Lower limb muscle fatigue during walking in children with cerebral palsy

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ABBREVIATION
RMS Root mean square

AIM To investigate whether more prominent signs of muscle fatigue occur during self-paced walking in children with cerebral palsy (CP) compared to typically developing peers.
METHOD In this case–control study, 13 children with CP (four males, nine females; mean age [SD] 11y 4mo [3y 8mo]; nine in Gross Motor Function Classification System [GMFCS] level I, three in GMFCS level II, and one in GMFCS level III) and 14 typically developing peers (nine males, five females; mean age [SD] 9y 10mo [1y 10mo]) walked 5 minutes overground at a self-selected walking speed. Electromyography (EMG) median frequency and root mean square (RMS) were identified per gait cycle from EMG recordings of the tibialis anterior, gastrocnemius medialis, soleus, rectus femoris, and semitendinosus. Rate of change in those variables was analysed using mixed linear model analyses.
RESULTS The decrease in EMG median frequency of gastrocnemius medialis and soleus and increase in EMG-RMS of tibialis anterior, gastrocnemius medialis, and soleus were significantly larger in the most affected leg of children with CP compared with typically developing peers.
INTERPRETATION Increased selective muscle fatigue of the lower leg muscles was observed during self-paced walking in children with mild-to-moderate severe CP. This could contribute to and account for limited walking capacity.

Cerebral palsy (CP) describes a group of disorders caused by lesions of the brain in the developing fetus or infant.[1] With incidence rates of 1.5 to 2.5 per 1000 live births, CP is the most common neurodevelopmental condition in children.[2] CP primarily leads to impairments of movement and posture,[3] which in turn can lead to limitations in activities and participation.[1] Commonly reported primary motor impairments are muscle spasticity, impaired selective motor control, and increased muscle coactivation.[4] Following the progression of primary motor impairments, children with CP often show reduced muscle strength.[5] Even children with CP who demonstrate only few functional limitations have been found to be substantially weaker than typically developing peers.[6]

Muscle weakness is thought to be an important contributor to the limitations in activities of daily life in children with CP.[5] Because of muscle weakness, individuals with CP have to generate relatively higher forces to perform activities of daily life, such as walking. It is a common belief that reduced muscle strength leads to higher relative forces that could potentially lead to muscle fatigue during walking.[7] For example, Parent et al.[7] observed that children with CP who walked in crouch increased their crouch after a 6-minute walking exercise. Parent et al.[7] suggested that these gait modifications are a consequence of muscle fatigue contributing to this type of gait. Nevertheless, while several researchers have suggested that individuals with CP could experience an early-onset muscle fatigue, there is a lack of research focusing on muscle fatigue *during* walking.[8]

Muscle fatigue is traditionally defined as 'any exercise-induced reduction in force generating capacity',[9] which is usually divided into two components; peripheral and central fatigue.[10] Peripheral fatigue is commonly defined as a loss in the force-generating capacity due to processes distal to the neuromuscular junction,[11] whereas central fatigue is described as a progressive exercise-induced reduction in voluntary activation.[11] Surface electromyography (EMG) has been used widely to observe these changes in neuromuscular activation associated with peripheral fatigue.[12] During walking, submaximal force output has to be maintained to continue walking. When muscles fatigue and

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force capacity reduces concomitantly, a larger part of the muscle has to be activated to maintain the required force output and the voluntary activation needed to increase progressively. Thus, the descending drive increases to counteract fatigue of the exercising muscles, leading to an increase in root mean square (RMS) of EMG recordings.[13] Simultaneously, as a muscle fatigues there is a concomitant shift towards lower frequencies in the surface EMG signal.[14] Physiologically, the frequency shift has been attributed to peripheral factors such as a reduction in conduction velocity of the action potential, changes in the intracellular action potentials, and central factors, such as synchronization of motor units.[15] In this study, a decrease in median frequency and an increase in RMS signals are interpreted as signs of muscle fatigue.[12]

The aim of this study was to investigate whether signs of muscle fatigue are present in leg muscles during walking in children with CP and typically developing peers. As reduced strength levels have been reported in various leg muscle groups of children with CP,[5] it was hypothesized that more prominent signs of muscle fatigue would be observed during prolonged walking in different lower limb muscles of children with CP versus typically developing peers. In addition, as muscle weakness has been shown to be more pronounced in the distal muscles of children with CP,[6] it was hypothesized that distal muscles would show more prominent signs of muscle fatigue.

METHOD

Participants

In this case–control study, a convenience sample of 13 children diagnosed with unilateral and bilateral CP (Gross Motor Function Classification System [GMFCS] level I, II, or III)[16] were recruited from the neuro-orthopaedic outpatient clinic at St Olavs Hospital, Trondheim University Hospital, Trondheim, Norway (Table I). Potential participants were excluded if they had received botulinum toxin A treatment in the preceding 3 months and/or surgery in the preceding 12 months. Fifteen age-matched and sex-matched children with no motor impairments were recruited from public schools (Table I). The study protocol was approved by the Regional Committee of Ethics in Medical Research and written informed consent was obtained from the children's parents before participation in the study. Information such as sex, age, height, weight, and body mass index were obtained for each patient. CP-related characteristics were also noted: either a unilateral or bilateral involvement of CP and GMFCS level. Spasticity was evaluated using the clinical Tardieu Scale.[17] If children with CP had bilateral involvement, passive range of motion and level of spasticity in the calf muscles was taken into account when ascertaining which of the legs was the most affected and which was least affected.

Walking test

All participants walked for 5 minutes at their self-selected comfortable walking speed (5-Minute Walk Test), back and forth, on a 40m path. Children with CP wore their regular shoes and ankle–foot orthoses when needed. Test performance was defined as the distance covered in 5 minutes, which was used to calculate average walking speed. Triaxial accelerometers (Axivity, Newcastle upon Tyne, UK) were placed on the forefoot of both shoes to identify separate gait cycles. Surface EMG of the tibialis anterior, rectus femoris, gastrocnemius medialis, soleus, and semitendinosus sampled at 2000Hz were recorded bilaterally using wireless EMG (Myon, Schwarzenberg, Switzerland). Electrode placement and skin preparations were done according to the Surface Electromyography for the Non-Invasive Assessment of Muscles guidelines.[18] To synchronize the EMG and acceleration signals, a heel drop was performed at the start and end of the walking test. The heel drops were executed by standing at their toes and dropping their heels firmly to the ground.

What this paper adds

- Children with cerebral palsy (CP) show more signs of lower leg muscle fatigue than typically developing peers.
- No signs of muscle fatigue were observed in upper leg muscles of children with CP.

Data analysis

Accelerometer and EMG recordings were synchronized offline by identifying clear spikes of the impact of the heel drop in both the EMG and acceleration signals using Matlab version R2010b (The Mathworks, Natick, MA, USA). Gait cycles of both feet were identified based on detection of impact (peak detection) in the raw acceleration signals. Movement artifacts were removed from the EMG recordings using high-pass filtering at 20Hz.[19] Further, a notch filter (50Hz and its harmonics at 100Hz and 200Hz) was applied to remove power line noise. EMG median frequency of the power spectrum was determined in hertz using fast Fourier transformation for gait cycle individually. Thereafter, EMG signals were rectified and low-pass filtered (second-order Butterworth, bidirectional at 5Hz) to obtain smoothed, rectified EMG envelopes, from which the RMS in millivolts was determined for each separate gait cycle (EMG-RMS). EMG median frequency and EMG-RMS were normalized for further analysis. Normalization was done to correct for inter-participant detection difference, i.e. EMG recordings could be influenced by external factors.[20] For the normalization, a linear regression ($y=ax+b$, for which y represents the dependent variable [i.e. EMG median frequency or EMG-RMS], x represents gait cycle number, and a and b are regression coefficients) was constructed per participant per muscle, for EMG median frequency or EMG-RMS separately. Data from the first 10 gait cycles of the walking test and five gait cycles before and after the turns were excluded from the analysis. The EMG median frequency and EMG-RMS of each individual gait cycle was normalized to the intercept (b) of the individual linear regression equations. The normalized

Table I: Characteristics of typically developing (TD) children and children with cerebral palsy (CP)

	TD (n=14)	CP (n=13)		t/χ^2	p
Sex (F/M)	8/6	4/9		1.889	0.168
Age (y:mo)	9y 10mo (1y 9mo)	11y 4mo (3y 8mo)		−1.067	0.297
Height (m)	1.42 (0.1)	1.43 (0.2)		−0.201	0.843
Weight (kg)	36.43 (10.3)	40.1 (18.4)		−0.620	0.541
BMI (kg/m^2)	17.7 (2.7)	18.6 (5.1)		−0.577	0.569
Number of children with CP with unilateral or bilateral involvement (F/M)	NA	10/3			
Number of children classified as GMFCS level I/II/III	NA	9/3/1			
ROM ankle dorsiflexion (°), knee in 90°, median (range)	NA	Most affected leg	5 (−5 to 30)		
		Least affected leg	0 (−15 to 25)		
Spasticity in soleus, knee in 90°, median (range)[a]	NA	Most affected leg	2 (0 to 3)		
		Least affected leg	0 (0 to 3)		
Spasticity in gastrocnemius, knee in 90°, median (range)[a]	NA	Most affected leg	2 (0 to 3)		
		Least affected leg	0 (0 to 3)		

[a]Tardieu Scale (0–4). Data are mean (SD) unless otherwise stated. F, female; M, male; BMI, body mass index; NA, not applicable; GMFCS, Gross Motor Function Classification System; ROM, range of motion.

EMG median frequency and EMG-RMS data points for each gait cycle for each participant were used in further analyses.

Statistical analysis

Differences in patient characteristics between children with CP and typically developing children were identified using independent samples t-tests or the χ^2 test. Changes in EMG median frequency and EMG-RMS over the course of the walking test were analysed using mixed linear model analysis. Separate models were constructed for each muscle individually and for EMG median frequency and EMG-RMS. EMG median frequency or EMG-RMS was set as the dependent variable and group and the cycle (number) were set as the independent variables. An interaction term of group×cycle number was added to the model. The control group was set as the reference group, with the least affected leg and most affected leg of children with CP as following groups. The regression coefficient of cycle number represented the change in EMG median frequency or EMG-RMS for typically developing children. The regression coefficients of the interaction terms represented the difference in change of EMG median frequency or EMG-RMS between typically developing children and either the least affected leg or most affected leg of children with CP. Significance was set at $p<0.05$. All analyses were performed using SPSS version 20 (IBM Corp., Armonk, NY, USA).

RESULTS

Thirteen children with CP and 14 typically developing peers were included. Participant characteristics were similar in children with CP and typically developing peers (Table I). Children with CP covered significantly shorter distances (data given as mean [SD] (CP: 302m [39m]; typically developing: 335m [34m]) and walked slightly slower than typically developing children in the 5-Minute Walk Test (CP: 1.04m/s [0.09m/s]; typically developing: 1.13m/s [0.13m/s]; t=1.563, p=0.059). Typical individual examples of the change in EMG median frequency and EMG-RMS as a function of time are given in Figure 1. Group values of the normalized slopes of EMG median frequency and EMG-RMS are shown in Figure 2.

Results of the mixed-models analysis to investigate the rate of change in EMG median frequency and EMG-RMS are shown in Table II (shortened version; extended version: Table SI, online supporting information). For the EMG median frequency and EMG-RMS of tibialis anterior, gastrocnemius medialis, and soleus, the interaction term between group and gait cycle was significant when comparing typically developing children with the most affected leg of children with CP. This indicates that the decrease in EMG median frequency and increase in EMG-RMS were larger per gait cycle in the most affected leg of children with CP than in typically developing children. Similarly, interaction terms between the least affected leg of children with CP and gait cycle were also significant for soleus and gastrocnemius medialis muscles, showing that regression coefficients of EMG median frequency and EMG-RMS in soleus muscle and EMG-RMS in gastrocnemius medialis muscle were larger in the least affected leg of children with CP than in typically developing children.

DISCUSSION

The present explorative study reports on signs of lower limb muscle fatigue during overground walking at self-paced speed in children with spastic CP by evaluating a decline in EMG median frequency and an increase in EMG-RMS over the course of a 5-minute self-paced walking trial. Results of the study confirm our hypothesis, indicating that for distal muscles, i.e. tibialis anterior, gastrocnemius medialis, and soleus, the rates of change in EMG median frequency and EMG-RMS were larger in the most affected leg of children with CP than in typically developing children. For the gastrocnemius medialis and soleus muscles, the rate of change was larger in the least affected leg in children with CP than in typically developing children. These observations indicate that in these lower leg muscles, children with CP show more signs of

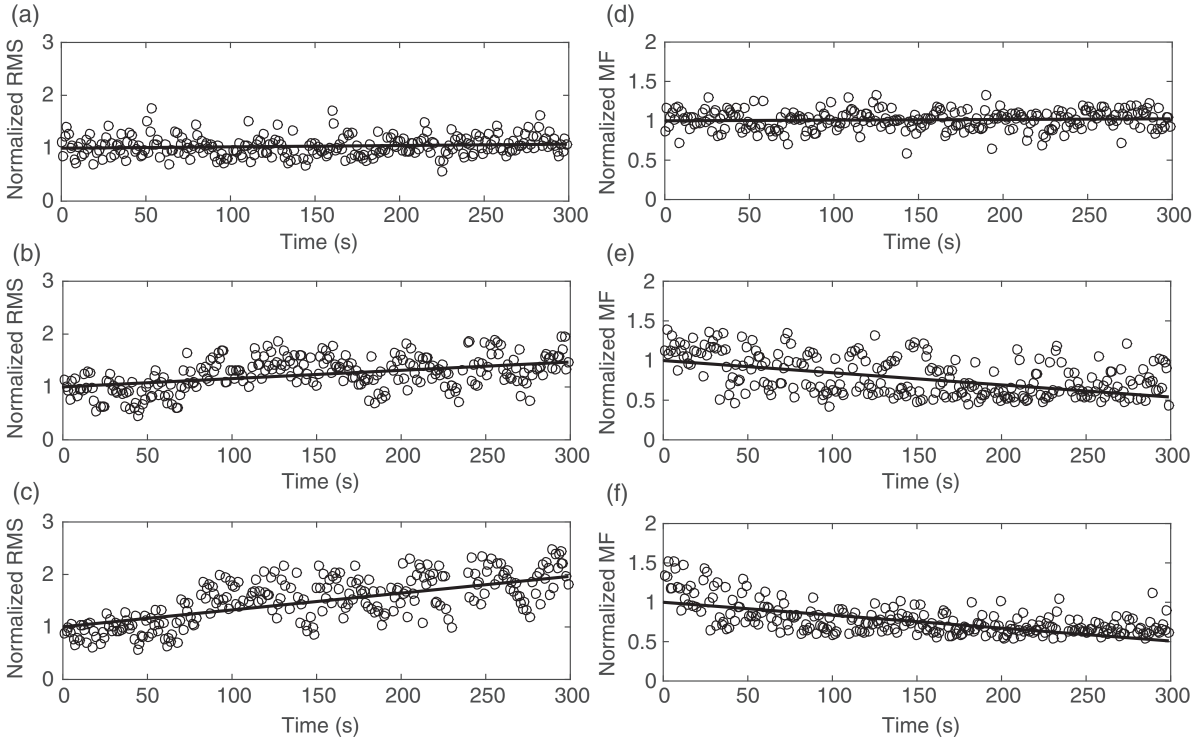

Figure 1: Typical examples of an increase in normalized root mean square (RMS) of electromyography (EMG) recordings and a decline in normalized EMG median frequency (MF) of the gastrocnemius muscle, where (a) and (d) display the left leg of a typically developing child, (b) and (e) display the least affected leg of a child with cerebral palsy (CP), and (c) and (f) display the most affected leg of the same child with CP. The solid line in the figures represents the regression line.

muscle fatigue than typically developing peers. For the other leg muscles assessed in this study, specifically the upper leg rectus femoris and semitendinosus, EMG median frequency and EMG-RMS remained constant in children with CP and their typically developing peers, and thus no muscle fatigue was present in these muscles. Thus, it appears that in this relatively well functioning group of children with CP, muscle fatigue occurs more prominently in lower leg muscles, but not upper leg muscles, than in typically developing peers during 5 minutes of walking at self-paced speed. This lower leg muscle fatigue could be one of the contributing factors to reduced walking capacity reported in children with CP.[21]

The fact that muscle fatigue most prominently occurs in the lower leg muscles of children with CP during self-paced walking versus other muscle groups can be explained by several factors. Previous research has shown that strength is mostly affected in the lower leg muscles, more specifically the calf muscles, of children with CP when comparing lower limb muscle strength levels in typically developing peers.[22,23] In addition, ambulant children with CP have been shown to generate only 48% of the plantar flexor strength that typically developing children can generate.[6] This reduced force-generating capacity of calf muscle in children with CP might result in high relative demands on calf muscle during walking, making this muscle group more prone to fatigue.[7] Previous research used ‘failure analysis’ to investigate the amount of weakness the human musculoskeletal system can tolerate to be able to maintain walking ability.[24] From this muscle-driven simulation study it was clear that, besides weakness of hip abductors and hip flexors, weakness of the plantar flexors affected walking ability the most. Hence, the combination of weakness of plantar flexors and the relatively high forces this muscle group has to exert during walking serves as a plausible explanation for why muscle fatigue most prominently occurs in calf muscles. This information indicates that it can be beneficial for clinicians and therapists to focus therapy mostly on lower leg muscles in order to reduce muscle fatigue during walking. Whether an increase in lower leg muscle strength leads to reduction in muscle fatigue should be investigated in future research.

Excessive cocontraction observed in children with CP might be one of the factors that contributes to muscle fatigue occurring during walking.[25] Despite the fact that cocontraction can be beneficial in achieving joint stability, excessive cocontraction may lead to high metabolic costs during walking, as both muscles are active.[26] Cocontraction levels are shown to be elevated during walking in children with CP versus typically developing children.[27] Agonist force production is hampered, which could lead to an early onset of muscle fatigue, more than in typically

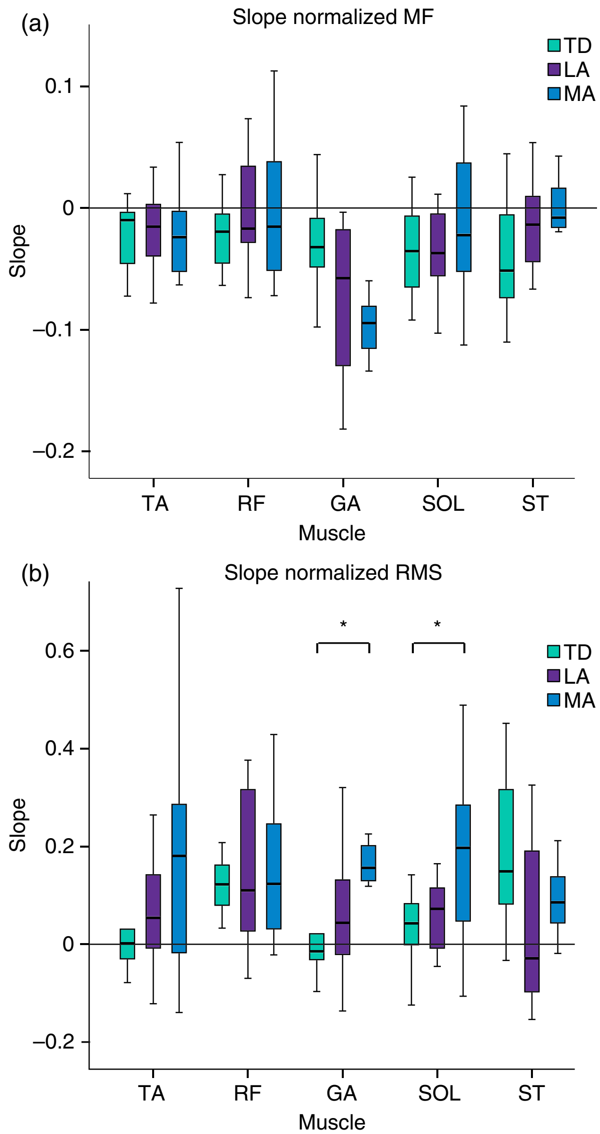

Figure 2: Boxplots of slopes of the (a) normalized median electromyography (EMG) frequency and (b) root mean square (RMS) of EMG recordings for typically developing (TD) children, least affected (LA) leg of children with cerebral palsy, and most affected (MA) leg of children with CP for separate muscles. The boxplots show the following: box, interquartile range (IQR; 25th–75th centiles, Q1–Q3); upper whisker, Q3–1.5 IQR; lower whisker, Q1–1.5 IQR. Significant differences are indicated by an asterisk ($p<0.05$). TA, tibialis anterior; RF, rectus femoris; GA, gastrocnemius medialis; SOL, soleus; ST, semitendinosus. [Colour figure can be viewed at wileyonlinelibrary.com].

developing children.[28] Another factor responsible for muscle fatigue might be muscle spasticity. Participants of the current study showed mild spasticity of lower leg muscles (see Table I). As suggested by Miller et al.,[29] this might also have contributed to muscle fatigue. Miller et al.[29] showed that a decline in phosphocreatine and intracellular pH was larger in spastic muscles during intermittent tetanic stimulation than in controls. These biomechanical changes in muscles of individuals with spasticity may contribute to their susceptibility to fatigue.[29] Future research should be conducted to investigate whether children with spasticity fatigue more than children without (or with less) spasticity.

While our results suggest that calf muscles of children with CP fatigue more during walking than their typically developing peers, seemingly contrasting results were reported in previous research, which showed better fatigue resistance in children with CP.[30] Greater fatigue resistance was also observed in other muscle groups of individuals with CP, their knee extensors, when imposing fatiguing protocols consisting of maximal voluntary contractions.[31] An explanation for the different findings is the usage of different methods to investigate muscle fatigue. Previous studies that reported on increased fatigue resistance in individuals with CP investigated muscle fatigue as a reduction in the maximal force-generating capacity. However, in other studies it was observed that children with CP have problems with maximally recruiting their muscles. Therefore, the submaximal effort at which they perform the maximal fatigue test underestimates their fatigability.[31] Although the investigation of fatigue during a submaximal test as walking does not assess fatigability at the muscle fibre level, it does reveal fatigability of a muscle during a functional task performed during daily life against real absolute load levels. Hence, regardless of physiological fibre type characteristics, in practice lower leg muscles of children with CP do seem to fatigue during an actual walking task.

In the current explorative study, we focused on muscle fatigue during a relatively simple task: walking. In certain cases greater muscle fatigue could occur, potentially causing problems for activities and participation. Firstly, when individuals with CP need to cover longer distances or perform more intensive tasks during daily life, greater muscle fatigue and/or muscle fatigue in other (leg) muscles could occur. This needs to be taken into account when interpreting these laboratory-based results to clinical practice. In addition, this study focused on children with CP who do not often report fatigue.[32] However, adolescents and adults with CP commonly report fatigue as a major problem/limitation during daily life,[33,34] and muscle fatigue could be an important factor. Future research is needed to investigate whether muscle fatigue is also present in adolescents and adults with CP.

The advantage of using surface EMG is that the presence of actual muscle fatigue during walking can be obtained. Having monitored changes in EMG, the present study adds new information to the existing literature. It can thus be tentatively suggested that muscle fatigue affects children with CP more than their typically developing peers. However, the current method still lacks the ability to assess the magnitude of muscle fatigue that children with CP are experiencing. Future research should focus on quantifying changes in surface EMG to indicate levels of muscle fatigue in children with CP during different activities of daily life.

Table II: Mixed linear model to identify the change in electromyography (EMG) median frequency and root mean square (RMS) of EMG recordings per gait cycle in typically developing (TD) children, and in the least affected and most affected leg of children with cerebral palsy (CP)

Variable	EMG median frequency			EMG-RMS		
Muscle: RF	β	95% CI	*p*	β	95% CI	*p*
Gait cycle	-0.08×10^{-3}	-0.46×10^{-3} to 0.31×10^{-3}	0.688	1.74×10^{-2}	-1.48×10^{-3} to 4.96×10^{-3}	0.264
Gait cycle×group						
Gait cycle×TD (Ref.)	0 (Ref.)			0 (Ref.)		
Gait cycle×CP least affected leg	-0.07×10^{-3}	-0.36×10^{-3} to 0.22×10^{-3}	0.617	0.53×10^{-3}	4.45×10^{-3} to 6.09×10^{-3}	0.511
Gait cycle×CP most affected leg	0.04×10^{-3}	-0.24×10^{-3} to 0.33×10^{-3}	0.765	-0.05×10^{-3}	-1.34×10^{-3} to 0.30×10^{-3}	0.214
Muscle: ST	β	95% CI	*p*	β	95% CI	*p*
Gait cycle	-0.04×10^{-3}	-0.75×10^{-3} to -0.05×10^{-3}	0.270	7.63×10^{-3}	-4.98×10^{-3} to 2.02×10^{-2}	0.212
Gait cycle×group						
Gait cycle×TD (Ref.)	0 (Ref.)			0 (Ref.)		
Gait cycle×CP least affected leg	0.03×10^{-3}	0.10×10^{-3} to 0.49×10^{-3}	0.300	0.13×10^{-3}	0.45×10^{-3} to 2.14×10^{-3}	0.334
Gait cycle×CP most affected leg	0.02×10^{-3}	-0.01×10^{-3} to 0.40×10^{-3}	0.600	0.09×10^{-3}	1.76×10^{-3} to 0.02×10^{-4}	0.598
Muscle: TA	β	95% CI	*p*	β	95% CI	*p*
Gait cycle	-0.04×10^{-3}	-0.62×10^{-3} to -0.09×10^{-3}	0.100	0.38×10^{-3}	-0.33×10^{-3} to 1.09×10^{-3}	0.268
Gait cycle×group						
Gait cycle×TD (Ref.)	0 (Ref.)			0 (Ref.)		
Gait cycle×CP least affected leg	0.28×10^{-3}	0.08×10^{-3} to 0.48×10^{-3}	0.214	-0.027×10^{-3}	-0.34×10^{-3} to 0.29×10^{-3}	0.863
Gait cycle×CP most affected leg	**-0.13×10^{-3}**	**-0.33×10^{-3} to 0.07×10^{-3}**	**0.006**	**1.98×10^{-3}**	**1.60×10^{-3} to 2.24×10^{-3}**	**<0.001**
Muscle: GA	β	95% CI	*p*	β	95% CI	*p*
Gait cycle	-0.30×10^{-3}	-0.74×10^{-3} to 0.13×10^{-3}	0.153	-0.10×10^{-3}	-0.60×10^{-3} to 0.40×10^{-3}	0.684
Gait cycle×group						
Gait cycle×TD (Ref.)	0 (Ref.)			0 (Ref.)		
Gait cycle×CP least affected leg	0.03×10^{-3}	-0.14×10^{-3} to 0.19×10^{-3}	0.760	**0.75×10^{-3}**	**0.46×10^{-3} to 1.04×10^{-3}**	**<0.001**
Gait cycle×CP most affected leg	**-0.63×10^{-3}**	**-0.81×10^{-3} to -0.45×10^{-3}**	**<0.001**	**2.17×10^{-3}**	**1.86×10^{-3} to 2.48×10^{-3}**	**<0.001**
Muscle: SO	β	95% CI	*p*	β	95% CI	*p*
Gait cycle	**-0.49×10^{-3}**	**-0.77×10^{-3} to -0.22×10^{-3}**	**0.001**	0.37×10^{-3}	-0.27×10^{-3} to 1.00×10^{-3}	0.235
Gait cycle×group						
Gait cycle×TD (Ref.)	0 (Ref.)			0 (Ref.)		
Gait cycle×CP least affected leg	**-0.22×10^{-3}**	**-0.60×10^{-3} to 0.39×10^{-3}**	**0.007**	**0.36×10^{-3}**	**0.10×10^{-3} to 0.63×10^{-3}**	**0.008**
Gait cycle×CP most affected leg	**-0.28×10^{-3}**	**-0.44×10^{-3} to 0.14×10^{-3}**	**0.001**	**1.79×10^{-3}**	**1.52×10^{-3} to 2.05×10^{-3}**	**<0.001**

Regression models are displayed, including the estimated regression coefficient (β), i.e. the change in EMG median frequency and EMG-RMS per gait cycle per group/leg, and the interaction effect of gait cycle×group/leg (see Table SI, online supporting information, for extended version of table including intercept). A significant interaction effect indicated that the change in EMG median frequency or EMG-RMS was significantly different in the least affected leg or most affected leg of children with CP from the reference group, i.e. typically developing children. Significant values are indicated in bold. RF, rectus femoris; CI, confidence interval; ST, semitendinosus; TA, tibialis anterior; GA, gastrocnemius medialis; SO, soleus.

The present results should be interpreted with some limitations in mind. Firstly, a relatively small and heterogenic sample of children with CP was included in the current study. Based on this small sample, no distinction could be made between children with mild CP, classified in GMFCS level I, and children with moderate CP, classified in GMFCS levels II and III. However, even in this explorative study with a small sample size, clear signs of muscle fatigue of lower leg muscles were apparent. Future research is required to further analyse muscle fatigue in a larger group of individuals with CP. We recommend future research focuses on lower leg muscles, because no signs of muscle fatigue were observed in other muscles.

In conclusion, this explorative study adds knowledge to the field of research as it shows that lower leg muscles, particularly calf muscles, of children with mild-to-moderate CP show more prominent signs of muscle fatigue during walking than their typically developing peers, especially in their most affected leg. These findings are derived from the rate of change in EMG recordings, showing a larger decrease in EMG median frequency and increase in EMG-RMS in the tibialis anterior, gastrocnemius medialis, and soleus in children with CP than in typically developing peers. In upper leg muscles, no signs of muscle fatigue were present in children with CP. Based on the findings of the current study, we can tentatively conclude that muscle fatigue of lower leg muscles is present in a group of children mildly affected with CP, and therefore could limit walking capacity of children with CP. Clinicians and therapists should focus strength training programmes on lower leg muscles in order to reduce muscle fatigue during walking in children with CP. The current study serves as an explorative study, highlighting the need for future research to confirm current findings in a larger group of individuals with CP. In addition, future research should investigate whether reduced muscle strength levels or spasticity primarily causes fatigue of calf muscles, to be able to construct relevant rehabilitation programmes for children with CP.

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SUPPORTING INFORMATION

The following additional material may be found online:

Table SI: Extended version of Table II.

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RESUMEN

FATIGA MUSCULAR EN EXTREMIDADES INFERIORES DURANTE LA MARCHA EN NIÑOS CON PARÁLISIS CEREBRAL

OBJETIVO Investigar la ocurrencia de signos prominentes de fatiga muscular durante la marcha a ritmo propio, en niños con parálisis cerebral (PC), comparado a sus pares con desarrollo típico.
MÈTODO En este estudio de caso control, 13 niños con PC (4 varones, 9 mujeres; edad promedio [DE] 11a 4m [3a 8m]; 9 en nivel I del Sistema de Clasificación de la Función Motora Gruesa [GMFCS], 3 en GMFCS nivel II, y 1 en GMFCS nivel III) y 14 pares con desarrollo típico (9 varones, 5 mujeres, edad promedio [DE] 9a 10m [1a 10m]) caminaron durante 5 minutos sobre una superficie a velocidad autoseleccionada. Se identificó la frecuencia media y la media cuadrática (RMS) por ciclo, de la señal electromiográfica (EMG) del tibial anterior, gastrocnemio medial, sóleo, recto femoral y semitendinoso. La tasa de cambio de estas variables fue analizada utilizando análisis con un modelo lineal mixto.
RESULTADOS La disminución en la frecuencia media de la EMG del gastrocnemio medial y sóleo, y el aumento en la RMS de la EMG del tibial anterior, gastrocnemio medial y sóleo, fueron significativamente mayores en la extremidad más afectada de niños con PC, comparado a sus pares con desarrollo típico.
INTERPRETACIÓN Se observó un aumento en la fatiga muscular selectiva en los músculos de la pierna durante la marcha a ritmo propio en niños con PC leve a grave. Esto podría contribuir y explicar la limitación en la capacidad de la marcha.

RESUMO

FADIGA DE MÚSULOS DOS MEMBROS INFERIORES DURANTE A MARCHA EM CRIANÇAS COM PARALISIA CEREBRAL

OBJETIVO Investigar se sinais mais proeminentes de fadiga muscular ocorrem durante marcha com velocidade auto-selecionada em crianças com paralisia cerebral (PC) em comparação com pares com desenvolvimento típico.
MÉTODO Neste estudo caso-controle, 13 crianças com PC (quatro do sexo masculino, cinco do sexo feminino; média de idade [DP] 11a 4m [3a 8m]; nove no nível I segundo o Sistema de Classificação da função motora grossa [GMFCS] I, três no nível GMFCS II, e uma no nível GMFCS III) e 14 pares com desenvolvimento típico (nove do sexo masculino, cinco do sexo feminino; média de idade [DP] 9a 10m [1a 10m] caminharam no solo por 5 minutos em velocidade auto-selecionada. A frequência mediana e a média da raiz quadrada (RMS) na eletromiograpia (EMG) foram identificadas por ciclo da marcha a partir de registros de EMG do tibial anterior, gastrocnêmio medial sóleo, reto femoral e semitendinoso. A taxa de mudança nestas variáveis foi analisada usando análise de modelo linear mista.
RESULTADOS A redução da frequência mediana do gastrocnêmio medial e sóleo e o aumento na RMS-EMG do tibial anterior, gastrocnêmio medial e sóleo foram significativamente maiores na perna mais afetada de crianças com PC em comparação com os pares típicos.
INTERPRETAÇÃO A fadiga aumentada e seletiva nos músculos dos membros inferiores foi observada durante a marcha em velocidade auto-selecionada em crianças com PC moderada a severa. Isso pode contribuir para e explicar a limitada capacidade de marcha.