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The influence of maximum isometric muscle force scaling on estimated muscle forces from musculoskeletal models of children with cerebral palsy

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Highlights

- A dynamometer based maximum isometric muscle forces scaling approach was introduced
- Dynamometer based MIMF scaling approach underestimated ankle muscle strength
- Previous published MIMF scaling methods had little influence on peak muscle forces

Abstract

Background

Musculoskeletal models do not include patient-specific muscle forces but rely on a scaled generic model, with muscle forces left unscaled in most cases. However, to use musculoskeletal simulations to inform clinical decision-making in children with cerebral palsy (CP), inclusion of subject-specific muscle forces is of utmost importance in order to represent each child's compensation mechanisms introduced through muscle weakness.

Research aim

The aims of this study were to (i) evaluate if maximum isometric muscle forces (MIMF) in musculoskeletal models of children with CP can be scaled based on strength measurements obtained with a hand-held-dynamometer (HHD), (ii) evaluate the impact of the HHD based scaling approach and previously published MIMF scaling methods on computed muscle forces during gait, and (iii) compare maximum muscle forces during gait between CP and TD children.

Methods

Strength and motion capture data of six CP and motion capture data of six TD children were collected. The HHD measurements to obtain hip, knee and ankle muscle strength were simulated in OpenSim and used to modify MIMF of the 2392-OpenSim model. These muscle forces were compared to the MIMF scaled on the child's body mass and a scaling approach, which included the body mass and muscle-tendon lengths. OpenSim was used to calculate peak muscle forces during gait.

Results

Ankle muscle strength was insufficient to reproduce joint moments during walking when MIMF were scaled based on HHD. During gait, peak hip and knee extensor muscle forces were higher and peak ankle dorsi-flexor forces were lower in CP compared to TD participants.

Significance

HHD measurements can be used to scale MIMF for the hip and knee muscle groups but underestimate the force capacity of the ankle muscle groups during walking. Muscle-tendon-length and mass based scaling methods affected muscle activations but had little influence on peak muscle forces during gait.

Keywords: Muscle strength; OpenSim; Cerebral Palsy; Hand-held dynamometer; Muscle force; Scaling.

Introduction

Three-dimensional gait analysis is used in the treatment decision-making process in children with cerebral palsy (CP). Most conventional gait models are limited to joint kinematics and kinetics analysis [1]. Musculoskeletal models (e.g. OpenSim [2]) are as reliable as the conventional models in estimating joint kinematics and kinetics [3] and have the advantage of enabling additional analyses, e.g. muscle-tendon length and force estimation [4]. However, only a small number of studies have analyzed muscle forces during walking in children with CP. Hicks et al. [5] showed that crouch gait reduces the potential of several lower limb muscles to generate extension accelerations of the knee and hip. Furthermore, Steele et al. [6] showed that crouch gait relies on the same muscles as TD gait, but requires higher muscle forces compared to unimpaired gait. Both studies used a musculoskeletal model with unscaled generic maximum isometric muscle forces (MIMF). However, most musculoskeletal models are built based on data of adult specimens and, therefore, the generic MIMF may not be representative for children or a population with muscle weakness, such as in children with CP [7]. To overcome this limitation, van der Krogt et al. [8] scaled MIMF in children using the subject's body mass (M) (Eq. 1), whereas Correa and Pandy [9] developed a scaling procedure which includes M and individual muscle-tendon lengths (l_{MT}) of the scaled and generic model (Eq. 2).

$$F_{max}^{scaled} = F_{max}^{generic} \times \left(\frac{M^{scaled}}{M^{generic}}\right)^{\frac{2}{3}} \quad (1)$$

$$F_{max}^{scaled} = F_{max}^{generic} \times \frac{M^{scaled}}{M^{generic}} \times \frac{l_{MT}^{generic}}{l_{MT}^{scaled}} \quad (2)$$

F_{max}^{scaled} and $F_{max}^{generic}$ in Equation 1 and 2 are the MIMF in the scaled and generic model, respectively. Both of these approaches are rough scaling estimates and do not account for the muscle weakness, which can be very subject-specific and muscle-specific and potentially influence the estimated muscle force distribution. Scaling MIMF based on patient-specific and muscle-group-specific strength measurements could potentially overcome this limitation.

In children with CP, manual muscle testing is commonly used to quantify muscle strength of lower limb muscle groups using the five-point Medical Research Council scale [10]. This measure, however, is known to be only reliable for children who are not able to move their

limbs against gravity [11]. Hand-held dynamometers (HHD) can be used to reliable measure maximum isometric muscle strength in children with CP, especially in children who are able to move their limbs against gravity [12,13]. Scaling MIMF based on patient-specific and muscle-group-specific strength measurements, e.g. HHD measures from manual muscle testing, could potentially overcome the limitations of the previous mentioned MIMF scaling methods. However, the usefulness of HHD measures to scale MIMF in musculoskeletal models of children with CP has not been assessed so far. Furthermore, it is not known how much MIMF differ between scaling approaches and how the choice of scaling approach affects the estimation of muscle activations and forces.

Isometric muscle strength tests showed that children with CP have weaker muscles than typically developing (TD) children [14–16]. Different muscle groups can be more or less affected by muscle weakness [16,17] and muscle strength significantly differs between Gross Motor Function Classification System levels [15]. After 15 minutes of walking, a decrease in maximum isometric muscle strength was observed in adolescents with CP [18], which indicates that CP walking requires a relatively higher level of muscle activation compared to TD walking. Furthermore, isometric muscle strength could not explain standing ability in children with CP [19]. Hence, it is questionable how well maximum isometric muscle strength represents the child's muscle force capability during dynamic activities. To the authors' knowledge, no studies compared maximum muscle activations and muscle forces during walking between CP and TD children using a musculoskeletal model with scaled MIMF.

The primary aim of this study was to investigate the use of different methods to include more subject-specific MIMF in musculoskeletal models. We assessed if MIMF scaled based on HHD measurements lead to valid estimates and evaluated the impact of previously published MIMF scaling methods on simulation results. The secondary aim of this study was to compare the maximum muscle activations and muscle forces during gait between CP and TD children using a musculoskeletal model with scaled MIMF. We hypothesized that (a) HHD based scaling approach lead to valid MIMF estimates in musculoskeletal models of children with CP, and (b) MIMF and maximum muscle activations during gait differ between scaling approaches but muscle forces during gait are the same. Furthermore, based on previous research [6], we assumed that that maximum muscle activations and muscle forces during gait are higher in CP than in TD participants.

Methods

Participants

Motion capture data and strength data of six children with CP (1 girl, 5 boys, detailed participant information are in Table 1) were collected at the Clinical Motion Analysis Laboratory of the University Hospital of Pellenberg (Belgium). Additionally, motion capture data of six TD children (mean age: 9.1±1.1 years, weight: 28.8±3.8kg, height: 1.4±0.1m, 3 girls, 3 boys) was collected. Ethics approval was obtained from UZ Leuven's ethics committee.

Strength measurements in participants with CP

Assessment of hip flexor, hip extensor, hip abductor, knee flexor, knee extensor, ankle plantar-flexor and ankle dorsi-flexor muscle strength was obtained by manual muscle testing in conjunction with a HHD (MicroFET 2, Hogan Health Industries, Utah, USA). The reliability of strength measurements with a HHD in children with CP has been assessed in several previous studies, which showed overall acceptable to good reliability [12,13,20]. Thigh, shank and foot segment lengths were measured with a ruler and the HHD was placed at 75% of the relevant segment length. The maximal obtained force from three maximum voluntary isometric contraction trials together with the measured lever arm was used to calculate net joint moments for each muscle group ($Mmax\_{MVIC}$). Additionally, muscle strength was quantified using the Medical Research Council (MRC) scale [10].

Motion capturing

An extended version of the Plug-in-Gait marker set [1,21] was placed on each CP participant. The TD participants only had the standard Plug-in-Gait markers. Marker trajectories of one static and at least three walking trials at a self-selected walking speed were collected using a 10-15 camera motion capture system (Vicon Motion Systems, Oxford, UK). Simultaneously, ground reaction forces were acquired using two force plates (AMTI, Watertown, MA, USA) and electromyography (EMG) data of following muscle were collected using a 16 channel EMG-system (Zerowire, Cometa, Italy): left and right rectus femoris, vastus lateralis, biceps femoris, semitendinous, tibialis anterior, medial gastrocnemicus, soleus and gluteus medius.

Musculoskeletal modelling and MIMF scaling approaches

The 'gait2392' OpenSim model [22] was modified to allow knee ab-/adduction and internal/external rotations additionally to knee flexion/extension and was used as the reference model. This was done to have a model with similar degrees-of-freedom as the conventional clinically used gait model. Due to insufficient number of surface markers on the foot segment to track the talocrural as well as the subtalar degree-of-freedom, the subtalar joint was locked in our TD models. The model was scaled to each participant's anthropometry using scale factors derived from surface marker locations and calculated joint centers [23]. Afterwards, inverse kinematics and inverse dynamics were used to calculate joint angles and moments, respectively, using OpenSim 3.3 [2].

The three MIMF scaling approaches included in this study were:

1) The body mass (BM) scaling approach (Eq. 1).

2) The body mass muscle tendon length (BM-MTL) scaling approach (Eq. 2).

3) A dynamometer (DYN) scaling approach developed for this study. First, the generic musculoskeletal model was positioned in a pose representative for the strength measurement position for each muscle group test. Next, MIMF in the model were decreased in 5% steps until a further decrease resulted in a model that was too weak to generate $Mmax\_{MVIC}$ obtained from the HHD. To assess whether the model could generate the measured isometric moments, $Mmax\_{MVIC}$ was input to a static optimization procedure to calculate muscle forces and residual actuators (Figure 1). Small residual actuators indicated that the model could produce the measured isometric moment. The smallest MIMF that were able to generate the measured isometric moments were used as the MIMF. DYN scaling was performed using a customized MATLAB script (R2016b, The Math Works, Natick, USA).

The model's MIMF were updated with the values obtained from the different scaling approaches and static optimization was used to obtain muscle activations, muscle forces and residual actuators during gait. The secondary degrees of freedom at the knee joint (ab-/adduction, internal/external rotation) were locked during static optimization. Simulations were judged successful if the residual actuators for hip, knee and ankle flexion/extension movements and hip ab-/adduction movements did not exceed 5% of the corresponding peak joint moments [24].

Data analysis

For each participant's gait pattern, the mean of the maximum muscle activations (Amax_gait) and muscle forces (Fmax_gait) from all muscles of each analyzed muscle group was calculated. The model's MIMF, Amax_gait and Fmax_gait from the left and right leg were analyzed independently. For the primary investigations on new and published MIMF scaling methods, we evaluated the usefulness of HHD measurements for scaling MIMF indirectly by assessing if the CP models with the DYN scaled MIMF were able to generate each participant's gait motion (residual actuators smaller than 5% of the corresponding peak joint moments). This approach was chosen due to the lack of a gold standard for measuring MIMF in vivo. To investigate if there was a difference between scaling methods, we compared MIMF, Amax_gait and Fmax_gait between the different scaling methods using a repeated measure general linear model. For our secondary investigation, we compared the Amax_gait and Fmax_gait, obtained from the BM scaled MIMF models, between CP and TD participants, using a general linear model. In the case of significant interactions in the general linear models, post-hoc comparisons were performed using Bonferroni corrections. IBM SPSS Statistics 24 (IBM Corporation, New York, USA) was used for all statistical analyses and the significance level was $p<0.05$.

Results

Mmax_MVIC in children with CP

Mmax_MVIC in children with CP normalized to body mass were, on average, 0.98±0.35Nm/kg, 1.25±0.28Nm/kg, 0.74±0.20Nm/kg, 0.80±0.23Nm/kg, 0.96±0.30Nm/kg, 0.29±0.10Nm/kg and 0.20±0.09Nm/kg for hip flexor, hip extensor, hip abductor, knee flexor, knee extensor, ankle plantar-flexor and ankle dorsi-flexor muscle groups, respectively (Figure 2). Inter-trial variability of the strength measurements with the HHD was on average 12±3% of the Mmax_MVIC, ranging from 0.02Nm/kg for the ankle dorsi-flexor muscle group to 0.19Nm/kg for the hip extensor muscle group. Muscle strength of all participants was between grade 3 and 5 on the MRC scale.

Assessment of the usefulness of HHD measurements to scale MIMF

The DYN models, scaled based on the HHD measurements, were in general able to successfully generate the participants' hip and knee joint moments during gait (except for the right knee joint moment in CP01) but failed to generate the required ankle joint moments in all participants. Residual actuators were, on average, 0.8±1.0%, 0.8±0.9%, 2.8±7.2% and 42±18% of the corresponding peak joint moments for hip flexion/extension, hip ab-/adduction, knee flexion/extension and ankle plantar-/dorsiflexion movements, respectively.

Comparison of MIMF and simulation results between different scaling approaches

MIMF of the unscaled model were significantly higher ($p<0.05$) compared to all scaled models. Mean MIMF were similar between all three scaling approaches, except for the hip flexor and ankle plantar- and dorsiflexor muscle groups (Figure 3). Hip flexor MIMF were significantly higher ($p<0.01$) and ankle plantar- and dorsiflexor MIMF were significantly lower ($p<0.001$) when using DYN compared to the BW and BW-MTL approaches. MIMF were significantly different ($p<0.05$) between the BW and BW-MTL scaled models for all muscle groups but the average difference between both approaches was 0.7±0.4N/kg and, therefore, did not have any practical relevance.

During gait, muscle activation magnitudes differed between scaling approaches, but the overall activation pattern were similar and showed reasonable agreement with the EMG excitation pattern (Figure 4). Amax_gait and Fmax_gait from the DYN scaled models are not presented due to the inability of the DYN models to generate the required ankle joint moments. Fmax_gait for each analyzed muscle group were significantly different ($p<0.05$) between the unscaled, BW and BW-MTL scaled models, except for hip abductor, knee extensor and ankle plantar-flexor muscle forces between the BW and BW-MTL scaling approach (supplementary Figure A4). However, the mean differences in Fmax_gait were negligible for the comparison between the BW and BW-MTL approach (0.02±0.01N/kg) and very small for the comparison of the unscaled model with the BW and BW-MTL scaled models (0.56±0.49N/kg and 0.58±0.51N/kg respectively).

Amax_gait for each analyzed muscle group were significantly different ($p<0.05$) between the unscaled, BW and BW-MTL scaled models, except for hip abductor, knee flexor and extensor and ankle plantar-flexor muscle activations between the BW and BW-MTL scaling approach.

However, the mean difference in Amax_gait between the BW and BW-MTL approach was negligible (1.2±0.6%). Amax_gait of the BW and BW-MTL scaled models were, on average, 10.7±4.6% and 12.3±5.4% higher than in the unscaled models (supplementary Figure A5).

Comparison of Amax_gait and Fmax_gait between CP and TD participants

Amax_gait for the hip extensor, knee flexor and knee extensor muscle groups were significantly higher ($p<0.05$) in CP compared to TD participants, whereas for the ankle plantar- and dorsi-flexor muscle groups Amax_gait were significantly lower ($p<0.05$) in CP (Figure 5). Hip and knee extensor Fmax_gait were significantly higher ($p<0.05$) in CP and ankle dorsi-flexor Fmax_gait were significantly lower ($p<0.05$) in CP compared to TD participants.

Discussion

This was the first study in which strength measurements were used to scale MIMF in musculoskeletal models of children with CP. The obtained MIMFs from the DYN method were able to generate hip and knee joint moments but were unable to generate each child's ankle moments and, therefore, our first hypothesis could only be partly confirmed. Except for hip flexor and ankle plantar-/dorsi-flexor muscles, MIMF from the DYN methods were not significantly different to the BM and BM-MTL scaled MIMF, which partly contradicted our second hypothesis.

The $Mmax_{MVIC}$ obtained with the HHD in our study were very similar to previously published HHD measurements of children with CP [7]. Dallmeijer et al. [28] compared the joint moments measured with a HHD during maximum isometric contractions to those calculated during gait using inverse dynamics, and found that ankle peak moments largely exceeded the $Mmax_{MVIC}$ of the plantar flexors. Our findings confirmed their results and highlighted that isometric $Mmax_{MVIC}$ of the plantar-flexor muscles underestimated their dynamic force capacity and, therefore, should not be used to scale MIMF in musculoskeletal models. Reasons for that could be (i) the inability to activate muscle groups in isolation, (ii) co-contraction of agonist and antagonist muscles, which would result in lower net joint moments during the manual muscle testing, (iii) inability to maximally activate the muscles in the test situation and/or (iv) the passive contribution of the Achilles tendon that contributes to the net joint moments during gait, but not during the $Mmax_{MVIC}$ test. In one of our participants, the DYN scaled

MIMF failed to generate the required knee moments on the right leg, but was successful in generating the corresponding moments on the left leg. The right leg of this participant had a deficit of 25 degrees in passive knee extension range of motion and the muscles on the right leg were characterized by higher levels of spasticity than the muscles on the left leg (Table 1). Joint contractures and spasticity were not modeled in this study, which could be a reason for the observed discrepancies between both legs when using DYN.

Our assumption that MIMF differ between scaling approaches did not hold because most hip and knee MIMF were surprisingly similar between the BM, BM-MTL and DYN scaling approaches. It should be noted that some muscle groups of our CP participants were quite strong, which could be a reason why the BM-MTL scaling method, developed for TD children, showed similar results to the DYN scaling approach in our CP participants. However, the DYN method was the only scaling approach that took inter-individual and inter-muscle group differences into account, as evident in the larger deviations in MIMF compared to the other scaling approaches.

Fmax_gait obtained with the unscaled and all scaled models were very similar but Amax_gait, as expected, differed between methods. Our findings indicate that for research that mainly focuses on muscle forces contributions to motion, the scaling method does not have an impact on the simulation results as long as the model can generate the required motion. When the magnitude of muscle activation is of interest or when musculoskeletal models are used for predictive simulations (e.g. [29]), it is important to adjust MIMF to the participant's strength as good as possible. If subject-specific strength measurements are not available, either the BM or BM-MTL could be used to scale MIMF because both approaches led to successful simulations, almost identical Fmax_gait and very similar Amax_gait. However, researchers should be aware that the BM and BM-MTL scaling approaches do not account for subject-specific differences in strength between agonist and antagonist muscles, which potentially influences the muscle force contribution to motion.

Peak hip and knee extensor activations and forces were higher in CP and peak ankle dorsi-flexor activations and forces were lower in CP when compared to TD participants, which partly confirmed the assumption of our secondary objective and is in agreement with previous findings [6,25]. Interestingly, except of the ankle dorsi-flexor muscle group, Fmax_gait were similar or higher in CP when compared to TD participants, although isometric muscle strength

tests showed that children with CP have weaker muscles than TD children [14,15]. This might be due to limited selective motor control in children with CP, which could lead to an underestimation of muscle strength during isometric tests. Additionally, considering that CP children have shorter muscles than TD children [26], the posture during the isometric strength test may influence the results. An isokinetic test situation provides information on the whole muscle force-length curve and might show different results. Furthermore, TD gait is more efficient and therefore needs lower joint moments, lower muscle activations and lower muscle forces compared to CP gait [27].

This study has some limitations. First, we only had a small number of participants with CP, who all walked with an increased knee flexion angle. Considering the large variability in CP gait, we cannot draw broad conclusions for the general CP population with our findings. Future studies should therefore assess muscles forces in a larger participant pool, including sub-groups with different CP gait characteristics. Second, our models were created by scaling a generic model, which does not account for subject-specific bony deformities. Correa et al. [30] compared scaled-generic with MRI-based models and found similar muscle functions between both models in CP children. Therefore, we expect to observe similar results with medical-image based models. Third, we did not account for abnormal muscle control. However, the muscle activations from our simulation showed a reasonable agreement with the measured EMG activations. Fourth, relative differences in MIMF of agonistic muscles was not accounted for by any of the evaluated scaling approaches. Fifth, we could not assess the accuracy of scaling approaches on an individual muscle level due to the absence of a gold standard to measure individual MIMF. Sixth, considering that the MIMF and muscle activation are two equivalent gain settings (as one goes up the other goes down) and we did not have a gold standard for neither of the two measurements, it is impossible to judge which one is more likely to be correct. Seventh, other muscle parameters, e.g. tendon slack length or optimal fiber length, might be different in CP children compared to the generic model and could have influenced our findings.

Summarizing, our results showed that (i) HHD measurements can be used to scale MIMF for the hip and knee muscle groups but underestimate the force capacity of the ankle muscle groups during walking, (ii) different scaling methods lead to different Amax_gait but similar Fmax_gait, and (iii) our CP participants walked with larger hip and knee extensor Fmax_gait

but lower ankle dorsi-flexor Fmax_gait compared to our TD participants. If no subject-specific strength measurements are available, MIMF in musculoskeletal models of CP participants with muscle strength between 3 and 5 on the MRC scale should be scaled with either the BM or BM-MTL method, as both approaches led to very similar simulation results, and MIMF for hip and knee muscle groups were, except for the hip flexor muscle group, similar to the DYN method.

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Figure legends

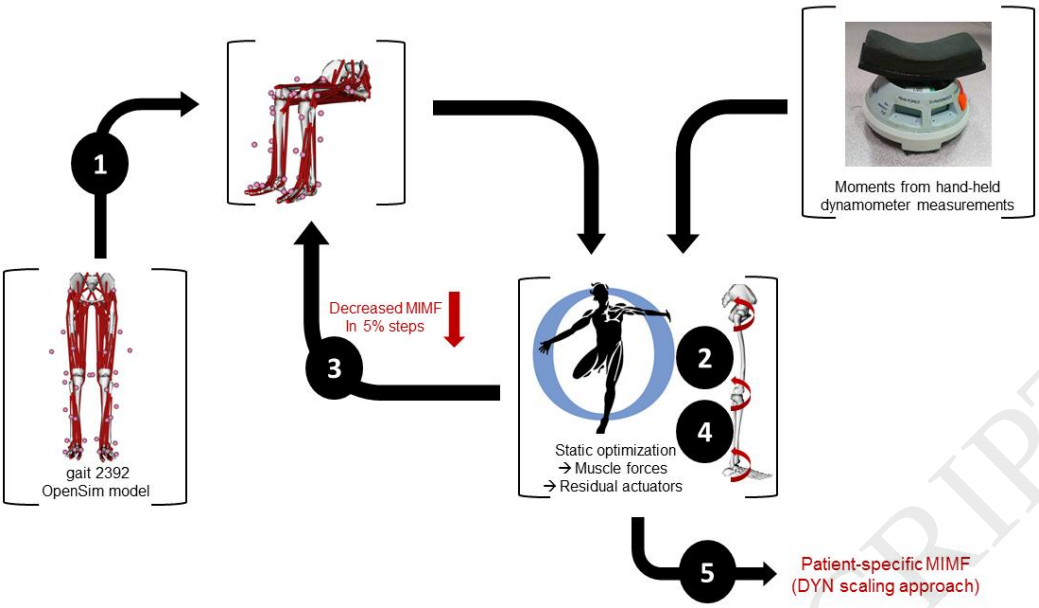
Figure 1. Schematic illustration of the dynamometer (DYN) scaling approach. First, the musculoskeletal model was positioned in the pose representative for the strength assessment position for each muscle group test (1). Using the moments from the hand-held dynamometer (Mmax_MVIC) as input, a static optimization procedure was used to calculate muscle forces and residual actuators (2). Next, the maximum isometric muscle forces (MIMF) for each muscle group in the original musculoskeletal model were iteratively decreased in 5% steps (3) until the model became incapable to generate the Mmax_MVIC (4), i.e. residual actuators reached 5% of the corresponding peak joint moments [23]. The smallest MIMF that were able to generate the motion were used as the MIMF (5). For bi-articular muscles (e.g. gastrocnemius) used in more than one test, the maximum value from all tests was chosen as the MIMF.

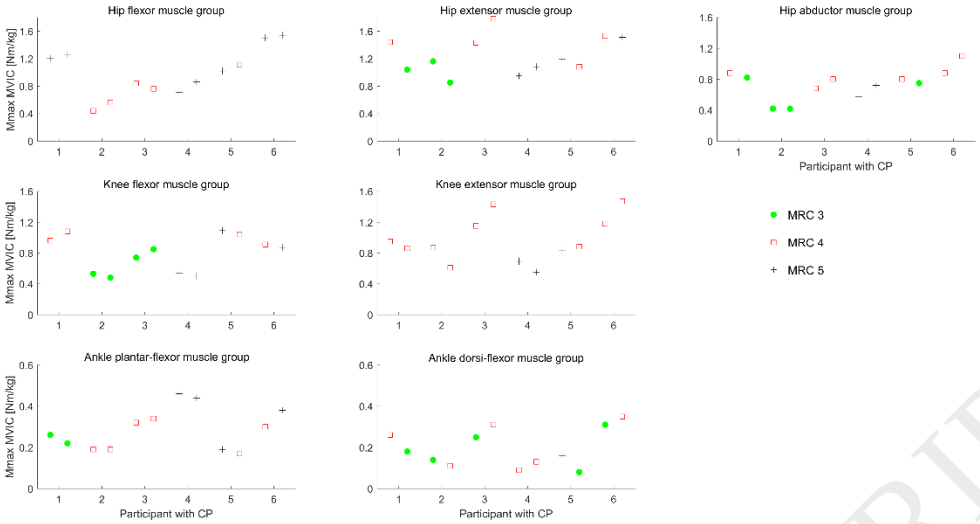
Figure 2. Maximum moments obtained from the strength measurements with the hand-held dynamometer (Mmax MVIC) for each muscle group, each leg and all participants with CP. Moments were normalized to body mass. Note the difference in muscle strength between the left and right side in some participants (e.g. hip extensor strength in CP 01) as well as the relationship to the MRC scales (e.g. knee flexor Mmax MVIC between the left and right leg in participant CP 06 were almost identical but the MRC score differed between both legs).

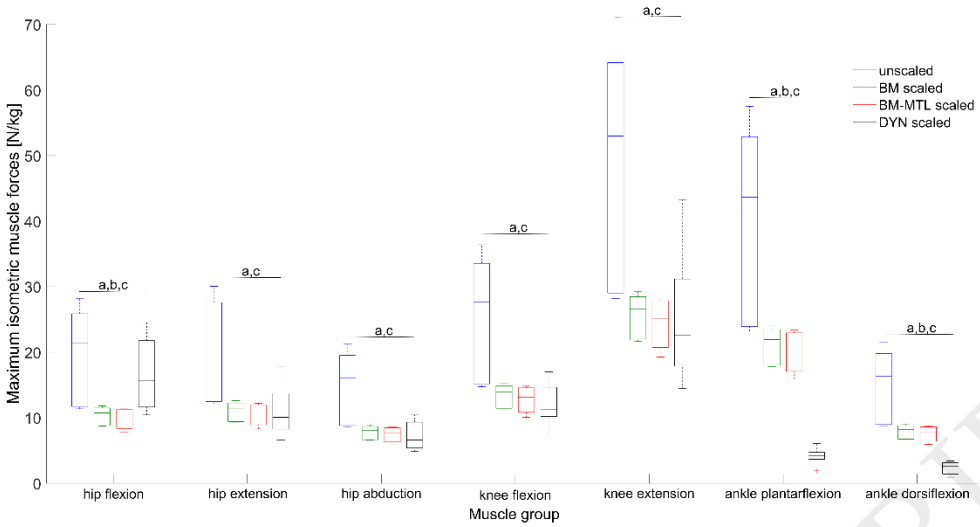
Figure 3. Boxplot of the maximum isometric muscle forces (MIMF) obtained from the three scaling approaches (BM, BM-MTL, DYN) and the model with unscaled MIMF. MIMF are shown normalized to body weight. a = significant differences ($p<0.05$) in MIMF between the unscaled model and the BM, BM-MTL and DYN scaled models. b = significant differences ($p<0.05$) in MIMF between the DYN scaled model and the BM and BM-MTL scaled models. c = significant differences ($p<0.05$) in MIMF between the BM and BM-MTL scaled models.

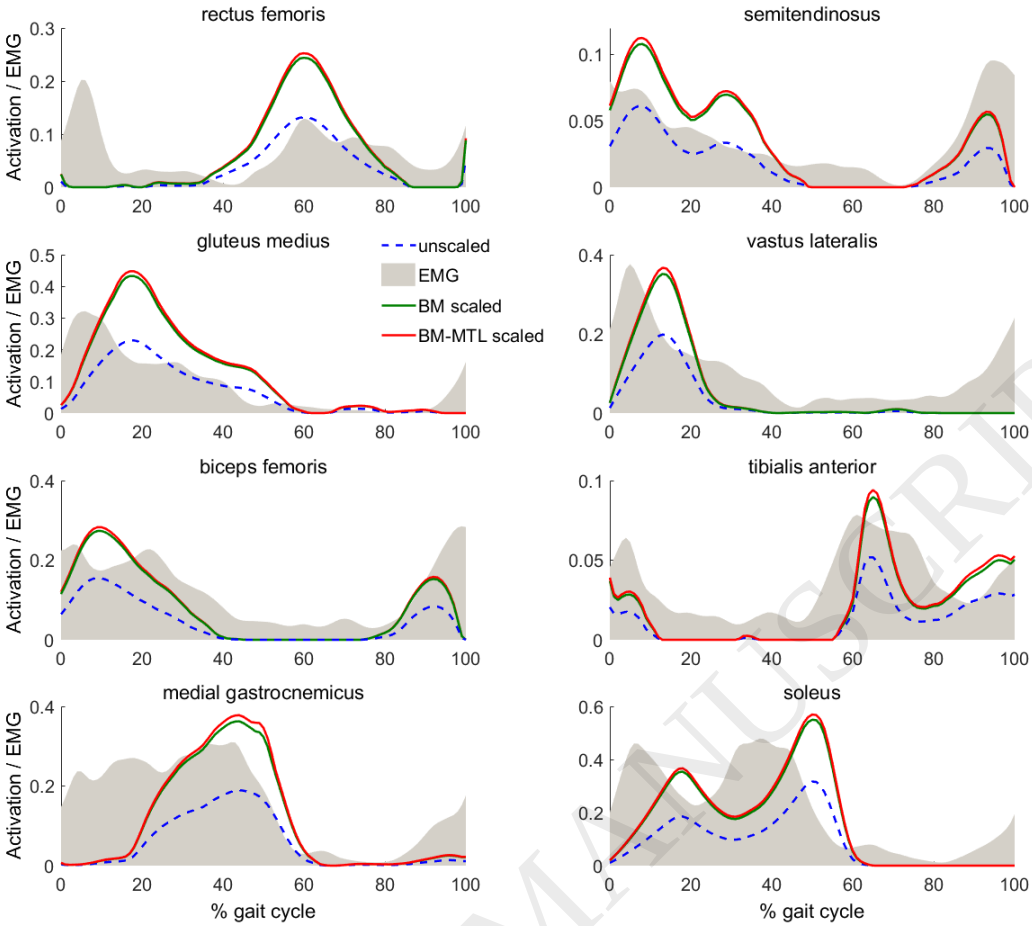
Figure 4. Muscle activations obtained from the unscaled, BM and BM-MTL scaled models and experimentally measured electromyography (EMG) excitations averaged over all participants with CP and normalized to one gait cycle.

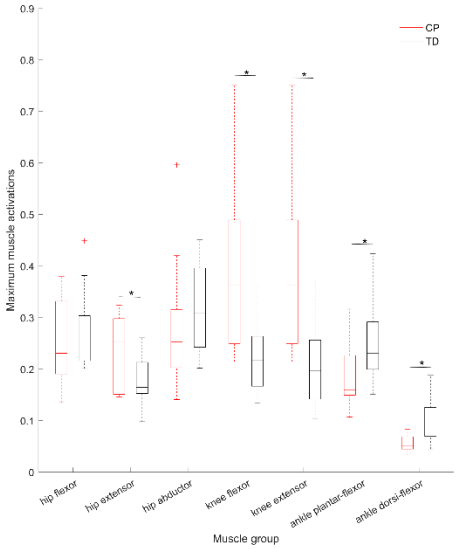
Figure 5. Boxplot of the maximum muscle activations (Amax_gait) and maximum muscle forces (Fmax_gait) observed during gait in CP and TD participants. Maximum muscle forces are shown normalized to body mass. The BM scaled models were used to obtain the muscle activations and muscle forces. * indicates significant differences ($p<0.05$) between CP and TD participants.











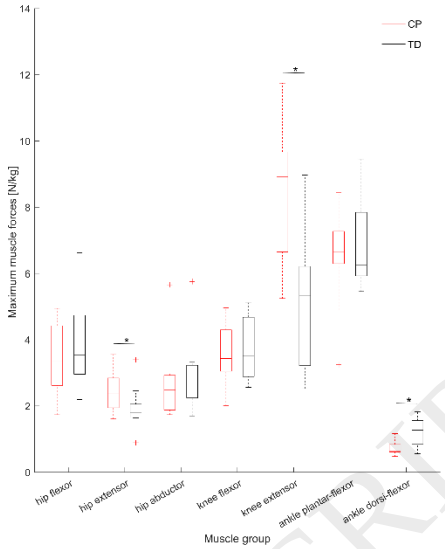


Table 1. Detailed CP participant information including clinical measurement results. Spasticity was graded with the Modified Ashworth Scale. All passive range of motion measurements were performed in supine. Abbreviations in alphabetic order: GMFCS = Gross Motor Function Classification System; N.M. not measured; R = right; 0^0 = zero degrees of knee flexion (full extension); 90^0 = ninety degrees of knee flexion.

Participant information	**CP 01**	**CP 02**	**CP 03**	**CP 04**	**CP 05**	**CP 06**
Age [years]	15.93	9.31	7.77	6.51	11.71	6.47
Weight [kilogram]	49.1	32.6	20.4	22.2	50.6	22.9
Height [meters]	1.71	1.23	1.16	1.20	1.57	1.23
Diagnosis	Diplegic	Diplegic	Diplegic	Diplegic	Hemiplegic R	Diplegic
GMFCS	I	II	II	I	I	I
Passive range of motion [degrees]						
Hip flexion right	110	110	130	115	130	115
Hip flexion left	105	105	115	120	115	120
Hip extension right	-10	0	0	0	0	0
Hip extension left	0	-5	0	0	0	0
Knee flexion right	150	150	140	145	140	140
Knee flexion left	160	150	145	150	140	150
Knee extension right	-25	0	10	0	0	0
Knee extension left	10	0	10	5	0	0
Plantar flexion right 0^0	20	50	50	35	35	60
Plantar flexion left 0^0	10	50	50	40	45	50
Dorsiflexion right 0^0	-20	10	20	-5	-5	10
Dorsiflexion left 0^0	10	5	20	5	10	5
Spasticity						
Hip flexors right	2	1+	0	0	0	0
Hip flexors left	1+	1+	0	1	0	0
Knee flexors right	2	3	0	2	1+	1
Knee flexors left	1+	3	1+	2	1	1+
Knee extensors right	0	1	1	N.M.	0	0
Knee extensors left	1+	1	1	N.M.	0	0
Plantar flexors right 0^0	3	3	0	3	2	1+
Plantar flexors left 0^0	3	3	1	2	0	1+
Selective motor control [29]						
Hip flexion right	2	2	2	2	2	2
Hip flexion left	2	2	2	2	2	2
Hip extension right	1.5	1.5	1.5	2	2	2
Hip extension left	2	1.5	1.5	2	2	2
Hip abduction right	2	1.5	2	2	1.5	2
Hip abduction left	2	1.5	2	2	2	2
Knee extension right	1.5	1.5	2	2	2	2
Knee extension left	1.5	1.5	2	2	2	2
Knee flexion right	1.5	1.5	1.5	2	2	2
Knee flexion left	1.5	1.5	1.5	2	2	2
Dorsiflexion right 90^0	1.5	1.5	2	2	1.5	2
Dorsiflexion left 90^0	1.5	1.5	2	1.5	2	1.5
Plantarflexion right 90^0	1.5	1.5	1.5	2	2	2
Plantar flexion left 90^0	1.5	1.5	1.5	2	2	2