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Original article

Effects of forward tilted seating and foot-support on postural adjustments in children with spastic cerebral palsy: An EMG-study

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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; step two of two-step-project.
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 and kinematics of head and reaching arm (step one of two-step-project) were recorded. 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

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Abbreviations: BS-CP, bilateral spastic CP; CP, cerebral palsy; EMG, (surface) electromyography; FW-tilting, forward tilting of seat surface; GMFCS, Gross Motor Function Classification System; LE, lumbar extensor muscle; NF, neck flexor or sternocleidomastoid muscle; NE, neck extensor muscle; MUs, number of Movement Unit (kinematic reaching parameter); RA, rectus abdominis muscle; TE, thoracic extensor muscle; US-CP, unilateral spastic CP.

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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 was associated with improved reaching quality. FW-tilting did not affect postural muscle activity.

1. 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] but also debated.[10–17]

Postural control is the basis of motor function. To maintain posture and balance in space or in correspondence to gravity, such as during sitting while reaching, a complex interaction of the musculoskeletal and neural systems is required.[1] In terms of motor control, the nervous system creates postural synergies to deal with the problem of many degrees of freedom. In the neural control of postural synergies which involves the control of postural muscle activity, two functional levels may be distinguished.[18] The first level consists of direction-specificity, implying for instance that during forward reaching the dorsal postural muscles are primarily activated. The second level involves the fine-tuning of the direction-specific adjustments, for example by (a) selecting the recruitment order of the agonist muscles (e.g., top-down or bottom-up recruitment); (b) presence of anticipatory postural activity[19–21]; and (c) modulation of the degree of postural muscle contraction (reflected by surfaced electromyography (EMG)-amplitude). The latter (c) is the most subtle form of postural fine-tuning.[1,18,21]

The kinematics of reaching movements furnishes information on the control of the movements. In adults a typical reaching movement is programmed in a feedforward way and consists of one acceleration and one deceleration; the combination of one acceleration and one deceleration is called a movement unit (MU).[22] During early development, reaching movements are performed with trial and error during which inaccurately feedforward programmed movements are corrected multiple times by feedback. As a result, early reaching movements consist of multiple MUs and they have a curved and relative long movement trajectory. With increasing age and increasing experience feedforward control improves, and major part of the movement is covered by 1 MU (the transport MU). In other words, a better kinematic movement quality, that mostly relies on feedforward control, is especially reflected by fewer MUs and a relatively long transport MU. It also results in movements with a less curved and shorter trajectory.[1,22,23]

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 bilateral spastic CP (BS-CP) than in children with unilateral (US-CP).[1,2] Also, reaching movements of school-age children with CP show impairments, for example, they consist less often of one MU and have a smaller transport MU than those of age-matched typically developing peers.[24]

Most likely, the debate on the most appropriate seat inclination in ambulatory children with CP is caused by the many factors playing a role: different outcome measures used to evaluate the adequacy of seating,[10,12,13,16,25–27] heterogeneity in CP, the degree of postural support provided, and variation in seat-angle (5°,[17,26] 10°,[13,26] and 15°[12,13,17,26–28]). Yet, in children with GMFCS levels I-III, a 10° and 15° forward tilting of the seat surface (FW-tilting) is generally recommended.[12,13,26] As 15° FW-tilting was associated with better postural stability (reflected by an improved ratio between anterior-posterior and medial-lateral sway) during forward reaching and better reaching kinematics (reflected by shorter movement times) than the 10° configuration,[26] we decided to further evaluate the 15° FW-tilting.

Previously, only Hadders-Algra et al.[28] specified CP-subtypes. Their study included 58 children with US-CP and BS-CP, functioning at GMFCS level I-IV. Hadders-Algra et al. demonstrated that only in children with US-CP, the 15° FW-tilting improved postural efficiency and quality of reaching. The improved postural efficiency was reflected by a reduced phasic activity of the postural muscles, which was associated with a better kinematic quality of reaching. The improved reaching quality was reflected by reaching movements during which a greater part of the movement was covered by the transport MU. In contrast, in children with BS-CP, the horizontal seat surface was associated with less sway of the head and a more mobile trunk compared to the FW tilting position.[28]

However, Hadders-Algra et al.[28] did not apply foot-support – due to the fact that their research line has a developmental approach, starting in early infancy when foot-support during sitting is uncommon. Others evaluated the effect of seat inclinations in the presence of foot-support but did not address its contribution.[11–14,16,17,26,27] Based on studies in adults, it is generally acknowledged that the lower limbs have an essential role in balancing the body in seated reaching tasks; they prevent falling forward and provide postural stability by means of a load through the feet typically occurring around the end of the reach. The forces acting at the feet facilitate the return of the upper body to the upright position.[29] In addition, foot-support furnishes sensory information that may be used to control posture. In this respect it is interesting to note that part of children with BS-CP are known to have sensorimotor perceptual impairments that are associated with impaired postural adjustments and decreased efficiency of reaching while being seated.[30] As we lacked information on the effect of foot-support in addition to seat surface inclination in children with CP, we recently replicated the Hadders-Algra et al. study[28] while also evaluating the effect of foot-support as a possible factor affecting postural control. We embarked on a two-step-project.

In step one of the project, we evaluated the effect on the kinematics of the head in space and reaching quality.[31] The data confirmed the differential effect of FW-inclination on kinematic reaching quality: only children with US-CP benefitted from FW-tilting, the children with BS-CP performed better on a horizontal seat surface.[31] No effect of FW-tilting on head stability was found, presumably because the children in our study[31] were less severely affected than those in the Hadders-Algra (2007) study[28] (GMFCS levels I-III and I-IV, respectively). Interestingly, in all children with CP, foot-support in the FW-tilted position was associated with higher reaching velocity, a similar effect was absent in the horizontal condition. In children with US-CP, foot-support in the FW-tilted position also was associated with a shorter reaching duration. However, in the children with BS-CP foot-support in the FW-tilted position had a deteriorating effect: it induced longer total path lengths and longer reaching durations.[31]

In step two, the current study, we address the effect of the seating modifications on postural adjustments. To the best of our knowledge, no other study focused on the specific effect of foot-support as a possible factor affecting postural muscular adjustments during forward reaching. We aim 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:

(1) 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.
(2) 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?
(3) Do the putative effects depend on the type of CP, or GMFCS levels?

2. Material and methods

2.1. Participants

Nineteen children with CP participated in our two-step-project in which we recorded simultaneously kinematic and EMG data (seven boys, 12 girls; GMFCS levels I to III; 6–12 years old (median age: 8 years 9 months)). In step one we reported on the kinematics of head sway and reaching movements.[31] The current study (step two) addresses the EMG-data. Ten children were diagnosed with US-CP and nine with BS-CP.[32] 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.

2.2. Procedures

We used a repeated measures design in which reaching performance of the 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-min break during which the examiner adjusted the seating condition, and the child rated the pleasantness of the previous seating.[31] The assessments were performed with standardized portable equipment either at the research institute or in an assessment room in 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[20,33] 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. Five practise trials were carried out before testing in every participant.[31]

The entire reaching session was recorded on video. Each assessment consisted of a simultaneous recording of EMG and kinematic data. The kinematics of the head and reaching arm were analysed in step one of the project.[31] Muscle activity was recorded with surface EMGs of (a) postural muscles of the neck and trunk on the ipsilateral side of the reaching arm; and (b) of the reaching arm muscles. We recorded the ipsilateral postural muscles as we previously found that children recruit these muscles more frequently than the contralateral ones.[34] Others reported that arm movements in children with CP generated comparable muscle activity in the ipsilateral and contralateral muscles.[35] Bipolar surface electrodes (interelectrode distance: 14 mm) were mounted over the bellies of 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) that has good reliability and validity.[36] Finally, the degree of spasticity of the biceps brachii of the dominant arm was assessed using the modified Tardieu Scale[37] that classifies spasticity grades ranging from 0 to 4. The psychometric properties of the scale are sufficient.[37]

2.3. Analysis

2.3.1. EMG analyses

Electromyographic analyses were carried out by the first author and a medical master student with the PedEMG Program.[21] This program allows for a synchronized analysis of video, kinematic and EMG signals. For the EMG-analysis, PedEMG uses the dynamic threshold statistical algorithm of Staude and Wolf (1999)[38] to determine onsets of phasic EMG-activity.[21] When appropriate we first corrected the signals for interference from artefacts and cardiac muscle activity before applying the detection algorithm. The signals were filtered for 50 Hz noise using a fifth-order band Chebyshev stop filter and its higher harmonics. Evident signal artifacts were identified manually. Cardiac activity (QRS-complexes) was identified by using a pattern recognition algorithm searching for the regularly repeating pattern and specific shape of QRS-complexes. The result of the algorithm was visually inspected.[21]

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 ms before activation of the “prime mover,” that is, the arm muscle that was activated first, and the duration (the first 1000 ms) of the reaching movement.[39,40] In our ontogenetic research line we opted for the 100 ms time window to catch anticipatory postural activity instead of a longer time window (e.g. the 500 ms window used by Witherington et al (2002)[41]), as the longer window generated too many false positive activities (children producing other movements not related to the reaching).[39] The 100 ms window is also in line with others evaluating postural adjustments in children with CP.[35] For each seating condition and each child, four EMG-parameters of the postural adjustments were calculated: first, the percentage of direction-specific trials at the neck or trunk level. Postural activity was defined as direction-specificity when the ‘direction-specific’ (i.e., dorsal) muscle was recruited before the antagonistic ventral muscle or without antagonistic activation.[21] The other EMG parameters (recruitment order, anticipatory postural activity, and relative mean amplitudes of NE, TE and LE muscle) were only calculated if direction-specificity at the trunk level was present. Our second parameter was recruitment order, i.e. the percentage of trials with top-down or bottom-up recruitment of the direction-specific muscles.[1] Top-down recruitment meant that the neck muscle was recruited prior to the trunk muscles; bottom-up implied the reverse recruitment order. The recruitment order could only be determined when at least two direction-specific muscles showed significant phasic activity. Our third parameter consisted of the percentage of trials with anticipatory postural activity at the neck or trunk level (i.e., activation starting within 100 ms (ms) before activation of the “prime mover”). Our fourth set of parameters consisted of the relative mean amplitudes of NE, TE and LE in three intervals – after subtracting baseline activity. The first time interval (I1) ranged from 100 ms before the activation of the prime mover (anticipatory postural muscle activity). The second time interval (I2) covered the first 100 ms after the start of the prime mover, after which the third time interval (I3) started, ranging from 100 to 1000 ms. The I2 interval reflects a mix of anticipatory and compensatory postural control, whereas the I3 interval reflects reactive, feedback activity.[2,28] 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 during one entire seating condition determined using the Staude and Wolf algorithms.[38]

To determine whether the children were able to modulate EMG amplitude to head stability and reaching specifics, we used the kinematic parameters of head stability and reaching as described in the step one part of the project.[31] The kinematic parameters consisted of the angle of the head in space and seven reaching parameters: number of MUs; proportion of trials with one MU; size of the transport MU, i.e. proportional length of the first MU relative to total reaching movement path length; index of curvature; average wrist speed; total path length; and reaching duration.[31]

2.3.2. Statistical analysis

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 significance.

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.

3. 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.[31] The participants generated 1065 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.[31]

3.1. *Seating condition and postural muscle activity (research question 1)*

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 (research question 3) 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). The data did not allow for the analysis of the effect of the severity of CP (expressed by GMFCS or GMFM) due to the low number of subjects per category.

3.2. *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 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 (TE baseline and transport MU: rho (ρ) = 0.589, $p < 0.01$; LE baseline and transport MU: $\rho = 0.611$, $p < 0.01$; see Fig. 1 and Supplementary Table S3).

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)	10 y 6mo (6 y 3mo–12 y 11mo)	8 y 6mo (6 y 2mo–12 y 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, $p = 0.346$.

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

Response variable (μV) (NE, TE, LE)	Horizontal seating		FW Tilt seating		P-value[a]
	Without foot support (CI)	With foot support (CI)	Without foot support (CI)	With foot support (CI)	
NE baseline					0.09
Type CP=US	1.49 [1.05–2.12]	1.63 [1.14–2.31]	1.55 [1.08–2.24]	1.46 [1.03–2.07]	(0.26)
Type CP=BS	1.51 [1.04–2.19]	2.58 [1.78–3.74]	1.47 [1.02–1.08]	1.76 [1.20–2.53]	
NE1					0.12
Type CP=US	2.80 [2.19–3.58]	2.49 [1.95–3.18]	2.50 [1.94–3.24]	2.73 [2.14–3.49]	(0.32)
Type CP=BS	2.53 [1.96–3.28]	1.73 [1.34–2.24]	2.49 [1.93–3.23]	2.06 [1.59–2.67]	
NE2					0.17
Type CP=US	3.15 [2.40–3.13]	3.19 [2.44–4.18]	2.96 [2.24–3.92]	3.22 [2.46–4.22]	(0.06)
Type CP=BS	2.96 [2.23–3.94]	1.83 [1.38–2.44]	2.84 [2.13–3.77]	2.33 [1.75–3.10]	
NE3					0.09
Type CP=US	3.19 [2.41–4.22]	1.86 [1.40–2.46]	2.86 [2.16–3.74]	2.28 [1.72–3.02]	(0.07)
Type CP=BS	3.48 [2.66–4.54]	3.36 [2.58–4.39]	3.15 [2.38–4.16]	3.49 [2.68–4.56]	
TE baseline					<0.001**
Type CP=US	1.50 [0.97–2.32]	2.34 [1.52–3.62]	1.51 [0.96–2.36]	2.49 [1.61–3.84]	(0.92)
Type CP=BS	1.68 [1.05–2.70]	2.58 [1.63–4.08]	1.42 [0.90–2.25]	2.49 [1.57–3.94]	
TE1					0.009**
Type CP=US	3.72 [2.39–5.78]	2.83 [1.82–4.40]	3.88 [2.47–6.12]	2.44 [1.57–3.79]	0.96
Type CP=BS	4.44 [2.74–7.19]	3.33 [2.09–5.30]	4.00 [2.51–6.39]	2.73 [1.71–4.35]	
TE2					0.05
Type CP=US	5.92 [3.72–9.40]	4.68 [2.95–7.44]	6.05 [3.75–9.76]	4.24 [2.67–6.73]	(0.98)
Type CP=BS	5.32 [3.21–8.83]	4.12 [2.52–6.71]	5.08 [3.11–8.28]	3.39 [2.08–5.53]	
TE3					0.011*
Type CP=US	7.13 [4.50–11.31]	5.05 [3.19–8.02]	7.81 [4.85–12.58]	4.76 [3.00–7.55]	(0.95)
Type CP=BS	6.16 [3.72–10.21]	4.23 [2.60–6.89]	5.70 [3.50–9.28]	4.01 [2.46–6.53]	
LE baseline					0.005**
Type CP=US	1.16 [0.69–1.95]	1.93 [1.15–3.23]	1.28 [0.75–2.19]	1.99 [1.19–3.34]	(0.92)
Type CP=BS	1.11 [0.64–1.91]	2.22 [1.29–3.83]	1.20 [0.69–2.07]	1.83 [1.06–3.16]	
LE1					0.36
Type CP=US	2.02 [1.16–3.51]	1.58 [0.91–2.75]	1.99 [1.13–3.52]	1.60 [0.92–2.78]	(0.92)
Type CP=BS	1.48 [0.82–2.65]	1.03 [0.57–1.84]	1.40 [0.78–2.50]	1.34 [0.75–2.40]	
LE2					0.46
Type CP=US	2.20 [1.23–3.92]	1.79 [1.00–3.20]	2.13 [1.17–3.86]	1.79 [1.01–3.21]	(0.94)
Type CP=BS	1.55 [0.84–2.86]	1.10 [0.60–2.04]	1.54 [0.84–2.85]	1.40 [0.76–2.59]	

Table 2 – (*continued*)

Response variable (μV) (NE, TE, LE)	Horizontal seating		FW Tilt seating		P-value[a]
	Without foot support (CI)	With foot support (CI)	Without foot support (CI)	With foot support (CI)	
LE3					0.59
Type CP=US	2.60 [1.38–4.91]	2.21 [1.17–4.17]	2.93 [1.52–5.64]	2.26 [4.26–1.02]	(0.84)
Type CP=BS	1.80 [0.92–3.51]	1.39 [0.71–2.72]	1.85 [0.95–3.62]	1.99 [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 cm, and BMI = 17.353 kg/m^2, and type of CP. (Generalized) linear mixed-effects models: * = p-value < 0.05 and ** = p-value< 0.01.

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). The unit of measurements is in microvolt (μV).

[a] 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.

4. 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 trunk extensors. An increased background EMG-amplitude was, in turn, associated with better reaching kinematics.

The answer to our first question was that FW-tilting did not affect postural muscle activity. This finding does not correspond to those of two other studies.[13,28] Sochaniwskyj et al.[13] reported in 1991 that FW-tilting during quiet sitting in school-age children with BS-CP was associated with increased background EMG-amplitude of trunk extensors. However, the authors only reported descriptive data without statistical analyses. Hadders-Algra et al.[28] indicated that in children with US-CP, FW-tilting during seated reaching was associated with statistically significantly lower phasic EMG-amplitudes in trunk extensors. The differences between the latter study and ours may be due to: (1) differences in the number of participants and their age ranges; (2) the Hadders-Algra study did not adjust for the confounding effects of anthropometrics and age.[28] 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.

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

Response variable (μV) (Whole group of participants)	Without foot-support	With foot-support	P-value[a]
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 cm, and BMI = 17.353 kg/m^2. The post-hoc contrast focuses on the difference between the sitting without foot-support and with foot-support condition (irrespective of seat surface tilting). The unit of measurements is in microvolt (μV).

**(Generalized) linear mixed-effects models; p-value < 0.01.

[a] The p-values are the values of the Type III test of the fixed effects of two sitting conditions (without vs with foot-support).

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.[24,31] 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 of previous observational reports[25,28] that only provided observational changes on the effect of foot-support.

The minor beneficial effect of foot-support agrees with the findings of studies in adults with and without neurological pathology. They indicated that foot-support during a seated reaching task is associated with increased loading of the feet, especially during reaches beyond arm length.[29,42] Up until now the effect of foot-support during functional activities in sitting in children has received very little attention, with the study of Ratka et al. (2017)[43] being an exception. They reported that foot-support in typically developing children was associated with faster and further reaching; the foot-support had however a rather limited effect on the COP excursions of the trunk and pelvis. This could mean that foot-support in children induces only a minor effect on biomechanical stability,

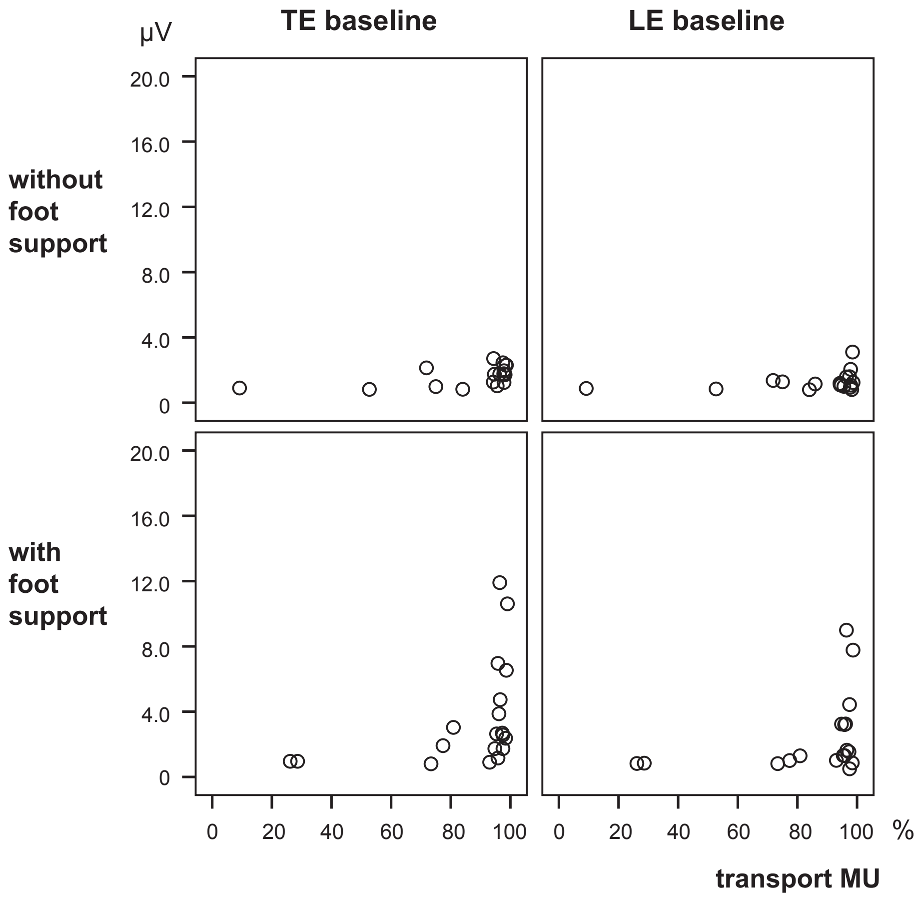

Fig. 1 – Scatter plots of relationships between baseline EMG-amplitudes of TE and LE and the proportional length of the transport MU in the seating conditions with and without foot support.

and that its major effect is the provision of additional sensory information. It is well-known that children with CP often have deficits in the processing of sensory information.[1,30] It is conceivable that the provision of additional sensory information by foot-support partially compensates this processing deficit. The clinical notion that foot-support is an important component of adaptive seating[6,25,22,44] is supported by our findings. However, it might be that the underlying mechanisms are not restricted to biomechanical ones, such as decreasing the degrees of freedom of the lower extremities.[1,25,44]

On the basis of our entire two-step-project on the effect of FW-tilting and foot-support, we conclude the following. The kinematic study[31] 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.[31] The current EMG-data suggest that the better reaching kinematics in the foot-support condition may have been partially 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-surface 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, the findings of our two-step-project 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, a horizontal seating is best. It is possible that the latter children may benefit from foot-support in this situation, but the data suggest that the effect possibly is just a minor one.

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 (research question 3) 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 set-up precluding direct generalization to the variety of everyday activities.

5. Conclusion

Foot-support enhanced the capacity of children with spastic CP to modulate trunk extensor activity, which was relatively associated with improved reaching quality. FW-tilt did not affect postural muscle activity. Based on both steps of our project 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.

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Author's contributions

Dr Hadders-Algra, Dr Angsupaisal, and Dr Maathuis: concept/idea/research design.

Dr Angsupaisal, Mr Dijkstra, and Dr Hadders-Algra: writing/original draft preparation and project management.

Mr Dijkstra: Data curation, Software, Validation.

Dr Angsupaisal and Mr Dijkstra: data collection.

Dr Angsupaisal and Mr Dijkstra: Visualisation.

Dr la Bastide-van Gemert, Dr Angsupaisal, Mr Dijkstra and Dr Hadders-Algra: Formal analysis.

Dr Hadders-Algra and Dr Angsupaisal: funding acquisition.

Dr Hadders-Algra: supervision.

Dr van Hoorn and Dr Burger: participants recruitment and selection, and facilities/equipment.

Dr Maathuis and Dr Hadders-Algra provided institutional liaisons.

Dr Angsupaisal: administrative support.

Dr Angsupaisal, Dr la Bastide-van Gemert, Dr van Hoorn, Dr Burger, and Dr Maathuis commenting on and editing of drafts of the manuscript.

Contributors' statements

All authors approved the final manuscript as submitted and have agreed to be accountable for all aspects of the work.

Conflict of interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ejpn.2019.07.001.

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