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Upper Extremity Muscle Endurance in Children with Cerebral Palsy

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Abstract

Aim: The aim of this study was to evaluate whether submaximal muscle endurance at 20% of maximal voluntary isometric contraction (MVIC) is as reduced as muscle strength in elbow flexion in children with cerebral palsy (CP), and whether motor unit recruitment to compensate muscle fatigue is hampered in this group.

Methods: Twelve subjects with cerebral palsy and seventeen control subjects performed three MVICs of elbow extension and flexion, and an endurance task holding a load of approximately 20% of MVIC until exhaustion. Both tasks involved either the affected or the non-dominant arm. During the MVICs, elbow extension and flexion torque and surface electromyography (EMG) from biceps brachii, triceps longus and triceps lateralis were collected. During the endurance task EMG from the same three muscles, in addition to accelerometer and inclinometer data were collected.

Results: The CP group produced some lower torque and significant lower agonist EMG amplitudes during MVIC compared to the control group. The holding time to exhaustion was similar in the two groups. The CP group did not increase EMG amplitudes during this task, while the control group did. This difference between the two groups was significant. The median frequency (MDF) from start to end of the endurance task decreased on average 50% less in the CP group, but this difference between the two groups was not significant. Standard deviation (SD) of angle increased from start to end in both groups, increasing significantly more in the control group. SD of acceleration increased significantly in both groups, increasing more in the control group.

Conclusion: The CP and the control group carried out the endurance task to exhaustion. The CP and the control group had similar holding time at the same relative load during the endurance task indicating muscle endurance was similar affected as muscle strength in children with CP. Agonist muscle activity during the endurance task did not increase in the CP group. Consequently, the CP subjects were not able to recruit additional motor units and had relatively lower levels of muscle fatigue.

Key words: Cerebral palsy, MVIC, endurance, 20% of MVIC, holding time, EMG, biceps brachii, motor unit recruitment, muscle fatigue.

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1.0 Introduction

Cerebral Palsy (CP) is an umbrella term describing a heterogeneous group of motor disorders arising in the nervous system either in a fetal or an infant stage, with permanent and non-progressive disturbance of movement and posture (Rose & McGill, 1998; Surveillance of Cerebral Palsy in Europe, 2000). The prevalence of children with CP in Norway is about 2.1 per 1000 live births (Andersen et al., 2008), and is the most common disorder of physical disability in children (Koman et al., 2004). Affection of the hand is reported in 70% of the CP cases (Andersen et al., 2008) and problems related to daily activities at home, school and during leisure activities may occur as a result of this affection. Common physical and neuromuscular deficits in CP are spasticity (Bartlett & Palisano, 2002; Rose & McGill, 2005; Scholtes et al., 2006), muscle weakness (Elder et al., 2003; Rose & McGill, 1998, 2005; Jahnsen et al., 2003), increased physical fatigue (Jahnsen et al., 2003) and increased co-activation (Damiano et al., 2000; Elder et al., 2003; Stackhouse et al., 2005; Tedroff et al., 2008).

The force produced during maximal voluntary isometric contractions (MVICs) is approximately 50% reduced in CP subjects compared to healthy subjects (Damiano et al., 2000; Elder et al., 2003; Rose & McGill, 2005; Stackhouse et al., 2005). Voluntary agonist muscle activation during MVIC is also reduced in CP subjects, with a reduction up to 50% compared to healthy subjects (Akataki et al., 1996; Rose & McGill, 2005; Stackhouse et al., 2005). Co-activation has been reported to be increased in CP subjects, especially in the lower extremity, and is one factor contributing to muscle weakness (Damiano et al., 2000; Elder et al., 2003; Stackhouse et al., 2005; Tedroff et al., 2008). The strength reduction is mainly caused by reduced motor unit (MU) recruitment (Akataki et al., 1996; Rose & McGill, 2005; Rosenfalck & Andreassen, 1980). An electro stimulation study suggest that similar total numbers of MUs are available in CP subjects as in healthy controls, even though the CP subjects had reduced voluntary force and muscle activation (Rose & McGill, 2005). CP subjects were not able to recruit higher threshold MUs or to drive lower threshold MUs to higher firing rates.

In contrast to maximal voluntary contractions, during submaximal contractions up to 25% of MVIC normal MU recruitment is generally observed in CP subjects (Rose & McGill, 2005). In healthy controls an isometric submaximal force is sustained by increased MU recruitment (Enoka, 1995), from small and slow MUs to larger and faster MUs. There is a hypothesis that CP subjects use the same MUs for longer durations as a result of inability to increase the recruitment of MUs (Ito et al., 1996; Rose et al., 1994; Stackhouse et al., 2005). The MUs recruited at an early stage produces smaller forces, but are most susceptible to endure (Enoka, 1995; Henneman, 1957). This may indicate that CP subjects can endure over longer time periods, despite reduced MU recruitment.

When performing submaximal contractions over a longer time period the muscle fatigues. Muscle fatigue can be defined as the decline in the ability of a muscle to produce force which occurs during sustained activity (Bigland-Ritchie et al., 1983; Moreau et al, 2009). In healthy subjects sustaining an isometric contraction, a decrease in power median frequency (MDF) is a sign of muscle fatigue and decreased conduction velocity of action potentials over the muscle fibre (Stulen & De Luca, 1981; Hägg, 1992), while an increase in electromyography (EMG) amplitude indicates additional MU recruitment to compensate muscle fatigue (Leunkeu et al., 2010; Hägg, 1992). Moreover, stronger subjects have been suggested to have shorter time to muscle fatigue during sustained isometric contractions at similar relative force levels (Hunter & Enoka, 2001; Leunkeu et al., 2010; Moreau et al., 2008, 2009). One study done at 50% of MVC in knee extension testing healthy children's right leg and both legs of CP children, found no difference in time to exhaustion between the CP and the control group (Leunkeu et al., 2010). Throughout this endurance test MU recruitment and the MDF decrease in rectus femoris and vastus lateralis were lower in CP children, suggesting muscle fatigue occurred sooner in these subjects. However, this study had a relative load of 50% of MVIC and the time to exhaustion was tested in the leg. This test procedure and these findings in Leunkeu et al. (2010) are not necessary valid and comparable to our study which used a relative load of 20% of MVIC and tested time to exhaustion in the arm.

The aim of this study was to evaluate whether submaximal muscle endurance at 20% of MVIC was as reduced as muscle strength in elbow flexion in children with CP, and whether motor unit recruitment to compensate muscle fatigue was hampered in these subjects.

2.0 Methods

2.1 Subjects

Fifteen children with CP (nine boys, six girls; aged 8-17 years) agreed to participate in the study. These children were recruited by a physiotherapist at St. Olav's Hospital in Trondheim, Norway, and the study was carried out in the muscle laboratory at NTNU, Trondheim, Norway. Selection of the CP subjects was based on following inclusion criteria: (1) affection of upper extremity; (2) 8-18years old; and (3) ability to understand verbal instructions. Exclusion criteria of the CP subjects included orthopedic or other major surgery in the upper extremity the previous two years, and being treated with Botulinum Toxin A injections in the upper extremity within the previous six months. There were three dropouts during and after the test procedure, giving a total of twelve CP subjects (eight boys, four girls; aged 8-17 years) included in the study (Table I).

Seventeen physically healthy subjects (eleven boys, six girls; aged 8-16 years) were recruited as a gender- and age-matched control group (Table I). These control subjects were recruited as a convenience sample, and were children of employers at NTNU.

Verbal information about the study and inform that the subject could resign at any time was given prior to the test procedure. Informed consent was obtained from each subject and their parent or legal guardian. The study was approved by Regional Committees for Medical and Health Research Ethic (REK).

2.2 Equipment

Two data systems were used in the test procedure: (1) a stationary Biodex dynamometer (System 3 Pro; Biodex Medical Systems, Shirley, NY, USA) and (2) Noraxon TeleMyo™ 2400T Direct Transmission system with wireless bipolar surface EMG sensors, 3D accelerometer and 2D inclinometer, and Noraxon software (Noraxon USA, Inc.). Signals from the analogue Biodex (torque) and Noraxon sensors were simultaneously collected by the Noraxon system and thereby synchronized. The data were recorded with a sampling rate of 1500 Hz. At sensor location, the data were sampled with 3000Hz, and resampled with

1500 Hz prior to telemetric transmission. Prior to sampling, all data were low pass filtered with a cut of frequency of 1500 Hz. Also, prior to data collection, the EMG signals were high pass filtered with a cut off frequency of 10 Hz and Biodex data was low pass filtered with a cut off frequency of 500Hz.

2.3 Test procedure

The affected arm of the CP subjects and the non-dominant arm of the control subjects were tested. The test procedure consisted of three parts: (1) collection of anthropometrics and subject characteristics, (2) three MVICs of both elbow extension and flexion, and (3) an endurance task holding a relative load of approximately 20% of MVIC. In total, three examiners were present during the test procedure. One examiner managed the Biodex system by starting the correct routines and controlling the time intervals of work and recovery; the second examiner managed the Noraxon software by recording signals from the different sensors during the test procedure; and the third examiner took care of the subject and gave verbal instructions when performing the MVICs and the endurance task.

2.3.1 Anthropometrics and subject characteristics

First, the examiner asked for the following subject characteristics: gender, age and affected/non-dominant arm. The non-dominant arm was defined as the arm the subject normally did not use for writing and throwing. Thereafter, anthropometric measurements of height, weight, circumference at the upper arm, forearm length and skin fold thickness at both biceps and triceps brachii were performed. Height (cm) and weight (kg) were measured with t-shirt and pants, without shoes. Circumference at the upper, affected or non-dominant arm (cm) was completed at the bulk of the biceps brachii with the arm along the side of the body. The forearm length (cm) was measured from the head of radius at the lateral side to processus styloideus of ulna, and was executed with 90 degrees in the elbow and the hand in neutral position. Skinfold thickness (mm) at biceps and triceps brachii was done using a caliper measurement at the bulk of the biceps brachii and at the bulk of the triceps brachii.

2.3.2 Sensor placement of bipolar EMG

The two circular conductive areas of the dual electrodes of the bipolar EMG sensors were each 1 cm in diameter, and the inter-electrode distance was 2 cm. Three bipolar EMG electrodes were placed in the muscle fibre direction on the affected or non-dominant arm according to SENIAM (Enschede, the Netherlands); (1) on the bulk of biceps brachii (BB), (2) on the bulk of triceps longus (MTB), and (3) on the bulk of triceps lateralis (LTB). Before starting the test procedure EMG sensors were checked in the Noraxon software to secure good signals.

2.3.3 MVIC, elbow extension and flexion

As mentioned, the Biodex System 3 was synchronized with the Noraxon sensors in the Noraxon software, recording torque and EMG amplitudes during the MVIC. First, the subject was strapped to the Biodex chair, before individual adjustments of the chair and elbow attachment. A wrist orthosis and a flexion glove were used to fix the wrist and secure a good grip around the handle, since CP subjects may have problems with their grip strength and grip ability. The wrist orthosis and the flexion glove was used on both CP and control subjects. The arm tested was positioned with 60 degrees in the elbow joint, with the shoulder slightly flexed and abducted. The forearm was in neutral position, with the thumb facing up. A band was strapped distally over the upper arm to make sure that the elbow joint was in contact with the Biodex chair. The test procedure consisted of three MVIC trails. Each trail contained one extension and one flexion each of 5 seconds, with 10 seconds recovery time in between. After each trail there was 30 seconds recovery time. The subjects were instructed to perform maximal effort – as much as they could, as fast as they could.

2.3.4 Endurance task

For the endurance task the subjects continued to sit in the Biodex chair, but the Biodex dynamometer was not used. The position of the subjects was individualized, with the forearm positioned horizontally and in a neutral position (thumb facing up). The shoulder had the same position as during the MVICs. The wrist orthosis was used stabilizing the wrist. In addition to the three EMG sensors, an accelerometer and an inclinometer were used. The accelerometer sensor was placed on the proximal phalanx of the first finger and was used to investigate acceleration in elbow extension and flexion (down/up direction). The inclinometer sensor was used to give visual feedback about the arm position during the endurance task, by

watching a computer screen. The exact placement of this sensor was dependent on left or right arm was tested; placement on the left arm was inside of the wrist, and placement on the right arm was outside of the wrist. Then, the inclinometer feedback became consistent, with a view to negative (extension) and positive (flexion) signs of the movement. The computer screen was 19 inches (37.7 cm x 30.3 cm), and was placed in eyelevel about 1 m from the subjects. The time range of the inclinometer feedback was 5 seconds, and the amplitude range was plus/minus 20 degrees.

The endurance task was performed in an isometric state. The endurance task involved holding a relative weight at approximately 20% of MVIC until exhaustion. This relative load was calculated from the MVIC trial with the highest peak torque (Nm) during elbow flexion of each subject. This peak torque was first divided by forearm length (m) and then divided by gravity (9.81), to find the absolute load (kg). This absolute load was then multiplied with 0.2, finding the relative load (%MVIC). The relative load was rounded off to the nearest 250 grams, and consisted of manual weights attached to a band placed over the wrist. The endurance task started when the examiner slipped the weight and when the inclinometer feedback was steady. The instruction was to hold the weight as long as possible until the inclinometer feedback deviate with at least 5 degrees. In addition to the first instruction, the subjects were instructed not to twist their hand/arm towards the center of the body, and not to move their hand and fingers. If the subject's arm was out of position the examiner informed the subject to get back to start position.

2.4 Data analysis

All outcome measures, including torque, holding time, EMG amplitudes, accelerometer and inclinometer data, were first analyzed with Matlab R2009a (The MathWorks, Inc., Natick, MA, USA). Excel 2010 was used in cases of plotting anthropometrics, percentage calculations and preparing variables from Matlab for statistical analysis.

2.4.1 MVIC analysis

First, the torque signals was low pass filtered with a cut off frequency of 6 Hz. Then the arm weight was removed and the peak torque (Nm) was obtained. This was carried out for MVICs during elbow extension (T_{peakEE}) and flexion (T_{peakEF}). Root mean square (RMS) (μV) of

the biceps brachii, triceps longus and lateralis EMG amplitudes was calculated with 0.5 seconds window width. For the three bipolar EMG sensors RMS at peak torque during elbow extension (mvcEE) and peak torque during elbow flexion (mvcEF) were computed.

2.4.2 Endurance analysis

The holding time (seconds) was defined as the time from start with stable inclinometer feedback, to stop, when the inclinometer feedback deviated with at least 5 degrees. Root mean square (RMS) of the EMG amplitudes (uV) at start and end were calculated with a 0.5 seconds window width. These RMS values were also normalized to the RMS of the same muscle at peak torque. Median frequency (MDF [Hz]) was calculated for the three EMG signals at start and end using a time window of 0.5 seconds. MDF was defined as the frequency that split the power density spectrum into two equal power areas. From the inclinometer data, the mean (angle in degrees) and standard deviation (degrees) of angle in the elbow joint was calculated. From the accelerometer data, the standard deviation (G) of change in velocity of the arm was calculated.

2.5 Statistics

Statistical processing was performed in PASW Statistics version 18 (SPSS Inc., Chicago, IL, USA). The Shapiro-Wilk test was used to test whether outcome measures were normally distributed. In all statistical analysis the significance level was set to 0.05.

Anthropometrics and subject characteristics, absolute load, relative load, MDF, and mean and standard deviation (SD) of acceleration were normally distributed. Peak torque during MVIC elbow extension and flexion were originally not normally distributed, but when splitting by gender because of a gender effect, both variables became normally distributed. Further, holding time was log transformed and thereby normally distributed. For these normally distributed variables parametric statistics were used. Univariate and multivariate ANOVA was used to test whether the means of groups was equal. ANOVA with the relative load as covariate was applied in some cases, to analyze the effect of group while taking the variation in calculation of 20 % of MVIC into account.

The RMS outcomes from the three muscles during MVIC elbow extension and flexion and the endurance task were not normally distributed. In addition, mean and SD of angle was not normally distributed. For these variables non-parametric statistics were used. Independent and related samples t-tests, Mann Whitney U tests and Wilcoxon Signed Rank tests, respectively, were used to test whether there was significant difference between and within the two groups.

3.0 Results

In total, fifteen subjects with CP, and seventeen control subjects was included in the test procedure. All of these subjects completed the three MVIC trails. One subject with CP did not accomplish the endurance task, and additional two subjects with CP were excluded because they did not carry out the endurance task properly. In total, twelve CP and seventeen control subjects were included in the analysis of the MVICs and the endurance task (Table I).

The mean and standard deviation (SD) of anthropometrics and subject characteristics are presented in Table I. On average the variables were approximately the same for the two groups. Moreover, there was no significant group difference in any of the variables ($p > 0.05$).

Table I: Mean (standard deviation) values of anthropometrics and subject characteristics.

Group	CP	Controls
N	12	17
Gender	♂ 8 ♀ 4	♂ 11 ♀ 6
Age (years)	12.31 (2.91)	12.35 (2.80)
Weight (kg)*	43.30 (13.36)	45.82 (13.04)
Height (cm)	151.82 (16.15)	155.88 (17.51)
Forearm length (cm)	21.13 (3.54)	22.19 (2.57)
Upper arm circumference (cm)	23.10 (3.11)	23.34 (2.74)
Skinfold, biceps brachii (mm)*	7.14 (2.40)	6.65 (2.57)
Skinfold, triceps brachii (mm)*	11.10 (3.88)	10.76 (3.88)

*One CP missing. All variables were not significant between groups.

3.1 MVIC, elbow extension and flexion

The peak torque and maximal agonist and antagonist EMG amplitudes produced during the MVICs are presented in figures 1 and 2 for girls and boys, respectively. The effect of group on T_{peakEE} and T_{peakEF} was tested by parametric statistics, using a multivariate ANOVA. There was no group difference in neither T_{peakEE} ($p = 0.216$) nor T_{peakEF} ($p = 0.166$), but there was a gender effect on T_{peakEE} ($p = 0.028$) and T_{peakEF} ($p = 0.034$). Further, the interaction between group and gender on T_{peakEE} ($p = 0.437$) and T_{peakEF} ($p = 0.643$) were not significant.

Girls in the CP group produced on average 44% ($p = 0.068$), and 51% ($p = 0.030$) lower peak torque compared to girls in the control group during elbow extension and flexion, respectively (Figure 1A). Boys in the CP group produced on average 8% ($p = 0.728$) and 17% ($p = 0.494$) lower peak torque compared to boys in the control group during elbow extension and flexion, respectively (Figure 1B).

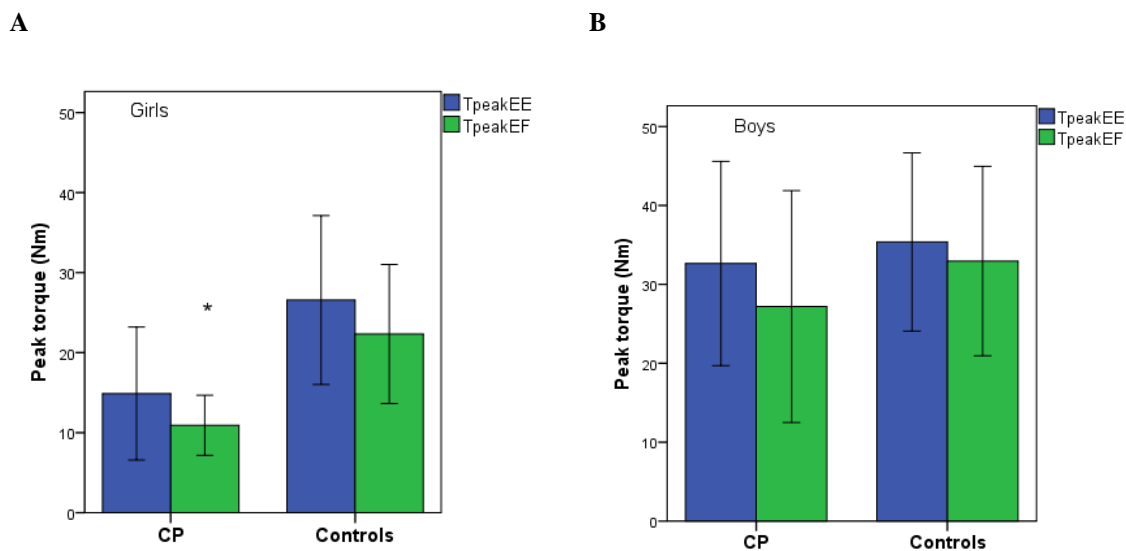


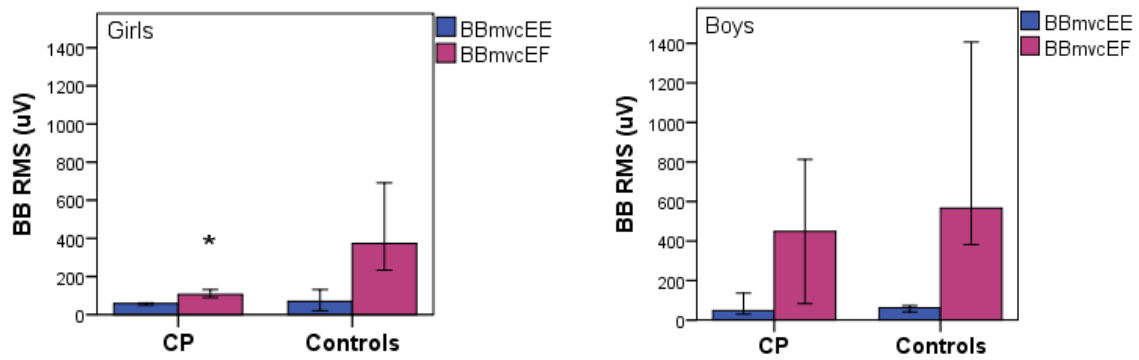
Figure 1. Mean peak torque with 95% confidence interval during MVIC of elbow extension (T_{peakEE}) and flexion (T_{peakEF}) of the CP and control group, for girls (A) and boys (B). * = Significant difference from control group.

Results of EMG amplitudes are presented in figure 2. There was a group effect ($p = 0.027$) and gender effect ($p = 0.013$) on BB EMG amplitude during elbow flexion (Figure 2A). BB EMG amplitude at peak torque was on average 66% reduced in the CP group, compared to the control group. Girls in the CP group produced 71% reduced BB EMG amplitude at peak torque in elbow flexion ($p = 0.011$) compared to girls in the control group. Boys in the CP group produced on average 20% lower BB EMG amplitude at peak torque ($p = 0.117$) in elbow flexion, compared to the boys in the control group.

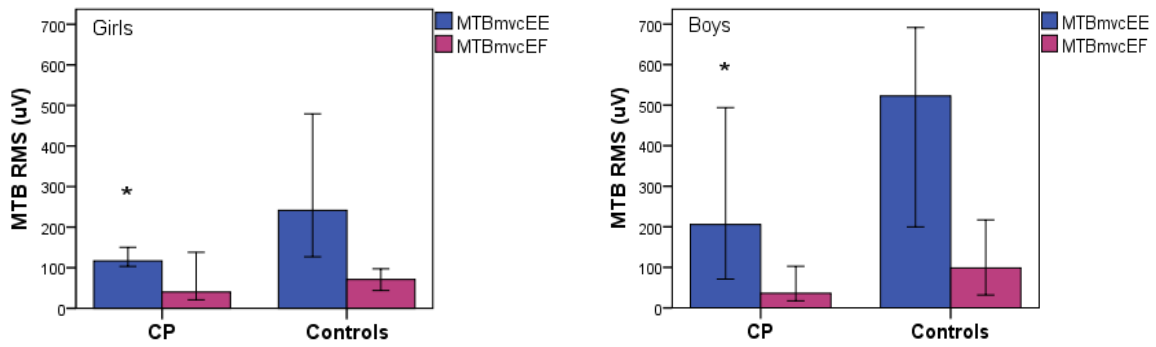
During elbow extension there was a group difference in MTB EMG amplitude ($p = 0.005$), and no group difference in LTB EMG amplitude ($p = 0.170$) (Figure 2B and C, respectively). There was also a gender effect on MTB EMG amplitude ($p = 0.009$), but this was not significant for LTB EMG amplitude ($p = 0.119$). MTB EMG amplitude was 65% reduced in the CP group, compared to the control group. LTB EMG amplitude was on average 35% lower in the CP group. Girls in the CP group produced respectively 52% ($p = 0.019$) and on average 38% ($p = 0.394$) lower MTB and LTB EMG amplitudes, compared to the girls in the control group. Boys in the CP group produced respectively 61% ($p = 0.013$) and on average 17% ($p = 0.248$) lower MTB and LTB EMG amplitudes, compared to the boys in the control group.

There was no effect of group ($p = 0.507$) or gender ($p = 0.680$) on BB EMG amplitude during elbow extension (Figure 2A). There was a group difference on MTB ($p = 0.017$) and LTB EMG amplitudes ($p = 0.002$) during elbow flexion (Figure 2B and C, respectively). In addition, there was no effect of gender on neither MTB ($p = 0.738$) nor LTB EMG amplitudes ($p = 1.000$).

A



B



C

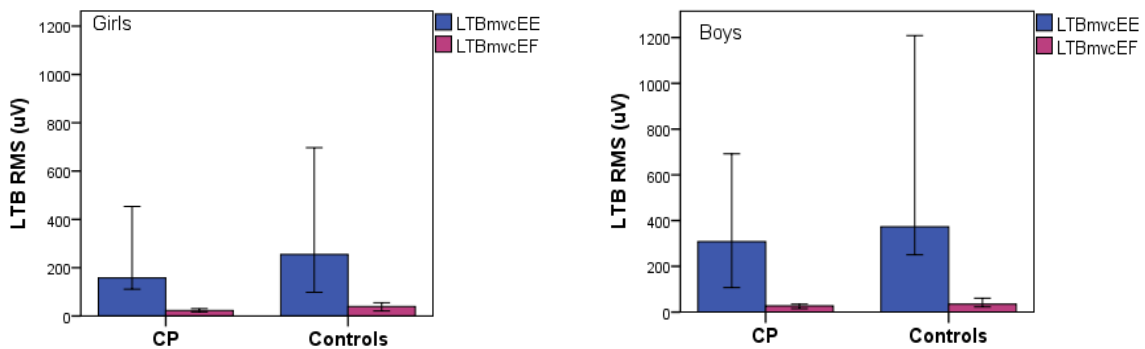


Figure 2. Median values of RMS with 95% confidence interval under MVIC flexion and extension of the CP and control group, for biceps brachii (BB) (A), triceps longus (MTB) (B), and triceps lateralis (LTB) (C), for girls and boys. RMS, root mean square; EE, elbow extension; EF, elbow flexion; mvcEE, EMG at peak torque elbow extension; mvcEF, EMG at peak torque elbow flexion. * = Significant difference from control group.

3.2 Muscle endurance

The median and range of holding time, and mean, range and SD of the load used during the endurance task are listed in Table II. The CP group and the control group had similar holding time ($p = 0.400$) and absolute load ($p = 0.107$). Although the mean relative load was similar for the two groups ($p = 0.676$) and about 20% of MVIC there was a large range in relative loads. This large range was a result of errors in the calculation of peak torque (Nm) to kilograms (kg) in the beginning of the data collection period. In contrast to muscle strength, during muscle endurance no systematic effect of gender or interaction between group and gender was observed.

Table II. Median values and range of holding time, and mean (SD) values and range of load for the CP and control group.

Group	N	Holding time, sec	Load, kg	Load, %MVIC
CP	12	168	1.91 (1.07)	23.66 (8.10)
Range		38 – 529	0.50 – 4.00	8.62 – 36.47
Controls	17	220	2.66 (1.28)	22.76 (3.07)
Range		30 – 637	1.50 – 6.00	17.12 – 27.89

SD, standard deviation. All variables were not significant between groups.

After log transformation, the holding time data were normally distributed and parametric statistics were applied, with load (%MVIC) as covariate. In the group as a whole ($p = 0.008$) load (%MVIC) affected holding time. Also, the holding time was not different between the two groups ($p = 0.371$).

Figure 3A and B shows mean and SD of angle at start and end of the endurance task, respectively. Inclinometer data was not normally distributed and non-parametric statistics were used. There was no effect of group at start, end or percentage of change in mean angle ($p > 0.05$). The mean angle at start and end was approximately the same and decreased approximately similar in the two groups throughout the endurance task. However, the confidence interval was larger in the CP group at start and end, and also included zero. This indicated that the difference between start and end in the CP group was not significant ($p = 0.480$), while significant in the control group ($p = 0.044$).

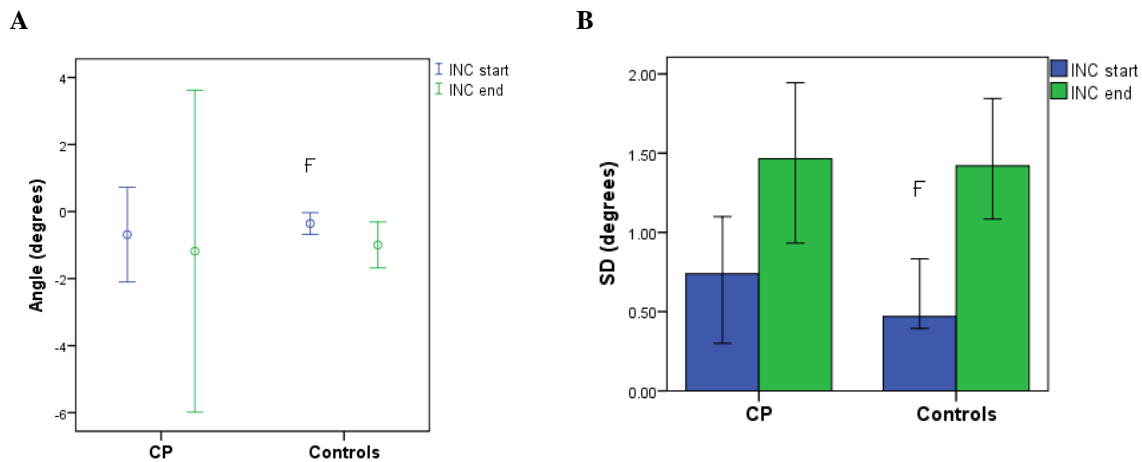


Figure 3. Mean angle (A) and median SD of angle (B) at start (INC start) and end (INC end) with 95% confidence interval during the endurance task of the CP and control group. INC, inclinometer; SD, standard deviation. F = Significant difference from end.

There was no effect of group at start, end or percentage of change SD of angle ($p > 0.05$). The CP group had on average 57% and 3% larger SD of angle at start and end, respectively. The CP group increased their SD of angle from start to end with 50%, while the control group increased with 67% from start to end. The difference between start and end of SD of angle was not significant in the CP group ($p = 0.084$), but significant in the control group ($p = 0.002$). SD of angle from start to end was on average 21% lower in the CP group compared to the control group ($p = 0.288$).

Figure 4 shows standard deviation (SD) of acceleration at start and end of the endurance task. Accelerometer data was normally distributed and parametric statistics were used. There was a group effect in SD at the end ($p = 0.035$), but not at start ($p = 0.288$). Load (%MVIC) affected SD of acceleration at start ($p = 0.003$) and the end ($p = 0.042$) in the control group. This effect was not found in the CP group. The CP group had smaller fluctuation at start and increased less from start to end, compared to the control group. The CP group had on average 18% lower ($p = 0.288$) and 41% ($p = 0.035$) reduced SD of acceleration at start and end, respectively. There was no effect of group on percentage of change in SD of acceleration. In the group as a whole load (%MVIC) had an effect ($p = 0.035$). On average, the CP group increased their SD from start to end with 53%, while the control group increased with 66%. The difference between start and end of SD was significant in the CP group ($p = 0.002$), and

the control group ($p = 0.005$). The percentage of change in SD of acceleration was on average 47% lower in the CP group compared to the control group ($p = 0.221$).

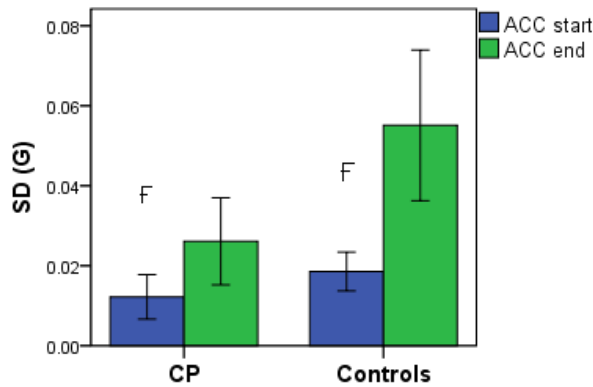


Figure 4. Mean SD of acceleration at start (ACC start) and end (ACC end) with 95% confidence interval during the endurance task of the CP and control group. ACC, accelerometer; SD, standard deviation. *F* = Significant difference from end.

Figure 5A, B and C show the RMS distribution of BB, MTB and LTB, respectively, at start and end of the endurance task. None of the RMS values of the three muscles were normally distributed, and non-parametric statistics were used. The BB RMS at start ($p = 0.021$) and end ($p = 0.007$) differed between the two groups. The CP group produced 49% and 58% reduced BB RMS at start and end, respectively, compared to the control group. There was also a group difference in the percentage of change from start to end in BB RMS ($p = 0.003$). On average, the CP group increased their BB RMS with 1.5% ($p = 0.695$), while the control group increased their BB RMS with 41% ($p = 0.001$).

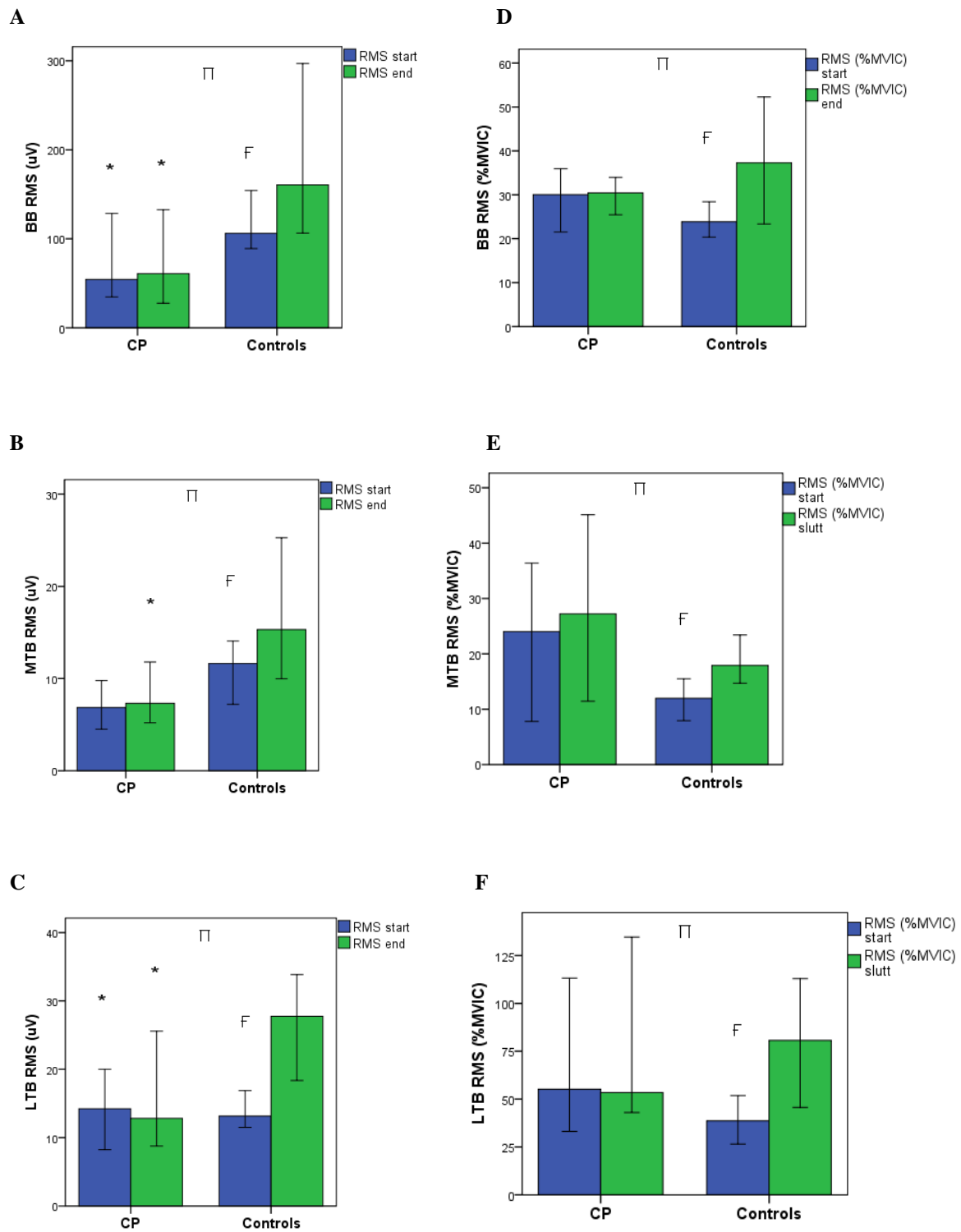


Figure 5. Median values of RMS (A, B, C) and normalized RMS (D, E, F) with 95% confidence interval of start (RMS start) and end (RMS end) during the endurance task of the CP and control group, for biceps brachii (BB) (A, D), triceps longus (MTB) (B, E), and triceps lateralis (LTB) (C, F). RMS, root mean square. * = Significant difference from control group. F = Significant difference from end. Π = Significant group difference in change.

The MTB RMS at the end ($p = 0.008$) and LTB RMS at start ($p = 0.025$) and end ($p = 0.004$) differed between the two groups. The CP group produced 48% lower MTB RMS at the end, compared to the control group. The LTB RMS values were 8% larger at start and 54% lower at the end in the CP group. There was also a group difference in the percentages of change from start to end in MTB ($p = 0.021$) and LTB RMS ($p = 0.002$). On average, the CP group increased their MTB RMS with 12% ($p = 0.084$) and decreased LTB RMS with 6% ($p = 0.480$), while the control group increased their MTB RMS with 70% ($p = 0.001$) and LTB RMS with 111% ($p = 0.001$).

Figure 5D, E and F shows the RMS (%MVIC) distribution of BB, MTB and LTB, respectively, at start and end of the endurance task. None of the RMS (%MVIC) values of the three muscles were normally distributed, and non-parametric statistics were used. The BB RMS (%MVIC) at start ($p = 0.111$) and end ($p = 0.376$) did not differ between the two groups. The CP group produced on average 26% larger BB RMS (%MVIC) at start and on average 18% lower BB RMS (%MVIC) at the end, compared to the control group. The BB RMS (%MVIC) percentage of change from start to end differed between the two groups ($p = 0.003$). The CP group did not increase their BB RMS (%MVIC) ($p = 0.695$), while the control group did ($p = 0.001$).

The MTB RMS (%MVIC) at start ($p = 0.092$) and end ($p = 0.308$) and the LTB RMS (%MVIC) at start ($p = 0.121$) and end ($p = 0.425$) did not differ between the two groups. The CP group produced on average 100% ($p = 0.092$) and 43% ($p = 0.121$) higher MTB and LTB RMS (%MVIC) at start, respectively. MTB RMS (%MVIC) at the end was on average 52% ($p = 0.308$) higher and LTB RMS (%MVIC) at the end was 34% ($p = 0.425$) lower in the CP group. There was a group difference in the percentages of change from start to end in MTB ($p = 0.021$) and LTB RMS (%MVIC) ($p = 0.002$). The CP group did not increase their MTB or LTB RMS (%MVIC) from start to end ($p = 0.099$ and $p = 0.480$, respectively), while the control group did ($p = 0.001$ and $p = 0.001$, respectively).

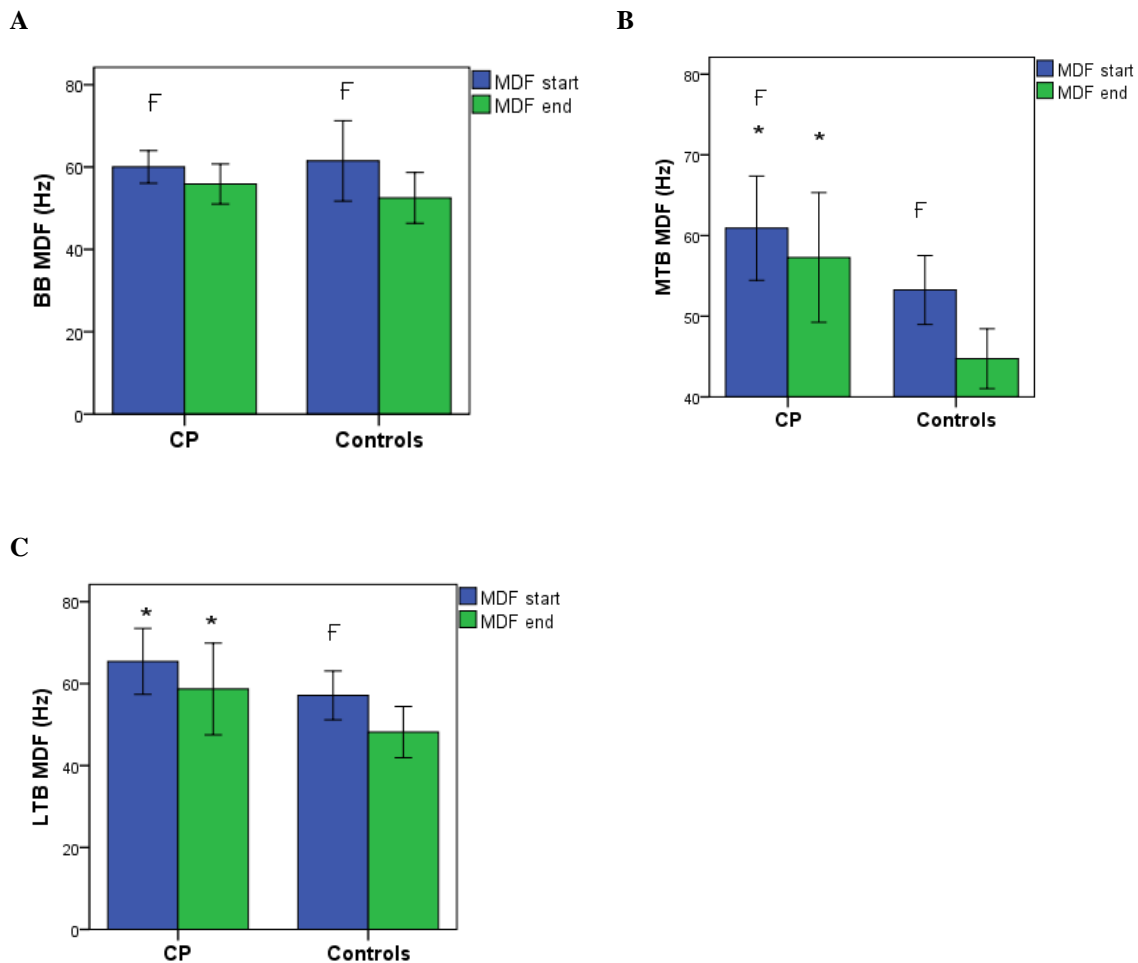


Figure 6. Mean MDF with 95% confidence interval of start (MDF start) and end (MDF end) during the endurance task of the CP and control group, for biceps brachii (BB) (A), triceps longus (MTB) (B), and triceps lateralis (LTB) (C). MDF, median frequency. * = Significant difference from control group. F = Significant difference from end.

Figure 6 show the MDF distribution in BB, MTB and LTB, respectively, from start and end of the endurance task. The MDF was normally distributed and parametric statistics were used. There was none effect of group or load (%MVIC) on neither BB MDF at start, end nor percentage of change ($p > 0.05$). Both groups were approximately at the same BB MDF at start and the CP group was at a higher BB MDF at the end, resulting in a somewhat smaller decrease in BB MDF in the CP group. In the CP group, the BB MDF decreased with 7% ($p = 0.029$), while BB MDF in the control group decreased with 13% ($p = 0.001$). In the group as a whole, load (%MVIC) had an effect on BB MDF percentage of change from start to end ($p = 0.023$).

There was a significant difference between the two groups in MTB MDF start ($p = 0.003$) and end ($p = 0.000$), and LTB MDF start ($p = 0.011$) and end ($p = 0.004$). The CP group started the endurance task at a higher MTB and LTB MDF, and ended at a higher MTB and LTB MDF, compared to the control group. There was none effect of load (%MVIC) on MDF at start and end in neither MTB nor LTB. Further, there was none effect of group or load (%MVIC) on neither MTB nor LTB MDF percentage of change ($p > 0.05$). In the CP group, the MDF decreased with 6% ($p = 0.047$) and on average 10% ($p = 0.070$) for MTB and LTB, respectively. The MDF in the control group decreased with 15% ($p = 0.001$) and 16% ($p = 0.000$) for MTB and LTB, respectively.

4.0 Discussion

Our results show similar holding time of a load of approximately 20% of MVIC in the CP and the control group. The submaximal muscle endurance was similar affected as muscle strength in CP subjects. However, the control subjects experienced relatively larger muscle fatigue and were able to compensate this by MU recruitment. Muscle strength and muscle activation during MVIC will be presented and discussed before evaluating the submaximal muscle endurance in children with CP. First, the endurance task itself, in terms of holding time, load and position of the arm, is considered. Second, muscle activation and muscle fatigue are discussed to evaluate MU recruitment and muscle endurance in the CP group.

4.1 Muscle strength

The peak torque during MVIC elbow extension and flexion of the CP subjects in this study was somewhat but not significantly lower compared to the control subjects. The peak torque was different between the gender groups, and was significantly lower between the girls in the two groups. On average, the extension and flexion peak torque were 21% and 44% reduced in the CP group, while other studies found a significant 50% reduction (Damiano et al., 2000; Elder et al., 2003; Rose & McGill, 2005; Stackhouse et al., 2005). Investigating gender, CP boys were relatively strong; they did not have reduced muscle strength, while the CP girls had significantly reduced muscle strength. This gender difference was most likely a result of

coincidences in the sample and therefore not considered as a main result. None of the studies found in literature has considered the effect of gender on muscle strength and this should be investigated more. The gender groups in our study had a small sample size and more investigation on the effect of gender should include a larger sample, with that the chance of coincidences could be less likely.

Like in peak torque, the agonist EMG amplitudes were lower in girls than in the boys. However, the CP gender groups had similarly affected agonist EMG amplitudes. Agonist EMG amplitude during elbow flexion was 66% reduced in the CP group, and during elbow extension agonist EMG amplitudes were reduced with 35-65%. Antagonist EMG amplitudes were not significantly increased in the CP group compared to the control group. Earlier reports, found agonist muscle activation to be reduced up to 50% (Akataki et al., 1996; Rose & McGill, 2005; Stackhouse et al., 2005), and co-activation to be increased in CP subjects (Damiano et al., 2000; Elder et al., 2003; Stackhouse et al., 2005; Tedroff et al., 2008). The literature has reported different percentages of reduction in muscle strength and agonist muscle activation, and also different percentages of increased co-activation. There is not a definite number which quantify the amount of muscle weakness in CP, but there is an agreement that muscle strength is 50% reduced and agonist muscle activation is reduced up to 50%. Factors such as severity and type of CP condition, extremity involved, type of movement and protocol executed, subject characteristics and coincidences may influence the amount of muscle weakness.

4.2 Muscle endurance

The inclinometer and accelerometer sensors can evaluate how the groups performed the endurance task. The results of the inclinometer showed no difference in angle or SD of angle between the two groups. Thus, both groups performed the endurance task correctly and performed the same voluntary endurance task. The result of SD of acceleration did only differ between the groups at the end of the endurance task. It seemed that the control group had larger fluctuation of rapid movements. This way the control group may have experienced relatively greater tremor and muscle fatigue. Prior to task failure tremor is most probably caused by synchronized activation of MUs resulting from an increased central drive, as

indicated by the increase in agonist muscle activation. In CP the central drive is reduced prior to task failure, thereby experiencing less tremor and muscle fatigue.

The holding time, absolute and relative load in this study were very similar in the CP and the control group. However, the relative load affected holding time similar in the CP group as in the control group. Thus, upper extremity holding time at approximately 20% of MVIC was similar for the two groups. Further, this may indicate that both groups endured and pushed themselves throughout the endurance task. The result of similar holding time at the same relative load in the CP and the control group is consistent with Leunkeu et al. (2010). In their study, Leunkeu et al. (2010) assessed voluntary isometric endurance time of the quadriceps muscle at a load of 50% of MVIC. They also found identical time to exhaustion at this relative load in the CP and the control group. So, despite our lower relative load we still found similar time to exhaustion in the two groups, although normal MU recruitment is expected up to 25% of MVIC (Rose & McGill, 2005). Whether or not holding a lower relative load would give different results should be investigated, even though this could give practical and psychological challenges. It is difficult to motivate children in holding a load stable for longer than 10 minutes. Regarding using the same absolute load for CP and control subjects, it would be difficult to quantify this load since CP and healthy subjects differ too much in maximal capacity. It would be almost impossible to find an absolute load that also the weakest subjects could hold for longer durations and that would cause exhaustion in the strongest subjects within 10 minutes.

4.3 Motor unit recruitment

Biceps brachii activation was lower in the CP group and did not increase throughout the endurance task while the control group increased, resulting in an even larger difference between the groups at the end of exhaustion. This finding may be a result of variation in increase of biceps brachii activation in the CP subjects. During the endurance task, normalized to activation under maximal torque production was not significantly lower in the CP group and did not increase while the control group increased. Skinfold of biceps brachii could be a factor affecting the EMG amplitude of this muscle. However, there was no group difference in biceps brachii skinfold and thereby lower activation of the biceps brachii is the cause to lower amplitude in the CP group. Further, no group difference in neither biceps

brachii skinfold nor upper arm circumference indicates that CP subjects did not have reduced muscle mass and this cannot explain muscle weakness during the endurance task. Lack of increase in biceps brachii activation in the CP muscle confirms an inability to recruit MUs and thus causes muscle endurance to be affected in CP subjects. This hampered MU recruitment in CP muscles is in agreement with the findings of MU recruitment during maximal voluntary contractions (Rose & McGill, 2005) and during a sustained isometric contraction (Leunkeu et al, 2010). The study of Leunkeu et al. (2010) testing quadriceps muscle fatigue at 50% of MVIC, found normalized RMS as percentage of initial values to be lower in CP children and suggested an inability to recruit higher threshold MUs or to drive lower threshold MUs to higher firing rates.

The median frequency of the agonist muscle decreased significantly in both groups, indicating decreased conduction velocity of action potentials over the muscle fibre and thus muscle fatigue (Stulen & De Luca, 1981). There was a tendency that the median frequency in the control group decreased more and was relatively more fatigued, but this difference was not significant between the two groups. However, this tendency might be a result of the CP group holding a lower absolute load. As mentioned, the central drive in CP is reduced prior to task failure. The increased central drive in healthy subjects causes increased synchronized activation of MUs, and the median frequency shifts to lower frequencies. This reduced central drive in CP can explain why there was a tendency of control subjects being relatively more fatigued. The result in this study is in contrast to Leunkeu et al. (2010). They reported significantly lower values of and greater decrease in median frequency of lower extremity in CP subjects during their endurance test. This suggested enhanced muscle fatigue in CP subjects, probably as a result of inability to recruit MUs. But, since the endurance time was similar between the groups this higher level of muscle fatigue in CP subjects seemed to occur sooner. Leunkeu et al. (2010) also had a relatively small sample (12 children with CP, 12 control children), but their results of median frequency differences between the two groups were however significant. This may be caused by testing the lower extremity at 50% of MVIC and not the upper extremity at 20% of MVIC as our study has done.

A possible mechanism to explain the tendency of relatively larger muscle fatigue in the control group can be the hypothesis that CP subjects use the same MUs for longer durations as a result of reduced recruitment of MUs (Ito et al., 1996; Rose et al., 1994; Stackhouse et al., 2005). Then it is reasonable to assume that the CP subjects would have shorter time to

exhaustion because they are not able to compensate muscle fatigue by MU recruitment. However, there is suggested that since stronger subjects are able to produce higher torque or have greater muscle mass, they have a higher susceptibility to fatigue (Hunter & Enoka, 2001). Hunter & Enoka (2001) studied sex differences in the fatigability of arm muscles in healthy adults, reported longer endurance time for women at a target force of 20 % of MVIC. They found the increase in EMG to be greater in men, thus they fatigued more rapidly and additional MUs were required to achieve the target force. The longer endurance time in women was associated with a lower absolute target force. Consequently, assuming weaker subjects, such as CP subjects, to be less susceptible to fatigue is reasonable. In our study, the endurance time in the CP group was similar to the endurance time in the control group. So, despite hampered MU recruitment in CP subjects they were able to endure.

A second mechanism to explain a possible larger muscle fatigue in the control group can be related to antagonist co-activation. The control group increased co-activation throughout the endurance task, while the CP group did not increase. This finding may be a result of variation in increase of triceps brachii activation in the CP subjects. Thus, co-activation was not affecting the muscle endurance of CP subjects in this study. Skinfold of triceps brachii could be a factor affecting the EMG amplitude of this muscle. However, there was no group difference in triceps brachii skinfold and thereby lower activation of the triceps brachii is the cause to lower amplitude in the CP group. In the literature increased co-activation in CP subjects is reported in the lower extremity during gait (Damiano et al., 2000) and maximal contractions (Elder et al., 2003) to increase joint stiffness and accuracy. When performing an upper extremity endurance task joint stiffness and accuracy may not be an important strategy as during gait and contractions of maximal effort. The median frequency of antagonist muscles was significantly higher in the CP group. However, the control group decreased up to 50% more in triceps brachii activation, and thereby more fatigued. It is reasonable to assume greater muscle fatigue in the agonist muscle when co-activation is increased due to involuntary resistance to movement. Since the CP group did not have increased co-activation in the endurance task, the agonist muscle fatigue was relatively smaller.

It is interesting to speculate about how the CP subjects were able to endure and have similar holding time as the control group at the same relative load, even though the CP group was not able to recruit additional MUs. This finding can be explained by the less decrease in median

frequency of agonist muscle and the less increase in standard deviation of angle and acceleration in the CP group, giving less or sooner muscle fatigue in this group.

4.4 Strengths and limitations

Our study was the first to evaluate MU recruitment and muscle endurance in children with CP at low force levels in arm. Also, our study was the first to consider gender association with muscle strength. Strength in our test procedure was the use holding time to evaluate the muscle endurance. Holding time is a more functional measure than for example series of maximal contractions with (Rose & McGill, 2005; Stackhouse et al., 2005) or without (Moreau et al., 2008) electro stimulation. Our method to measure muscle endurance may be useful in adjusting treatment and training for children with CP. Second, the use of visual feedback during the endurance task may have motivated the subjects to endure and thereby carried out the task as long as possible.

Limitations may include the relatively small number of subjects, since CP and spasticity are complex terms and the severity of these is of importance to recruit a homogeneous sample and secure less variation between subjects (Moreau et al., 2009). In our study the CP subjects were included based on age, affection of upper extremity and understanding verbal instructions. However, the severity of spasticity has not been investigated. The wide range of age in the groups might be a restriction, regarding possible differences in muscle strength, activity level and anthropometric characteristics. On the contrary, the groups were similar in age and other anthropometric characteristics, and control subjects were recruited as age-matched subjects.

As mentioned, the calculation of 20% of MVIC was not correct in the beginning of the data collection period, giving a wide range of the relative load in both groups. However, the means of the relative load were approximately the same in the groups, and the relative load was applied as covariate in certain analysis to control its effect on some variables. The result of boys in the CP group not having reduced muscle strength compared to boys in the control group was probably a result of coincidence, and the effect of gender turned out to be insignificant when analyzing the muscle endurance.

With a view to generalization of the present findings, this study has not considered the severity of CP and spasticity. Severity of CP and spasticity can for instance be a factor regarding the gender differences in muscle strength and muscle activity during MVIC – it is possible that girls with CP were more spastic than boys with CP. Further, spasticity is one of the primary contributors to motor dysfunction in CP (Rose & McGill, 1998; Scholtes et al., 2006), and therefore an important part of severity of muscle weakness and time to muscle fatigue (Moreau et al., 2008, 2009). According to Moreau et al. (2008, 2009), lower levels of muscle fatigue of the lower extremity in CP were associated with greater weakness of the agonist muscle. Further, increased co-activation and spasticity of the agonist muscle was related to less fatigue in this muscle. Therefore, severity of spasticity could be a factor explaining the gender differences in muscle strength and the not significant group difference in muscle fatigue of the agonist muscle.

5.0 Conclusion

The CP and the control group had carried out the endurance task to exhaustion. The CP group and the control group had similar holding time at the same relative load performing an upper extremity endurance task. This indicates that muscle endurance was similarly affected as muscle strength in children with CP. The muscle endurance in CP was neither less nor more reduced than muscle strength, but muscle endurance was as much affected as muscle strength. Further, the control group had relatively larger levels of muscle fatigue, but could compensate by MU recruitment and thereby endure. Muscle activity in the agonist during the endurance task did not increase in the CP group. Consequently, MU recruitment is hampered in CP subjects when performing an upper extremity endurance task at approximately 20% of MVIC.

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