upper extremities of children with cerebral palsy. *Dev Med Child Neurol.* 1992; **34**(1): 40–48.

18. Myhr U, von Wendt L, Norrlin S, et al. Five-Year Follow-up of Functional Sitting Position in Children with Cerebral Palsy. *Dev Med Child Neurol.* 1995; **37**(7): 587–596.
19. Cherng R-J, Lin H-C, Ju Y-H, et al. Effect of seat surface inclination on postural stability and forward reaching efficiency in children with spastic cerebral palsy. *Res Dev Disabil.* 2009; **30**(6): 1420–1427.
20. Tsai YS, Yu YC, Huang PC, et al. Seat surface inclination may affect postural stability during Boccia ball throwing in children with cerebral palsy. *Res Dev Disabil.* 2014; **35**(12): 3568–3573.
21. Hadders-Algra M, van der Heide JC, Fock JM, et al. Effect of Seat Surface Inclination on Postural Control During Reaching in Preterm Children With Cerebral Palsy. *Phys Ther.* 2007; **87**(7): 861–871.
22. Angsupaisal M, Dijkstra LJ, la Bastide-van Gemert S, et al. Best seating condition in children with spastic cerebral palsy: One type does not fit all. *Res Dev Disabil.* 2017; **71**: 42–52.
23. Forssberg H, Hirschfeld H. Postural adjustments in sitting humans following external perturbations: muscle activity and kinematics. *Exp Brain Res.* 1994; **97**(3): 515–27.
24. Massion J. Postural control systems in developmental perspective. *Neurosci Biobehav Rev.* 1998; **22**(4): 465–472.
25. Hadders-Algra M. Typical and atypical development of reaching and postural control in infancy. *Dev Med Child Neurol.* 2013; **55**(Suppl 4): 5–8.
26. van Balen L, Dijkstra L, Hadders-Algra M. Development of postural adjustments during reaching in typically developing infants from 4 to 18 months. *Exp Brain Res.* 2012; **220**(2): 109–119.
27. Surveillance of cerebral palsy in Europe: a collaboration of cerebral palsy surveys and registers. *Dev Med Child Neurol.* 2000; **42**: 816–824.
28. Huang, H. H., Ellis, T. D., Wagenaar, R.C., & Fetters, L. (2013). The Impact of Body-Scaled Information on Reaching. *Phys Ther*, **93**(1), 41–49.
29. Russell DJ, Rosenbaum PL, Avery LM, Lane M. *Gross Motor Function Measure (GMFM-66 & GMFM-88): User's Manual.* London, United Kingdom: Mac Keith Press; 2002.
30. Boyd R, Graham H. Objective measurement of clinical findings in the use of botulinum toxin type A in the management of children with cerebral palsy. *Eur J Neurol.* 1999; **6**(suppl 4): S23–S35.
31. Staude G, Wolf W. Objective motor response onset detection in surface myoelectric signals. 449–467. *Med Eng Phys.* 1999; **21**: 449–467.
32. Boxum AG, van Balen LC, Dijkstra L-J, et al. Postural adjustments in infants at very high risk for cerebral palsy before and after developing the ability to sit independently. *Early Hum Dev.* 2014; **90**(9): 435–441.
33. Angsupaisal M, Visser B, Alkema A, et al. Therapist-designed adaptive riding in children with cerebral palsy: Results of a feasibility study. *Phys Ther.* 2015; **95**(8): 1151–1162.
34. van der Heide JC, Fock JM, Otten B, et al. Kinematic characteristics of reaching movements in preterm children with cerebral palsy. *Pediatr Res.* 2005; **57**(6): 883–889.
35. von Hofsten C. Structuring of early reaching movements: A longitudinal study. *J Mot Behav.* 1991; **23**(4): 280–292.
36. Ekblom B, Myhr U. Effects of hip abduction orthosis on muscle activity in children with cerebral palsy. *Physiother Theory Pract.* 2002; **18**: 55–63.
37. Ryan S. Lessons learned from studying the functional impact of adaptive seating interventions for children with cerebral palsy. *Dev Med Child Neurol.* 2016; **58**(Suppl 4): 78–82.