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LEG EXTENSOR MUSCLE STRENGTH DURING BILATERAL AND UNILATERAL CONTRACTIONS IN CHILDREN WITH CEREBRAL PALSY AND WITHOUT DISABILITIES

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Abstract. The aim of the present study was to compare voluntary isometric force production capacity of the leg extensor muscles during bilateral and unilateral contractions in children with spastic diplegic cerebral palsy (CP) and in children without disabilities. Thirteen 6-year-old children with mild-to-moderate spastic diplegic CP and 13 age- and gender-matched healthy children participated in this study. During the measurements the subjects were seated on a specially designed dynamometric chair with knee and hip angles equal to 110° and 120°, respectively. The isometric maximal force of the leg extensor muscles during bilateral contraction and the maximal force during bilateral contraction relative to body mass were lower ($P<0.05$) in children with spastic diplegic CP than in children without disabilities (34.6% and 30.7%, respectively). Children with spastic diplegic CP had also lower ($P<0.05$) isometric maximal force for right and left leg during unilateral contraction (29.8% and 36.9%, respectively) as compared to the controls. A marked bilateral strength deficit of the leg extensor muscles was observed in children with spastic diplegic CP and controls (25.5% and 22.0%, respectively), while significant difference between these groups was not observed ($P>0.05$). Correlation analysis indicated that bilateral strength deficit is most obvious in spastic diplegic children with considerably decreased maximal and body mass-related isometric voluntary force-generating capacity of the leg extensor muscles during bilateral contraction.

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Key words: Human leg extensor muscles – Isometric strength – Bilateral strength deficit - Children – Cerebral palsy

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Introduction

Several investigators have reported a reduction in voluntary isometric maximal force (MF) induced by simultaneous bilateral (BL) voluntary contraction as compared to the sum of MF of separately performed unilateral (UL) contractions of the right and left legs in adult subjects, and this phenomenon is designated as BL strength deficit [9,16,18,24,26,29]. No clear explanation for this phenomenon has emerged, but BL strength deficit would suggest a significant limitation of motor control. It is well known that UL muscle contraction is controlled mainly by the contralateral cerebral hemisphere and BL contraction is considered to be generated by the simultaneous activation of both hemispheres. Therefore, one explanation for the BL strength deficit is that it could be neural interaction between the two hemispheres connected by comissural nerve fibres [15,18]. It has been shown that BL strength deficit was associated with reduced movement-related cortical potentials caused by a mechanism of interhemispheric inhibition [9,16,17,18]. However, Jakobi and Cafarelli [12] demonstrated no evidence of a significant limitation in motor control between BL and UL isometric contractions of the knee extensor muscles in young male subjects. Thus, the mechanisms of BL strength deficit themselves have been discussed but are still unclear.

Cerebral palsy (CP) is a non-progressive disorder which consists of impaired motor function secondary to injury of the immature brain [11]. Two factors related to the impaired motor function are spasticity and muscle weakness. Spastic diplegia is one of the most prevalent type of CP that is characterized by impaired motor control and muscle weakness in the lower extremities. More than 50% less voluntary isometric MF has been found in the lower extremity muscles in children with spastic diplegic CP as compared to children without disabilities [4]. In children with spastic CP a significant lower extremity weakness is correlated with imbalance of muscle forces across the joints in lower extremities [30].

It has been suggested that despite BL lower extremity involvement, the majority of children with spastic diplegic CP have the capability to ambulate, albeit at a later age and less proficiency than normally developing peers [2,20]. Muscle force production during BL and UL isometric contractions of the leg extensors, and BL strength deficit in children with and without spastic CP has been less investigated. However, this investigation can increase our knowledge concerning the degree of muscle weakness and motor control impairment in children with spastic diplegic CP.

The purpose of the present study was to compare the voluntary isometric strength of the leg extensor muscles during UL and BL contractions in 6-year-old children with spastic diplegic CP and in age- and gender-matched children without disabilities. Leg extensor muscles play an important role in posture and movement, and therefore, the recordings were made from these muscles.

Material and Methods

Thirteen children, aged 6 years (8 girls and 5 boys) with spastic diplegic CP and 13 age- and gender-matched children without disabilities (also 8 girls and 5 boys) participated in this study. The clinical diagnosis of spastic diplegia was made by physician. A CP group consisted of children with mild-to-moderate spastic diplegia. All children were able to follow instructions and walk independently. The children were also free from the limitations of range of motion. None of the children had an impairment of visual, somatosensory, hearing or vestibular function. Informed parental consent was obtained prior to the children's participation in the experiment. The study carried the approval of the University Ethics Committee. The physical characteristics of the subjects are described in Table 1.

Table 1
The physical characteristics of the subjects (mean ±SE)

	Groups	
Variable	Children with spastic diplegic CP (n=13)	Children without disabilities (n=13)
Age (years)	6.4±0.2	6.3±0.3
Height (cm)	119.0±1.8	121.1±1.2
Body mass (kg)	21.4±0.5	23.6±1.1
Body mass index ($kg \cdot m^{-2}$)	15.4±0.3	16.0±0.6

CP = cerebral palsy

Before the present study, twenty-six 6-year-old randomly selected normally developed boys (n=12) and girls (n=14) participated in a pilot study to evaluate the test-retest reliability of measurement of isometric MF of the leg extensor muscles during BL and UL contraction conditions. The second testing session was carried out 1 week after the initial testing. Significant test-retest correlations (r = 0.86-0.92 in boys and r = 0.82-0.89 in girls) indicated acceptable test-retest reliability.

Twenty-four to 48 h before data collection the subjects were given instructions and the muscle strength testing procedures were demonstrated. This was followed by a practice session to familiarize the subjects with the procedures. Prior to testing, a 10-min warm-up period was used.

During the measurement the subjects were seated on a specially designed dynamometric chair in a horizontal frame with knee and hip angles equal to 110° and 120°, respectively [21]. The body position of the subjects was secured by two Velcro belts placed over the chest and hip. The feet were placed on a footplate mounted on a steel bar held in ball-bearings on the frame. The isometric force production of the leg extensor muscles was recorded by standard strain-gauge transducer connected with footplate. The electrical signals from the strain-gauge transducer were digitized online (sampling frequency 1 kHz) using a personal computer. During testing the subjects were instructed to push the footplate as forcefully as possible for 2-3 s in three cases: 1) UL contraction of the right leg, 2) UL contraction of the left leg and 3) BL contraction in random order. Three trials were performed for each case and the greatest force value was taken as isometric MF. Verbal encouragement and visual feedback were used to motivate the subjects to produce maximal effort. A rest period of 2 min was allowed between the trials. During UL exertions the contralateral leg was allowed to rest. Bilateral index (BI) was calculated by the formula described by Howard and Enoka [10]:

$$BI\ (\%) = 100\ [BL\ /(UL_R + UL_L)] - 100,$$

where BI is the bilateral index, BL is isometric MF during bilateral contraction, and UL_R and UL_L are isometric MF during unilaterlal contraction of right and left leg, respectively. A negative BI indicated a BL strength deficit, while a positive BI indicated a BL strength facilitation.

Standard statistical methods were used for calculation of means and standard errors (±SE). One-way analysis of variance (ANOVA) followed by Tukey post hoc comparisons were used to test for differences between groups of children and for each leg. Linear correlations were calculated to observe the relationships between the measured characteristics. A level of $P<0.05$ was selected to indicate statistical significance.

Results

No significant differences ($P<0.05$) in height, body mass and body mass index was observed between the groups of children with diplegic spastic CP and children without disabilities (Table 1).

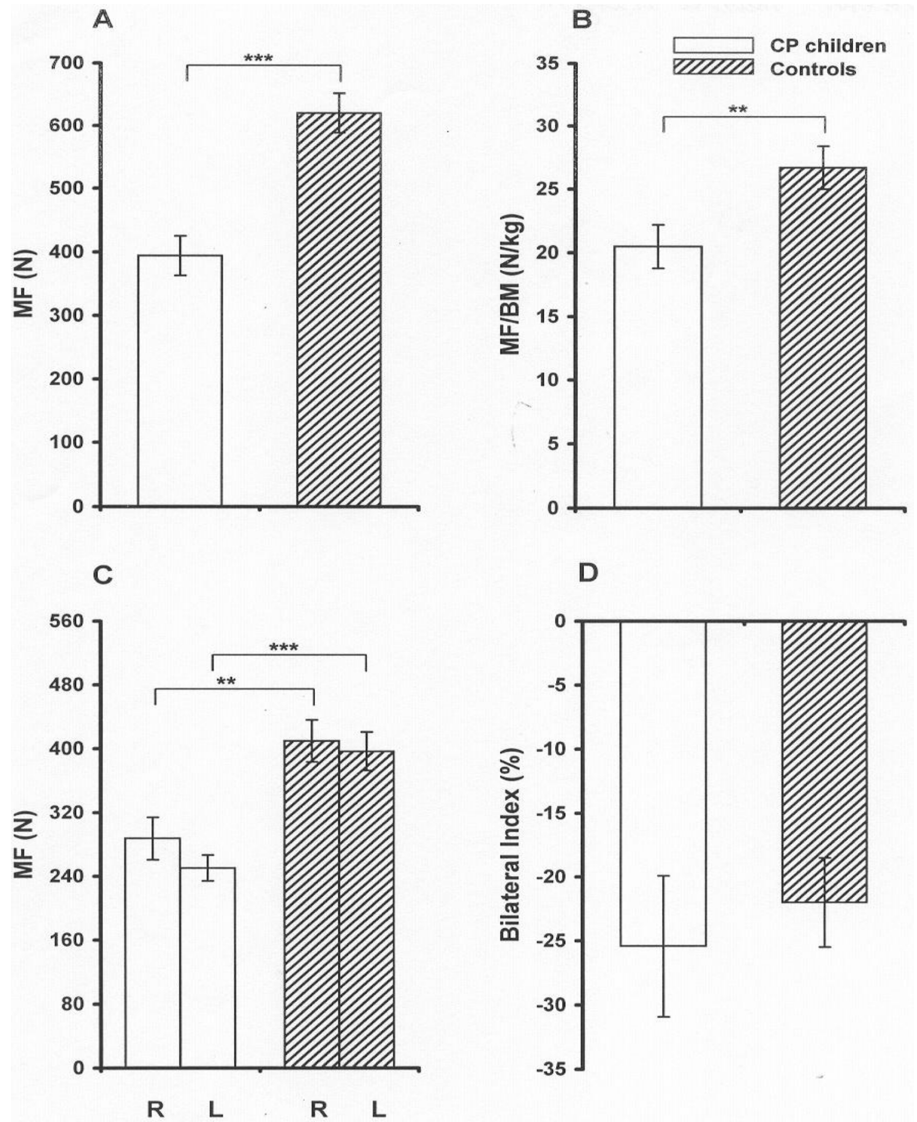

Fig. 1
Isometric maximal force (MF) of the leg extensor muscles during bilateral (BL) contraction (**A**), MF during BL contraction relative to body mass (**B**), isometric MF during unilateral (UL) contraction (**C**) and bilateral index (**D**) in children with spastic diplegic CP (n=13) and in children without disabilities (n=13);
Values are means ±SE; R - right leg; L - left leg; **P<0.01; ***P<0.001

Isometric MF of the leg extensor muscles during BL contraction (Fig. 1A) and MF during BL contraction relative to body mass (Fig. 1B) were greater (P<0.05) in children without disabilities as compared to children with spastic diplegic CP. Children with spastic diplegic CP had significantly less (P<0.05) isometric MF during right and left leg UL contractions as compared to children without disabilities (Fig. 1C). As shown on Fig. 1D, a marked negative BI, i.e. BL strength deficit of the knee extensor muscles was observed in children with spastic diplegic CP and controls. However, BI did not differ significantly (P>0.05) between the groups.

Isometric MF of the leg extensor muscles during BL contraction and MF during BL contraction relative to body mass correlated significantly (P<0.05) negatively with BMI (r=-0.56 and r=-0.61, respectively) and BI (r=-0.75 and r=-0.78, respectively) in children with spastic diplegic CP (Table 2). A significant (P<0.05) positive correlation was found between isometric MF of the leg extensor muscles during BL contraction, and MF during right and left leg UL contractions (r=0.65 ans r=0.56, respectively) in children without disabilities (Table 3). No significant (P>0.05) correlations was observed between BI and isometric MF of the leg extensor muscles during BL or UL contractions in children without disabilities.

Table 2

Correlations between measured characteristics in children with spastic diplegic CP (n=13)

Variable	Height	BM	BMI	UL_R	UL_L	BL	BL/BM	BI
Height	X	0.71*	-0.54	0.57*	0.01	0.40	0.17	0.05
BM		X	0.21	0.45	-0.13	0.01	-0.32	0.27
BMI			X	0.22	-0.14	-0.56*	-0.61*	0.27
UL_R				X	-0.31	0.43	0.26	0.12
UL_L					X	-0.13	-0.04	0.36
BL						X	0.95*	-0.75*
BL/BM							X	-0.78*
BI								X

CP-cerebral palsy; BM-body mass; BMI-body mass index (body mass/height^2); UL_R-isometric maximal force (MF) during unilateral contraction of the right leg; UL_L-isometric MF during unilateral contraction of the left leg; BL-isometric MF during bilateral contraction; BL/BM-isometric MF during bilateral contraction relative to body mass; BI-bilateral index; *P<0.05

Table 3
Correlations between measured characteristics in children without disabilities (n=13); for definitions see Table 2

Variable	Height	BM	BMI	UL_R	UL_L	BL	BL/BM	BI
Height	X	0.60*	0.24	-0.46	-0.32	0.16	-0.62*	-0.35
BM		X	0.92*	0.05	-0.01	0.36	-0.38	0.38
BMI			X	0.28	0.15	0.51	-0.16	0.29
UL_R				X	0.76*	0.65*	0.56*	0.38
UL_L					X	0.56*	0.55	0.46
BL						X	0.72*	-0.38
BL/BM							X	-0.11
BI								X

*P<0.05

Discussion

The results of the present study agreed with previous studies indicating that children with spastic diplegic CP demonstrate significant lower extremity weakness [4,5,8,23]. Our data indicate that voluntary isometric force-generating capacity of the leg extensor muscles was markedly lower in 6-year-old children with spastic diplegic CP during BL contraction as well as UL contraction than in age- and gender-matched nondisabled children. In children with spastic diplegic CP the isometric MF of the leg extensor muscles during BL contraction was on the average for 36.4% and MF during BL contraction relative to body mass for 30.7% lower, respectively, than in children without disabilities. Isometric MF of the right and left leg during UL contractions in children with spastic diplegic CP was on the average for 29.8% and 36.9% lower, respectively, as compared to children without disabilities. Damiano and Abel [4], who measured isometric MF of eight muscle groups in both lower extremities with a hand-held dynamometer, observed in children with spastic diplegic CP less than 50% of normal muscle force during UL isometric contraction. It has been observed that in children with spastic diplegic CP the muscle weakness is more pronounced in distal areas of the lower extremities than the proximal areas [30].

Impaired central motor drive, disuse atrophy and spasticity across the joints can hinder the voluntary isometric force-generating capacity of the leg extensor muscles in diplegic children. The pathophysiological changes underlying weakness include a decrease in the number of motor units and a reduced firing frequency of motor units as well as changes in morphology, proportion and contractile properties of muscle fibres of the spastic muscles. It has been shown that the spastic muscles in persons with CP exibited changes in its contractile properties (prolonged contraction time), as well as in its histochemistry and morphometry (increased variability of muscle fiber size and predominant slow-twitch fiber distribution) [7]. These altered changes may result from low motor unit firing, which has been demonstrated in subjects with CP [22]. Passive joint tension due to contractures or capsular contraints can limit force production in children with CP [8]. Muscle voluntry isometric force production may be limited by the central nervous system ability to activate maximally all agonist muscles and/or to control antagonistic muscles. Children with CP often demonstrate excessive amount of co-activation of antagonist muscles in the lower extremities in daily living activities as gait or standing [3], and during strength testing [6]. Therefore, increased levels of co-activation of antagonist muscles may restrain the action of the agonist muscles and reduce isometric strength in children with spastic diplegic CP. Spasticity, as defined as hypertonicity and hyperreflexia [1,14], may be one of the major factors responsible for the increased amount of co-activation of antagonist muscles in diplegic subjects.

This study indicated a marked negative BI, i.e. BL strength deficit of the leg extensor muscles in 6-year-old children with spastic diplegic CP and without disabilities. The mean values of BI in children with spastic diplegic CP and their age- and gender-matched controls were -25.4% and -22.0%, respectively, while significant differences between these groups were not observed. However, there were 4 children with spastic diplegic CP and 2 children without disabilities who had positive BI, i.e. BL strength facilitation. One possible explanation is that some children have difficulty performing reciprocal movement, and may potentially develop their bilateral force to a greater degree. Little information is available on lower extremity BL strength deficit in subjects with CP. Tihanyi and Horvath [28] reported that in patients with spastic CP aged 15-20 years BI of the knee extensor muscles was -32%. However, several investigators have observed BL strength deficit of the leg extensor muscles in healthy adult subjects. Taniguchi [27] published that BI ranged from -19% to - 7% in male students. Secher *et al.* [26]

reported BI of -20% in untrained, -14% in weightlifters and -24% in cyclists. The BI described in the study of Schantz *et al.* [24] were -14% in the untrained male group and -8% in heavy-resistance trained male group.

Neural mechanisms seems to be the likely cause of the BL strength deficit. To determine whether BL strength deficit is due to neural mechanisms, Howard and Enoka [10] studied three groups of differently trained subjects. Untrained subjects, cyclists, and weightlifters performed isometric maximal UL or BL contractions for which the two-limb combinations were either both legs or the left arm and the right leg. The untrained subjects exhibited a BL strength deficit of the leg extensor muscles, the cyclists did not, and the weightlifters produced a BL strength facilitation. These results suggest that interlimb interactions during maximal BL contractions are mediated by neural mechanisms. A strength deficit during BL contraction would occur if central drive is decreased or antagonist co-activation increased. The nature of the neural mechanism must ultimately involve altered motor unit discharge frequency and/or recruitment during maximum BL contraction. The BL strength deficit can be caused by a reduced activation of either low threshold (slow) motor units [25] or high threshold (fast) motor units [19, 29]. Some investigators have suggest that BL strength deficit is the consequence of a disproportionate increase in antagonist co-activation [10,13].

Correlation analysis indicated that in children with spastic diplegic CP isometric MF of the leg extensor muscles during BL contractions and MF during BL contraction relative to body mass correlated significantly negatively with BI. These results suggest that bilateral strength deficit was most obvious in spastic diplegic children with considerably decreased maximal and body mass-related voluntary isometric force-generating capacity of the leg extensor muscles during BL contraction. However, no significant correlation was observed between BI and maximal force during isometric BL or UL contractions of the leg extensor muscles in children without disabilities. Therefore, in children without disabilities the leg extensor muscle BL strength deficit may not necessarily be related to reduced isometric force-generating capacity during BL contraction.

The conclusion of this study is that in 6-year-old children with spastic diplegic CP the voluntary isometric force-generating capacity of the leg extensor muscles is significantly lowered compared with age- and gender-matched children without disabilities during BL contraction as well as during UL contraction. However, the observed BL strength deficit of the leg extensor muscles does not differ significantly in children with spastic diplegic CP and children without disabilities. BL strength deficit was most obvious in spastic diplegic children with considerably decreased maximal and body mass-related isometric voluntary force-generating capacity of the leg extensor muscles during BL contraction.

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