

ORIGINAL RESEARCH

Longitudinal Association Between Gross Motor Capacity and Neuromusculoskeletal Function in Children and Youth With Cerebral Palsy



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Abstract

Objective: To examine associations over longitudinal measurements between neuromusculoskeletal function and gross motor capacity in children and youth with cerebral palsy (CP).

Design: A prospective cohort study.

Setting: Rehabilitation departments of university medical centers and rehabilitations centers.

Participants: A sample (N=327) consisting of 148 children (aged 5–9y) and 179 youth (aged 11–20y) with CP, Gross Motor Function Classification System level I (n=180), level II (n=44), level III (n=36), level IV (n=34), and level V (n=33).

Interventions: Not applicable.

Main Outcome Measures: Gross motor capacity was assessed with the Gross Motor Function Measure-66 over a period of 2 to 4 years in different age cohorts. Neuromusculoskeletal function included selective motor control (SMC), muscle strength, spasticity, and range of motion (ROM) of the lower extremities.

Results: Multilevel analyses showed that SMC was significantly associated with gross motor capacity in children and youth with CP, showing higher values and a more favorable course of gross motor capacity in those with better SMC. Strength was only associated with gross motor capacity in youth. Reduced ROM of hip (children) and knee extension (youth) and spasticity of the hip adductors (youth) were additionally—but more weakly—associated with lower values and a less favorable course of gross motor capacity.

Conclusions: Results indicate that children and youth with more severely impaired SMC and youth with reduced muscle strength have a less favorable course of gross motor capacity, while spasticity and reduced ROM are less determinative.

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Cerebral palsy (CP) is the most common physical disability in pediatrics. Although CP is due to a nonprogressive lesion in the developing brain, the children's capacity to execute daily activities is unstable over time. It has been shown that their gross motor development, as assessed by the Gross Motor Function

Measure-66 (GMFM-66), is delayed in children with CP^{1,2} and can be predicted by the severity of CP.³

To match rehabilitation of individuals with CP to their individual needs, research has focused on describing the course of gross motor capacity. Patterns of gross motor development have been described by CP severity (using 5-level Gross Motor Function Classification System [GMFCS]) on the basis of longitudinal data for Canadian children and young adults (aged 1–21y).^{3–5} Individuals capable of walking without mobility devices (GMFCS levels I–II) show a rapid development during infancy, with a plateau at the age of 5. For individuals in need of assistive devices for mobility (GMFCS levels III–V), lower levels of gross motor capacity are found and gross motor capacity may deteriorate after a peak has been reached at the age of ~3.^{1,5}

We recently validated the gross motor development curves created by the Canadian study group for the Dutch population, confirming distinctive curves for the 5 GMFCS levels.² However, deterioration of gross motor capacity in individuals functioning at GMFCS levels III to V was not confirmed in the Dutch population.²

Even though the GMFCS level is strongly associated with gross motor capacity (83% and 87% of the explained variance),^{6,7} it explained only 9% of the variance of *changes* in gross motor capacity over a period of 1 year in children with CP.⁸ Clinically, limitations in gross motor capacity may be associated with underlying impairments in neuromusculoskeletal function, an observation supported by recent research in young children with CP.^{8,9} These impairments include reduction in range of motion (ROM) of the joints, spasticity of the large muscle groups, impaired selective motor control (SMC), and reduced muscle strength. Information on the associations over *longitudinal* measurements also takes *changes* in neuromusculoskeletal function and gross motor capacity into account, which is helpful for describing expected outcomes of medical treatments such as botulinum toxin and other therapies. Medical treatment is often targeted at the level of body function and structure, while the focus of rehabilitation is usually at the level of activities. Understanding the association between changing (improving) neuromusculoskeletal function and gross motor capacity is therefore important to clinicians.

A retrospective cross-sectional study¹⁰ has found that muscle strength, and to a lesser extent spasticity of the hip adductors, is related to gross motor capacity in children with spastic bilateral CP. Another cross-sectional study¹¹ found an association of spasticity, reduction in leg ROM (composition score of 10 joints), and SMC with gross motor capacity. The multivariable analysis¹¹ showed that SMC was the strongest associated factor of the included musculoskeletal functions.

The association over longitudinal measurements of impairments in neuromusculoskeletal function and gross motor capacity has only been assessed in adolescents with CP.^{3,12} A Canadian study³ found that the deterioration of gross motor capacity in

adolescents at GMFCS levels III to V was associated with limitations in ROM. However, the association of other potentially important neuromusculoskeletal functions such as SMC and muscle strength was not analyzed. In one¹² of our previous studies in adolescents (aged 9–13y), we found that SMC was most strongly associated with the course of gross motor capacity over a period of 2 years. However, the associations over longitudinal measurements between neuromusculoskeletal function and gross motor capacity have not yet been studied in individuals over a larger age range, including children, adolescents, and young adults.

The aim of the present study was to examine the associations over longitudinal measurements between neuromusculoskeletal function and gross motor capacity over a large age range in participants with CP, including children (aged 5–9y) and youth (aged 11–20y).

Methods

Design and participants

This study was performed as part of the PEdiatric Rehabilitation Research In the Netherlands (PERRIN) research program, a prospective longitudinal research program on the daily functioning of Dutch children, adolescents, and young adults with CP. Participants were recruited between 2002 and 2007 at the rehabilitation departments of 3 university medical centers and at rehabilitation centers. Individuals with a clinical diagnosis of CP were eligible. They were excluded when diagnosed with additional diseases or disorders affecting gross motor capacity and when they or their caregiver lacked a basic knowledge of the Dutch language. More detail of the recruitment process has been described elsewhere.^{12–14} The data were collected in 3 age cohort studies in the PERRIN research program: a cohort with children with CP, aged 5 and 7 years at baseline and followed yearly for 2 years (PERRIN5-9, n=116); a cohort with adolescents with CP, aged 9, 11, and 13 years at baseline and followed yearly for 3 years (PERRIN9-16, n=108); and a cohort with young adults with CP, aged between 16 and 20 years at baseline and measured biyearly over 4 years (PERRIN16-24, n=103). As a result, an age range of 5 to 24 years was covered. After first merging the date of the original 3 age cohorts, for the analysis of the present study data were regrouped by children (5–9y at baseline, n=148) and youth (11–20y at baseline, n=179). Data on the longitudinal associations between neuromusculoskeletal function and gross motor capacity over the first 2 years of the PERRIN9-16 cohort study have been published previously.¹² In the PERRIN16-24 cohort study, individuals with an intellectual disability (IQ<70) were excluded because the measurement instruments were unsuitable for this group.¹³ Informed consent was obtained from each participant and/or their parents or formal caregiver. Ethical approval for the study was obtained from the medical ethics committees of each participating center. Assessments were performed by a limited number of physical therapists or researchers who were trained in administering the tests and physical examination in each cohort by using standardized measurement protocols.

Measures

Gross motor capacity

Gross motor capacity was measured using the GMFM-66. The GMFM-66 is a standardized observational instrument designed to

List of abbreviations:

CP	cerebral palsy
GMFCS	Gross Motor Function Classification System
GMFM-66	Gross Motor Function Measure-66
PERRIN	PEdiatric Rehabilitation Research In the Netherlands
ROM	range of motion
SAROMM	Spinal Alignment and Range of Motion Measure
SMC	selective motor control

measure gross motor capacity in children and youth with CP.¹⁵ The GMFM-66 was measured without the use of mobility aids or orthoses. The interval score ranges from 0 (lowest mobility capacity) to 100 (highest mobility capacity).¹⁶

CP characteristics

The condition of the participants was classified by GMFCS levels I to V,⁶ type of motor impairment (spastic, dyskinetic, ataxic CP), and, within the spastic CP group, limb distribution (unilateral or bilateral CP).¹⁷

Neuromusculoskeletal function

The associated factors in the present study at the level of “body function and structure”¹⁸ were SMC, muscle strength, spasticity, and ROM of leg joints. SMC was measured only at the first measurement occasion, whereas the other neuromusculoskeletal functions were measured at all measurement occasions.

SMC is the ability to move an individual joint independently from posture and other joint movements in the same limb. To assess SMC, the children were asked to perform dorsiflexion of the ankle and extension of the knee of each leg in the sitting position on an examination table (ie, without support of the feet), while the occurrence of synergistic movements in the other joints was observed.¹⁹ When full selective movement was observed (ie, completely isolated movement), a score of 2 was assigned; when a partially isolated movement was seen (isolated movement only at the beginning of the movement), a score of 1 was assigned; and when only synergistic movement was observed, a score of 0 (ie, no selective movement) was assigned. This method has shown moderate to good interrater reliability.¹⁴ The scores of the left and right sides and both ankle and knee tests were summed, giving a score ranging between 0 and 8, which was subdivided into 3 categories: poor SMC (score 0–2), moderate SMC (score 3–5), and good SMC (score 6–8).¹²

Muscle strength was functionally measured on the basis of the ability to perform 8 squats. From a standing position, participants were asked to squat 8 times. If a participant was able to squat 8 times, leg muscle strength was categorized as “good” (score 2). In participants who were able to squat 1 to 7 times, muscle strength was categorized as “moderate” (score 1), and if they were not able to squat, their muscle strength was categorized as “poor” (score 0).¹² Support for balance was allowed, without supporting the actual upward squat movement.

Spasticity was clinically measured at both legs in all individuals (ie, also in those with unilateral involvement) as an increase in muscle tone, resulting in a catch or clonus, blocking further movement, during fast velocity stretch (<1s) in the hamstrings, hip adductors, gastrocnemius, and rectus femoris.²⁰ Hamstrings, hip adductors, and gastrocnemius muscles were measured in the supine position and spasticity of the rectus femoris in the prone position. This dichotomous outcome measure was used because previous studies showed that measuring the “angle of the catch” showed low reliability.^{20,21} For each muscle group, it was determined whether spasticity (ie, catch or clonus) was present or not. Subsequently, scores were defined as 2 when no spasticity was found in both legs, score 1 was given if spasticity was found in 1 leg, and score 0 was given for spasticity in both legs.

ROM was measured at both legs as joint angle using goniometry for hip extension (Thomas test),²² knee extension, and ankle dorsiflexion (with knees extended) in the supine position and hip exorotation (with knees flexed) in the prone position. Cutoff points for reduced ROM for each leg joint were based on the Spinal Alignment and Range of Motion Measure (SAROMM)

guidelines.²³ ROM was dichotomized as “good ROM,” including the full ROM or mildly impaired SAROMM categories, and as “impaired ROM,” including the moderate and severe SAROMM categories (table 1). Scores were defined as 2 for no restricted ROM in 2 legs, score 1 was given for reduced ROM in 1 leg, and score 0 was given for reduced ROM in both legs. The same procedure was used for individuals with bilateral and unilateral involvement.

Statistics

To analyze the longitudinal relation between neuromusculoskeletal function and gross motor capacity, multilevel analyses were performed using MLwiN software (version 2.21).^a This analysis considers the dependency of repeated measures within 1 person and allows for a variable number of observations per person.²⁴ To take into account that data from different age cohorts were combined, with repeated measures within the same person, 3 levels were defined: repeated observations (level 1) were clustered within persons and persons (level 2) were clustered within age cohorts (level 3). The analyses were done separately for children and youth. SMC (good, moderate, or poor), muscle strength (good, moderate, or poor), spasticity (no, 1, or both legs affected), and ROM (no, 1, or both legs affected) were analyzed as ordinal variables using dummy variables (ie, separate independent variables for each variable category), with the category with the least impairment as the reference category. GMFM-66 was the dependent variable, and SMC at baseline (time-independent variable) and muscle strength, spasticity, and ROM (as time-dependent variables) were included in the model as potential associated factors in addition to age. Age was included in all the models both as linear (age) and squared (age²) variable. First, initial analyses were done with each of the neuromusculoskeletal function variables (SMC, muscle strength, ROM: hip extension, hip exorotation, knee extension, ankle dorsiflexion, spasticity: hip adductors, rectus femoris, hamstrings, gastrocnemius) added to the model separately, in addition to age. Second, to determine which of these variables were significantly associated with the GMFM-66 in the multivariable model, the neuromusculoskeletal function variables with an association with $P < .1$ in the initial analyses were combined in a multivariable analysis. A backward selection procedure with $P < .05$ was used to create the final model with only significant neuromusculoskeletal function variables.

Results

The complete data set contained 973 observations on 148 children and 179 youth, including all GMFCS levels. Baseline characteristics of the children and youth are summarized in table 2. The

Table 1 Spinal Alignment and Range of Motion Measure

SAROMM	Full ROM (deg)	Impaired ROM (deg)		
		Mild	Moderate	Severe
Knee extension	Neutral extension	0 to 10	−10 to −20	>−20
Hip extension (Thomas test)	≥0	Neutral to 15	15 to 30	>30
Hip exorotation	≥45	30 to 45	15 to 30	<15
Ankle dorsiflexion	≥15	5 to 15	−10 to 5	>−10

Table 2 Baseline characteristics of children and youth

Characteristic	Children (5–9y at Baseline) (n = 148)	Youth (11–20y at Baseline) (n = 179)
Age at baseline (y)	6.9±1.5	15.8±3.4
Sex		
Boys	96 (65)	109 (61)
Girls	52 (35)	70 (39)
GMFCS		
Level I	71 (48)	107 (60)
Level II	23 (16)	22 (12)
Level III	23 (16)	14 (8)
Level IV	13 (9)	21 (12)
Level V	18 (12)	15 (8)
Subtype		
Spastic	125 (84)	150 (84)
Unilateral	54 (36)	68 (38)
Bilateral	71 (48)	82 (46)
Dyskinetic	17 (11)	25 (14)
Ataxic	6 (4)	4 (2)
GMFM-66		
GMFCS level I	83.2±7.4	91.5±7.8
GMFCS level II	67.7±5.6	74.0±6.5
GMFCS level III	55.0±5.9	60.8±6.9
GMFCS level IV	42.5±6.7	41.9±11.1
GMFCS level V	19.9±7.9	24.9±8.2
SMC		
Good	69 (47)	107 (60)
Moderate	28 (19)	28 (16)
Poor	45 (30)	42 (23)
Missing	6 (4)	2 (1)
Strength		
Good	84 (57)	117 (65)
Moderate	19 (13)	14 (8)
Poor	36 (24)	41 (23)
Missing	9 (6)	7 (4)
ROM hip extension		
No side	95 (64)	92 (51)
1 side	9 (6)	21 (12)
Both sides	31 (21)	63 (35)
Missing	13 (9)	3 (2)
ROM hip exorotation		
No side	121 (82)	105 (59)
1 side	9 (6)	43 (24)
Both sides	14 (9)	28 (16)
Missing	4 (3)	3 (2)
ROM knee extension		
No side	122 (82)	136 (76)
1 side	5 (3)	12 (7)
Both sides	17 (11)	30 (17)
Missing	4 (3)	1 (1)
ROM ankle dorsiflexion		
No side	24 (16)	18 (10)
1 side	48 (32)	50 (28)
Both sides	72 (49)	107 (60)
Missing	4 (3)	4 (2)
Spasticity hip adductors		
No side	67 (45)	55 (31)
1 side	8 (5)	12 (7)

(continued)

Table 2 (continued)

Characteristic	Children (5–9y at Baseline) (n = 148)	Youth (11–20y at Baseline) (n = 179)
Both sides	60 (41)	95 (53)
Missing	13 (9)	17 (9)
Spasticity rectus femoris		
No side	95 (64)	78 (44)
1 side	14 (9)	35 (20)
Both sides	29 (20)	49 (27)
Missing	10 (7)	17 (9)
Spasticity hamstrings		
No side	81 (55)	51 (28)
1 side	22 (15)	33 (18)
Both sides	36 (24)	76 (42)
Missing	9 (6)	19 (11)
Spasticity gastrocnemius		
No side	31 (21)	30 (17)
1 side	30 (20)	36 (20)
Both sides	77 (52)	97 (54)
Missing	10 (7)	16 (9)

NOTE. Values are mean ± SD or n (%).

observed data of the GMFM-66 for each age cohort and measurement occasion are presented in [table 3](#). Missing values for the neuromusculoskeletal function variables over all available measurements were <5% for SMC, strength, and ROM variables and <10% for the spasticity variables.

The regression coefficients of the separate models for each of the associated factors with gross motor capacity for the children and youth are presented in [table 4](#). The results of the final multivariable models are presented in [table 5](#). The analyses showed that SMC was significantly associated with GMFM-66 scores in both children and youth, showing higher values and more gain in individuals with good SMC compared with those with more severely affected SMC. A similar relation between GMFM-66 and SMC was found in children (regression coefficients [SE] for poor SMC: −42.1 [2.8]; moderate SMC: −9.5 [3.3], with good SMC as the reference category) and youth (for poor SMC: −36.0 [2.5]; moderate SMC: −11.2 [2.4]). Muscle strength was significantly associated with GMFM-66 scores in youth, but not in children. Higher GMFM-66 scores and larger increases were found in youth with good strength than in those with poor strength.

Weaker associations with gross motor capacity were found for ROM of hip extension in children and for ROM of knee extension and spasticity of the hip adductors in youth (see [table 5](#)).

Discussion

In this study, we investigated the associations over longitudinal measurements between neuromusculoskeletal function and gross motor capacity in both children and youth with CP across all GMFCS levels. Our results revealed that SMC shows the strongest association with the course of gross motor capacity in both children and youth. When SMC was taken into account, the association between muscle strength and gross motor capacity was significant only in youth. This indicates that the least favorable GMFM-66 scores were found for those with poor SMC or

Table 3 GMFM-66 scores for each age cohort and measurement occasion

Variable	Measurement Occasion									
	Baseline		Year 1		Year 2		Year 3		Year 4	
	n	Mean \pm SD	n	Mean \pm SD	n	Mean \pm SD	n	Mean \pm SD	n	Mean \pm SD
Age at baseline: 5 or 7y										
GMFCS level I	55	81.4 \pm 6.9	49	84.7 \pm 7.6	50	87.1 \pm 6.8		NA		NA
GMFCS level II	20	66.7 \pm 5.2	17	69.6 \pm 7.4	18	72.1 \pm 6.7		NA		NA
GMFCS level III	17	55.4 \pm 6.0	15	57.7 \pm 6.2	17	59.4 \pm 6.3		NA		NA
GMFCS level IV	9	44.2 \pm 6.1	8	44.7 \pm 7.9	8	43.9 \pm 9.2		NA		NA
GMFCS level V	14	21.2 \pm 6.7	13	20.2 \pm 7.7	12	19.8 \pm 6.1		NA		NA
Age at baseline: 9, 11, or 13y										
GMFCS level I	49	90.4 \pm 5.9	48	91.5 \pm 6.6	46	92.4 \pm 6.3	46	92.1 \pm 7.1		NA
GMFCS level II	15	76.7 \pm 6.4	14	76.9 \pm 7.2	12	79.1 \pm 6.6	9	76.4 \pm 7.4		NA
GMFCS level III	13	58.9 \pm 7.8	10	60.9 \pm 7.6	10	59.8 \pm 7.4	10	60.5 \pm 7.8		NA
GMFCS level IV	13	41.1 \pm 6.9	12	40.3 \pm 8.1	11	39.1 \pm 9.6	11	40.4 \pm 9.8		NA
GMFCS level V	18	23.3 \pm 9.5	18	23.4 \pm 8.8	18	23.3 \pm 8.4	17	23.7 \pm 7.6		NA
Age at baseline: 16–20y										
GMFCS level I	75	91.8 \pm 8.4		NA	62	91.6 \pm 8.7		NA	50	91.0 \pm 11.1
GMFCS level II	9	69.9 \pm 3.1		NA	8	70.3 \pm 4.8		NA	7	69.5 \pm 6.3
GMFCS level III	6	59.9 \pm 5.7		NA	4	65.3 \pm 6.7		NA	4	63.2 \pm 6.8
GMFCS level IV	12	42.5 \pm 6.7		NA	8	42.4 \pm 8.9		NA	4	42.4 \pm 8.9
GMFCS level V	1	16.0 \pm 0.0		NA	1	19.7 \pm 0.0		NA		NA

Abbreviation: NA, not applicable.

strength. Besides SMC and muscle strength, reduction in ROM of the hip extension (children) and in ROM of the knee extension and spasticity of the hip adductors (youth) were additionally—but more weakly—associated with less favorable gross motor capacity. These findings indicate that children with reduced hip ROM and youth with reduced knee ROM and spasticity in hip adductors have lower GMFM-66 values and a less favorable course of gross motor capacity than do individuals with milder impairments. The other ROM and spasticity variables showed no significant associations with GMFM-66 in the multivariable model. As expected, gross motor capacity was dependent on age in children but not in youth. Children increased their physical capacity over time, and the significant negative regression coefficient of age² indicates that this increase is smaller in older children. For youth with CP, gross motor capacity remained *on average* stable over time, but the results indicate that those with more severe impairments are more prone to low values or an unfavorable course.

This was the first study that analyzed the association between neuromusculoskeletal function and gross motor capacity in a longitudinal design over a large age range covering childhood, adolescence, and young adulthood. The present findings are in agreement with previous cross-sectional studies in (young) children, reporting that SMC¹¹ or strength¹⁰ was more strongly related to gross motor capacity than were spasticity^{10,11} and ROM.¹¹ These studies also showed that although cross-sectional associations with gross motor capacity were found for both spasticity and ROM, their contribution was not substantial when SMC or strength were considered in a multivariable model. The important effect of SMC on gross motor capacity is also in agreement with our previous findings in a subcohort of the present study that included adolescents in the age range of 9 to 16 years.¹² One other study in adolescents found that a deterioration of gross motor capacity in adolescents functioning at GMFCS levels III to V was associated with reduced ROM, but it did not analyze the association with SMC or muscle strength. In fact, the results of the

present longitudinal study that SMC is a stronger predictor of gross motor capacity show that our earlier published findings in adolescents¹² also apply to younger children and young adults. Although research on the variability and/or trainability of SMC is in its infancy, recent advances in SMC assessment and positive effects of training may be promising for future development of treatment strategies to improve SMC in children with CP.^{25,26}

The stronger association between muscle strength and gross motor capacity in youth than in children might be the result of the natural gain in body weight in combination with reduced strength due to a less physically active lifestyle during young adolescence. The present results indicate that improving or maintaining muscle strength may be important for preservation of gross motor capacity into adolescence and young adulthood. This might especially be true for those with more severe impairments because it should be kept in mind that in the present study individuals older than 16 years with intellectual disability and often more severe GMFCS levels were excluded. The trainability of muscle strength and the importance of adequate muscle strength levels for individuals with CP have been shown in several recent publications.²⁷

Study limitations

Some limitations of the present study should be considered. First, although SMC appeared to be the most important determinant of gross motor capacity, SMC was available only for the first measurement occasion and was therefore included as a time-independent variable. We showed that the course of GMFM-66 is less favorable in children with more impairments in SMC, but at present it is unknown to what extent SMC varies over time and whether this will affect the course of gross motor capacity. The variability in SMC over time and its trainability and effect on gross motor development need future research. Second, we used an indirect measure for lower extremity muscle strength, the ability to squat 8 times, which may also be affected by other impairments. As

Table 4 Results of the initial analyses showing separate models to determine the longitudinal association between each neuro-musculoskeletal function variable (in addition to age and age²) and gross motor function (GMFM) in children and youth with CP

Associated Factor	Children (n = 148)	P	Youth (n = 179)	P
Model 1: SMC				
Intercept	55.97 (4.09)	<.01	86.58 (6.60)	<.01
Age (y)	5.35 (0.86)	<.01	0.21 (0.71)	NS
Age ²	-0.24 (0.05)	<.01	-0.05 (0.02)	NS
SMC				
Good	0 (ref)		0 (ref)	
Moderate	-9.87 (3.24)	<.01	-12.88 (2.87)	<.01
Poor	-42.92 (2.78)	<.01	-47.61 (2.48)	<.01
Model 2: strength				
Intercept	39.53 (4.37)	<.01	72.89 (6.91)	<.01
Age (y)	5.67 (0.91)	<.01	0.47 (0.75)	NS
Age ²	-0.252 (0.051)	<.01	-0.01 (0.02)	NS
Strength				
Good	0 (ref)		0 (ref)	
Moderate	0.26 (0.83)	NS	-4.55 (1.17)	<.01
Poor	-3.70 (1.48)	<.05	-14.45 (1.71)	<.01
Model 3a: ROM				
Intercept	38.96 (4.30)	<.01	70.09 (6.95)	<.01
Age (y)	5.66 (0.88)	<.01	0.52 (0.74)	NS
Age ²	-0.252 (0.051)	<.01	-0.01 (0.02)	NS
ROM hip extension				
No side	0 (ref)		0 (ref)	
1 side	-1.72 (0.99)	<.10	0.28 (0.77)	NS
Both sides	-2.15 (0.90)	<.05	-1.47 (0.82)	NS
Model 3b: ROM				
Intercept	39.29 (4.37)	<.01	66.34 (6.98)	<.01
Age (y)	5.52 (0.89)	<.01	0.92 (0.75)	NS
Age ²	-0.24 (0.05)	<.01	-0.02 (0.02)	NS
ROM hip exorotation				
No side	0 (ref)		0 (ref)	
1 side	0.05 (0.79)	NS	0.24 (0.71)	NS
Both sides	-0.88 (0.94)	NS	0.75 (0.79)	NS
Model 3c: ROM				
Intercept	40.01 (4.26)	<.01	69.76 (6.92)	<.01
Age (y)	5.36 (0.88)	<.01	0.60 (0.74)	NS
Age ²	-0.23 (0.05)	<.01	-0.01 (0.02)	NS
ROM knee extension				
No side	0 (ref)		0 (ref)	
1 side	-0.92 (1.51)	NS	-3.78 (1.24)	<.01
Both sides	-1.51 (1.21)	NS	-5.23 (1.46)	<.01
Model 3d: ROM				
Intercept	40.18 (4.33)	<.01	67.79 (7.08)	<.01
Age (y)	5.37 (0.88)	<.01	0.80 (0.77)	NS
Age ²	-0.23 (0.05)	<.01	-0.02 (0.02)	NS
ROM ankle dorsiflexion				
No side	0 (ref)		0 (ref)	
1 side	-1.04 (0.77)	NS	-0.90 (1.33)	NS
Both sides	-1.04 (0.78)	NS	-0.34 (1.33)	NS
Model 4a: spasticity				
Intercept	40.13 (4.35)	<.01	69.22 (7.36)	<.01
Age (y)	5.40 (0.92)	<.01	0.57 (0.79)	NS
Age ²	-0.24 (0.05)	<.01	-0.01 (0.02)	NS
Spasticity hip adductors				
No side	0 (ref)		0 (ref)	
1 side	-0.92 (1.23)	NS	-1.52 (0.87)	NS
Both sides	0.17 (0.64)	NS	-1.75 (0.72)	<.05

(continued on next page)

Table 4 (continued)

Associated Factor	Children (n=148)	P	Youth (n=179)	P
Model 4b: spasticity				
Intercept	39.82 (4.37)	<.01	69.74 (6.26)	<.01
Age (y)	5.40 (0.92)	<.01	0.65 (0.66)	NS
Age ²	−0.23 (0.05)	<.01	−0.01 (0.02)	NS
Spasticity rectus femoris				
No side	0 (ref)		0 (ref)	
1 side	−1.34 (1.05)	NS	−0.36 (0.63)	NS
Both sides	−0.76 (0.92)	NS	−1.57 (0.75)	<.05
Model 4c: spasticity				
Intercept	39.64 (4.41)	<.01	67.36 (7.33)	<.01
Age (y)	5.40 (0.93)	<.01	0.72 (0.79)	NS
Age ²	−0.23 (0.05)	<.01	−0.01 (0.02)	NS
Spasticity hamstrings				
No side	0 (ref)		0 (ref)	
1 side	0.32 (0.67)	NS	−0.01 (0.77)	NS
Both sides	−0.51 (0.76)	NS	−1.10 (0.81)	NS
Model 4d: spasticity				
Intercept	38.10 (4.36)	<.01	67.90 (7.91)	<.01
Age (y)	5.69 (0.92)	<.01	0.61 (0.84)	NS
Age ²	−0.25 (0.05)	<.01	−0.01 (0.02)	NS
Spasticity gastrocnemius				
No side	0 (ref)		0 (ref)	
1 side	0.20 (0.82)	NS	0.69 (0.97)	NS
Both sides	0.09 (0.75)	NS	0.62 (0.93)	NS

NOTE. Regression coefficients (SE) are shown.

Abbreviations: NS, not significant; ref, reference category.

support for balance was allowed to reduce the effect of coordination deficits on test performance, and the functional multijoint squat movement may be less affected by impaired SMC, we assumed that test outcome can be used as a gross measure of lower extremity strength. Nevertheless, results need to be replicated using validated strength assessments. Third, it should be kept in mind that clinical measurements are subject to measurement errors. We attempted to reduce error as much as possible by using standardized measurement procedures and a limited number of experienced assessors. In addition, we used gross, dichotomized measures for ROM and spasticity. We could therefore not distinguish between different levels of spasticity in muscle groups and between different degrees of restrictions in ROM. Therefore, the results need to be confirmed in future research with more precise measures of neuromusculoskeletal function. Fourth, some data for the neuromusculoskeletal function variables were missing. Although overall percentage of missing values were acceptable (<10%), its effect on the association with gross motor capacity remains unknown. However, our findings are in agreement with previous cross-sectional studies that found a stronger association between SMC and muscle strength with gross motor capacity.^{10,11}

Despite these limitations, the present study makes a noteworthy contribution to the field of (developmental) pediatrics and pediatric rehabilitation medicine. This is attributable to the multivariable analysis that was based on longitudinal data of several previously identified impairments in neuromusculoskeletal function associated with gross motor capacity. Results aid decision making and the selection of effective and age-appropriate interventions to enhance gross motor capacity. Optimal gross motor capacity may be a prerequisite for reaching optimal participation. In addition to other interventions focusing on

improving self-efficacy, reaching these goals will require training in a meaningful environment.

Conclusions

The results of the present study indicate that individuals with more severely impaired SMC and muscle strength have an unfavorable course of gross motor capacity. In addition to treating spasticity and ROM, interventions in children and youth with CP should focus on optimizing muscle strength levels and, if possible, SMC.

Supplier

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Keywords

Adolescent; Cerebral palsy; Child; Motor disorders; Rehabilitation

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Table 5 Results of the final multivariable analyses, showing the longitudinal association between neuromusculoskeletal function and gross motor function (GMFM) in children and youth with CP

Associated Factor	Children (n = 148)		Youth (n = 179)	
	Regression Coefficient (SE)	P	Regression Coefficient (SE)	P
Intercept	55.20 (4.18)	<.01	88.63 (7.01)	<.01
Age (y)	5.50 (0.88)	<.01	0.05 (0.78)	NS
Age ²	−0.24 (0.05)	<.01	0.005 (0.02)	NS
SMC				
Good	0 (ref)		0 (ref)	
Moderate	−9.54 (3.25)	<.01	−11.18 (2.43)	<.01
Poor	−42.08 (2.81)	<.01	−36.03 (2.54)	<.01
Strength				
Good	NA		0 (ref)	
Moderate	NA		−3.27 (1.17)	<.01
Poor	NA		−10.66 (1.72)	<.01
ROM hip extension				
No side	0 (ref)		NA	
1 side	−1.84 (0.98)	<.05	NA	
Both sides	−1.83 (0.89)	<.05	NA	
ROM knee extension				
No side	NA		0 (ref)	
1 side	NA		−2.33 (1.33)	NS
Both sides	NA		−5.90 (1.66)	<.01
Spasticity hip adductors				
No side	NA		0 (ref)	
1 side	NA		−1.97 (0.88)	<.05
Both sides	NA		−1.84 (0.71)	<.01

NOTE. Only neuromusculoskeletal function variables with $P < .05$ (after the backward selection procedure) in the final multivariable analysis are shown. Abbreviations: NA, not applicable; NS, not significant; ref, reference category.

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