Original Article

Experience with jumping mechanography in children with cerebral palsy

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Abstract

Objectives: Jumping mechanography provides robust motor function indicators among healthy children. The aim of the study was to assess the reproducibility and validity of jumping mechanography conducted as single two-legged jump (S2LJ) in children with cerebral palsy (CP). **Methods:** 215 S2LJ investigations from a sample of 75 children with CP were eligible for evaluation. For the estimation of the reproducibility, only the baseline set of data per patient were used. Gross motor function was evaluated by the Gross Motor Function Measure (GMFM-66). In 135 S2LJ investigations, GMFM-66 was assessed within a week in the same child. This data was used for validity assessment. **Results:** Coefficients of variation for the main outcome parameters ranged between 6.15-9.71%, except for jump height (CV%=27.3%). The intraclass correlation coefficients for peak velocity (V_{max}) and peak power relative to body weight (P_{max}/mass) was 0.927 and 0.931. V_{max} and P_{max}/mass were also the test parameters with the strongest correlation to the GMFM-66 score (>0.7). **Conclusions:** S2LJ assessed in the present study provided reproducible outcome measures particularly for V_{max} and P_{max}/mass in children with CP. Further, V_{max} and P_{max}/mass showed the strongest correlation with the GMFM-66 score and seem to be the most relevant evaluation criteria.

Keywords: Jumping Mechanography, Cerebral Palsy, Reproducibility, Validity, Motor Function

| Abbreviations |
| --- |
| CI: confidence interval |
| CP: Cerebral Palsy |
| EFI: Esslinger Fitness Index |
| FE: Force Efficiency |
| GRFP: Ground Reaction Force Platform |
| GMFCS: Gross Motor Function Classification System |
| GMFM-66: Gross Motor Function Measure 66 |
| S2LJ: Single two-legged Jump |

Introduction

Jumping mechanography, performed on a ground reaction force platform (GRFP), measures the variation of force over time and enables the calculation of jump force, power and speed, providing reliable motor function indicators among adults and children[1-5]. Jumping mechanography studies among adults with frailty syndrome showed a good validity of these indicators to predict the risk of falling or restrictions in activity of daily living[6-9]. Jumping mechanography was also performed to assess the muscle power among healthy children as well as children with mitochondrial diseases, prematurity, Prader-Willi syndrome and hereditary motor and sensory neuropathy[10-14]. Recently, age-dependent reference data for jumping mechanography for healthy children and adolescents have been published[15-17].

Although cerebral palsy (CP) is the most common cause of physical impairment in children (incidence of about 2 per 1000 live births), no experience have been reported on the use of jumping mechanography to assess muscle power

Figure 1. Flow chart on sample selection and criteria.
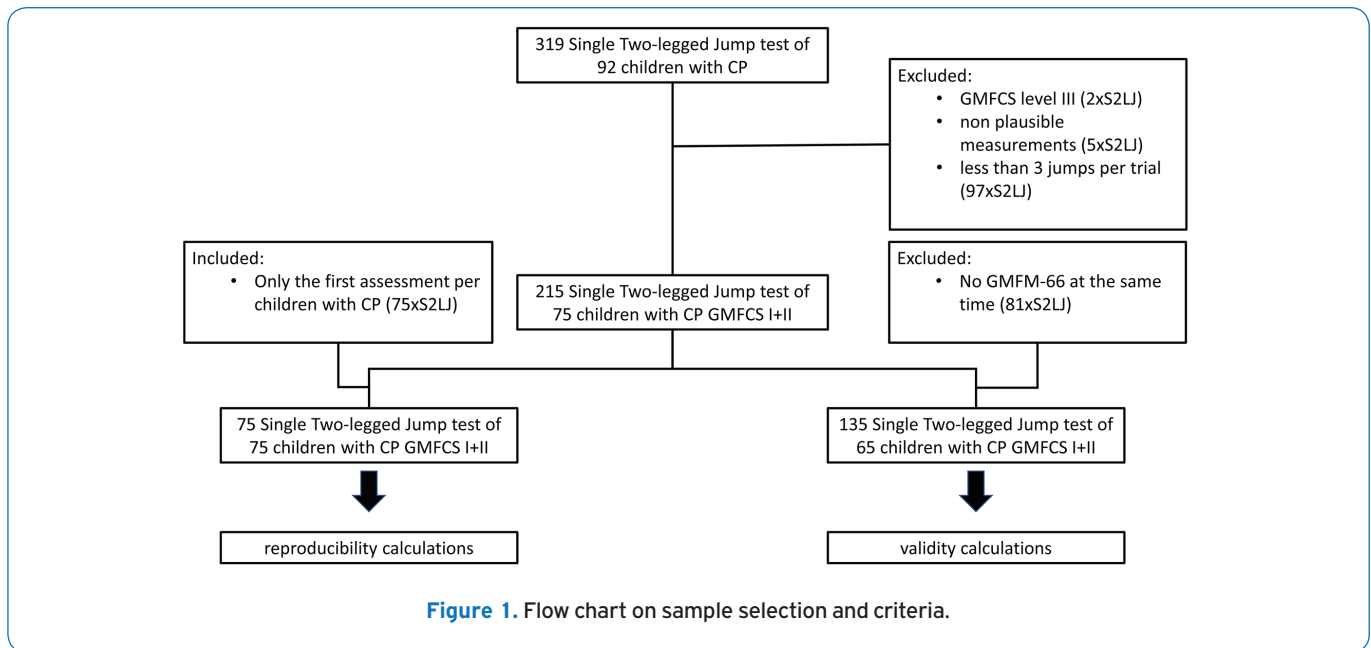
and motor performance in this population[18]. CP is a group of disorders caused by a permanent but not progressive damage to the developing brain[18]. Different CP subtypes, including spastic, dyskinetic, atactic, as well as mixed types, are clinically defined[18].

The reproducibility of procedures requiring the cooperation of subjects such as jumping mechanography is affected by device dependent, subject dependent as well as rater dependent factors. Veilleux et al. and Matheson et al. investigated the reproducibility of the test on a Leonardo® Mechanograph GRFP (Novotec Medical GmbH, Pforzheim, Germany) in healthy subjects, concluding that the influence of the subject dependent factors is the greatest[4,5]. Failure to understand, unwillingness to cooperate but also the biological motor function variability of the subjects are the major subject related factors limiting the test reproducibility[5]. These aspects are particularly important when performing jumping mechanography in children with CP suffering not only from a movement disorder, but also often from a cognitive or behavioral disorder[19]. Therefore, both cited groups of authors assumed that the greater variability of jumping mechanography results among patients with movement disorders, such as CP, may challenge the test reproducibility[4,5].

Thus, the aim of this study was to investigate the reproducibility and validity of jumping mechanography in children and adolescents with CP.

Methods

Study population

The study population consists of children and adolescents with CP, who participated in the rehabilitation

Table 1. Participants demographics by group.

	Reproducibility group	Validity group
Participants, N	75	65
S2LJ, N	75	135
Female, %	37.2	38.5
Age, years	11.2 (3.34)	11.3 (3.44)
Height, cm	142.8 (19.11)	143.6 (19.62)
BMI, kg/m	17.6 (3.33)	17.8 (3.23)
GMFCS I, %	51.6	51.1
CP Subtype, %		
bilateral spastic	54.9	55.6
unilateral spastic	30.2	29.6
dyskinetic	3.3	3.0
ataxic	2.8	2.2
mixed type	4.8	9.6
EFI, %	51.9 (18.2)	51.2 (18.6)

Data presented as mean (standard deviation).
EFI Esslinger Fitness Index.

concept "Auf die Beine" at the Center for Prevention and Rehabilitation of the University Hospital of Cologne from January 2006 to March 2017. The rehabilitation concept "Auf die Beine" has already been presented in detail in a previous publication[20]. Only measurements in children with Gross Motor Function Classification System (GMFCS) level I and II were further evaluated to have a homogeneous study population with regard to their motor

Figure 2. Leonardo Mechanograph Ground reaction force plate (GRFP)® (Novotec Medical GmbH, Pforzheim, Germany).

Table 2. Definitions of the jump parameters used in the present study.

Parameter	Unit	Definition
V_{max}	m/s	maximum velocity before lift up
Height	cm	maximum jumping height
F_{max}/BW	no Unit	maximum force per body weight
P_{max}/mass	W/kg	maximum power per body mass before lift up
pP_{max}/mass (EFI)	%	P_{max}/mass expressed as percentage of the expected age- and gender-adjusted value
Force Efficiency	%	$100 * \dfrac{EFI}{\left(\dfrac{F_{max}/BW}{2.4}\right) *100}$
EFI Esslinger Fitness Index, kg kilogram, m meter, s second, W watt.		

skills. The GMFCS is a validated and commonly used five level ordinal scale of functional limitation for children with CP. The movement quality though is hardly assessed using the GMFCS. Children with GMFCS level I and II can walk without support or with limitations respectively, but they are slower and less coordinated than same age-old, healthy children. Children with GMFCS level III and IV can only walk using hand-held mobility devices or powered mobility. Children with GMFCS level V are only passively transported in a manual wheelchair and show deficits in head and trunk control[21].

Overall, 319 S2LJ investigations were performed in 92 children with CP (GMFCS I-III) in the studied period (Figure 1). Only measurements in children with GMFCS stage I and II were further evaluated (90 children). After applying the additional exclusion criteria (97 not complete investigations, 5 investigations with implausible results) 215 S2LJ investigations with three consecutive S2LJ assessments each, from a sample of 75 children, were eligible for the reproducibility assessment (Figure 1). Participants demographics are given in Table 1.

After obtaining written informed consent for data analysis from the legal guardian of the child data of the participants of the rehabilitation concept "Auf die Beine" are stored in a prospective monocentric patient registry. The Ethics Committee of the University of Cologne approved this registry (16-269). A detailed description of the registry can be found at http://www.germanctr.de (DRKS00011331) which is a primary register of the International Clinical Trials Registry Platform of the World Health Organization.

Variables, investigations and GRFP

Four consecutive investigations using jumping mechanography were performed among all patients who were able to jump upon recruitment in the rehabilitation concept, at the beginning (first jump test), after 2-3 months (second jump test), after 4-6 months (third jump test) and after 12 months (forth jump test). The investigations were conducted using Leonardo Mechanograph GRFP® (Novotec Medical GmbH, Pforzheim, Germany), a square platform with an edge length of 66 cm and a height of 7 cm (Figure 2). It consists of two equally sized force plates (right and left), each measuring the ground reaction forces via four force sensors with a sample rate of 800 Hz. Data processing was

performed using the software Leonardo Mechanography® v. 4.2 (Novotec Medical GmbH, Pforzheim, Germany).

The children were positioned on the Leonardo Mechanograph GRFP® standing with only one foot on each force plate. Casual footwear and when needed orthoses were used. The children were instructed to jump as high as possible. Arms swinging and knee flexion prior to jump were permitted (jump for maximum height without arm restriction). The investigated jump is referred to in the literature as *single two-legged (countermovement) jump (S2LJ)*[4]. It is considered a screening test, measuring primarily the anaerobic motor performance[22]. Usually, in jumping mechanography, three jumps were performed and the 'best' one is selected (e.g. by jumping height) for the final report. Therefore, a *S2LJ investigation* was considered complete only if three consecutive S2LJs were performed.

S2LJ investigations were excluded from evaluation, if they were not complete (Figure 1). Furthermore, S2LJ investigations were excluded, if the results were not plausible, e.g. measured jump height of 5 m.

The S2J2 were carried out by three experienced examiners (Rater A, B, C). The jump with the most efficient Esslinger Fitness Index (EFI) was evaluated. The EFI is defined as follows[23]:

$$EFI = \frac{P_{max}/mass}{\text{age and gender adapted expected value for } P_{max}/mass}$$

$$P_{max}/mass = \frac{\text{max peak power during jump (W)}}{\text{mass of the patient (kg)}}$$

The age- and gender- related reference data used were extracted from the investigation of healthy German subjects of 6-88 years of age[1,10]. The study variables are summarized in Table 2.

Anthropometry

The patients' height was measured in 0.1 cm increments using the stadiometer seca 213 (SECA GmbH, Hamburg, Germany). The weight was measured by the GRFP in 0.1 kg increments.

Reproducibility und validity

The S2LJ investigations were performed up to four times among many children with CP, with a minimum interval of two months. Only the first investigations were used for estimating reproducibility. Usually in mechanography, three jumps were performed and only the 'best' one was selected for the final report. Therefore, to establish reproducibility of mechanography, it would have been necessary to perform two series of three jumps. For each of the two series, the best jump would have to be selected. Reproducibility would have to be calculated based on these two selected best jumps. The present study determined reproducibility for a mechanography protocol that uses only one jump to produce a final result. This was different from the usual use of mechanography. Since this was a retrospective analysis of database material, only this form of evaluation could be carried out.

To evaluate the construct validity of the S2LJ investigations, the results were compared with the Gross Motor Function Measure 66 (GMFM-66) assessments of the children with CP collected within one week. The GMFM-66 consists of 66 motor tasks (items) and is validated and commonly used to quantify the motor skills of children with CP[24,25]. The results of the individual items were documented and analyzed using *The Gross Motor Ability Estimator (Versions 1 and 2) Scoring Software for the GMFM®* (CanChild, McMaster University, Ontario, Canada), when at least 23 items were examined. Avery et al. recommended that the examination of 13 items is sufficient for the GMFM-66. However, they point out that a larger number of tested item correlates with a more accurate GMFM-66 assessment[26].

Statistical analysis

The S2LJ parameters were not normally distributed. Hence, we used the Friedmann test to examine if there was a significant difference between the three consecutive S2LJ per S2LJ investigation.

We used the intraclass correlation coefficients (ICC) to assess the intra-day and intra-rater reliability of the S2LJ. According to McGraw and Wong, the ICC (C,1) was used for an adjusted (consistency) two-way random model for single values[27]. According to Cicchetti, ICC values between 0.60 and 0.74 reveal a good, and ICC values ≥0.75 an excellent reproducibility respectively[28]. Additionally, the empirical coefficient of variation (CV%) and the least statistically significant difference (least significant change= 2.77 x CV%) were calculated for each S2LJ parameter.

The ICC could not be used to assess the interrater reliability since there were no simultaneous S2LJ investigations performed by different raters. Depending on the rater who performed the measurement (A, B, C), we divided the S2LJ investigations into three groups. We used the Fisher's exact test to examine whether the three groups differed significantly in age, weight, height, gender, GMFCS level or CP subtype. Performing ANOVA for systematic differences between the raters was not possible since the dependent variables were not normally distributed. Subsequently, the S2LJ results were examined using the Kruskal-Wallis H test.

We used the Spearman's correlation coefficient (Spearman's rho) to assess the correlation of results of the S2LJ investigations and the GMFM-66 score because, in contrast to the Pearson's correlation coefficient, it also recognizes nonlinear, monotonic relationships. Although there are no general guidelines for interpreting the correlation coefficient, a rho of 0.5-0.8 in medical field is often used to indicate a significant correlation between two variables. To rule out a mock correlation, the partial correlation coefficient between the S2LJ parameters and the GMFM-66 score was adjusted for the age. It could have been that the S2LJ parameters correlate with the age, and the age with the GMFM-66 score.

Statistical analyses were conducted using the software SPSS Statistics® Version 24 (SPSS Inc., Illinois, USA).

Table 3. Changes in jump parameters between the three jumps per Single Two-legged jump (n=75).

Mean (SD) of	Jump number			p-value for		
	1	2	3	1 to 2	1 to 3	2 to 3
V_{max}, m/s	1.27 (0.390)	1.30 (0.372)	1.33 (0.383)	0.150	*0.002*	0.425
Jump height, cm	13.1 (8.7)	12.5 (7.8)	14.0 (7.8)	0.362	*0.001*	0.124
F_{max}/BW	21.47 (3.53)	21.71 (3.25)	21.84 (3.28)	0.253	0.253	0.253
P_{max}/mass	19.74 (7.23)	20.21 (6.85)	20.76 (6.98)	0.217	*0.002*	0.362
pP_{max}/mass (EFI)	48.90 (22.50)	49.87 (22.36)	51.24 (23.24)	0.307	*0.008*	0.495
Force Efficiency	52.64 (23.48)	53.72 (24.01)	54.90 (24.93)	0.052	*0.052*	0.052

Data presented as mean (standard deviation, SD).
Changes over jump number were evaluated with the Friedman test.
P values are adjusted with the Bonferroni correction due to multiple testing.
Significance level was <0.05 for italic values.

Table 4. Reproducibility measures for each S2LJ parameters, intra-day and intra-rater.

Parameter	Single Two-legged jump in children with CP (N=75)		
	CV (%) (95% CI)	LSC (%) (95%CI)	ICC(1) (95% CI)
V_{max}	8.05 (5.72-10.38)	22.30 (15.84-28.75)	0.927 (0.895-0.950)
Height	27.28 (21.23-33.34)	76.56 (58.81-92.35)	0.776 (0.693-0.844)
F_{max}/BW	6.15 (5.11-7.18)	17.04 (14.15-19.89)	0.783 (0.702-0.849)
P_{max}/mass	9.71 (7.20-12.21)	26.90 (19.94-33.82)	0.931 (0.901-0.953)
pP_{max}/mass (EFI)	8.22 (6.98-9.45)	22.77 (19.33-26.18)	0.956 (0.936-0.970)
Force Efficiency	9.38 (8.17-10.59)	25.98 (22.63-29.33)	0.940 (0.914-0.960)

CP Cerebral Palsy, CV coefficient of variation, EFI Esslinger Fitness Index, ICC intraclass coefficient, LSC least significant change, S2LJ single two-legged jump.

Table 5. Inter-rater reproducibility measures for each Single Two-legged jump parameters.

S2LJ Parameter	Rater			Changes over Rater
	A (n=34) Mean (95%CI)	B (n=36) Mean (95%CI)	C (n=5) Mean (95%CI)	p-value
V_{max}, m/s	1.38 (1.27-1.49)	1.27 (1.25-1.42)	1.45 (0.91-1.98)	0.269
Height, cm	14.5 (12.1-16.9)	13.9 (10.9-16.9)	15.1 (5.6-24.6)	0.670
F_{max}/BW	22.8 (21.6-24.1)	21.1 (20.2-22.0)	20.4 (15.8-24.9)	0.059
P_{max}/mass, W/kg	21.9 (19.9-23.9)	19.4 (16.7-22.2)	22.5 (14.9-30.2)	0.149
pP_{max}/mass (EFI), %	58.2 (52.0-64.3)	43.5 (34.5-52.4)	60.2 (41.1-79.3)	*0.011a*
Efficiency, %	60.8 (54.3-67.4)	47.0 (37.5-56.4)	71.8 (41.8-101.8)	*0.012[a]*

Only evaluation of the third S2LJ of each S2LJ investigation is given.
Changes over rater were evaluated with the Kruskal-Wallis test.
Significance level was <0.05 for italic values.
S2LJ single two-legged jump.
[a]Results from rater A and B differed significantly.

Results

Study population

From a sample of 75 children, 215 S2LJ investigations with three consecutive S2LJ assessments each were eligible for evaluation. Only the baseline set of data per patient were used for the reproducibility assessment (Figure 1). Participants demographics are given in Table 1. Mean age of the children included for the reproducibility group was 11.2 ($\pm$3.34) years of age (Table 1). Among the investigated children, 37.2% (= 80/215) were girls and 51.6% (=111/215) had a GMFCS level I.

In 135 cases, the GMFM-66 was assessed within a week from the S2LJ investigation. The results were used to assess the validity of the S2LJ investigations. The mean age of the children in the validity group was 11.3 ($\pm$3.44) years. 38.2% (= 52/135) of the children were girls and 51.1% (= 69/135) had a GMFCS level I (Table 1).

Reproducibility

Significant differences (p=0.001 to p=0.008) were found for all S2LJ parameters, except for the F_{max}/BW and Force Efficiency (FE), between the first single S2LJ and third S2LJ. The exact p-values are depicted in Table 3.

The ICC was for V_{max}, P_{max}/mass, EFI and FE > 0.9 (Table 4). For Hmax and F_{max}/BW the values for the ICC were 0.776 (95% CI: 0.693-0.844) and 0.783 (95% CI: 0.702-0.849) respectively. The respective values for CV% and LSC% are depicted in Table 4.

Rater A had performed 34, Rater B 36 and Rater C 5 of 75 S2LJ investigations. The three groups of children studied by the different rater (A, B, C) showed no significant difference in age, height, weight, gender, GMFCS level or CP subtype. V_{max}, jump height, F_{max}/BW and P_{max}/mass showed no significant difference between the groups (Table 5). EFI and FE were significantly higher in group A in comparison to group B (Table 5). There were no significant differences between the groups investigated by the rater A and C, respectively B and C.

Validity

V_{max} and P_{max}/mass were the variables with the strongest correlation to the GMFM-66 score (0.730-0.751 and 0.707-0.732, Table 5). The only parameter that did not correlate with the GMFM-66 score was F_{max}/BW.

The selection and evaluation of the parameters of the "best" single S2LJ did not influence the correlation with the GMFM-66 score (Table 5).

Discussion

In this study, we examined the reproducibility, in particular the intra-day and intra-rater reliability, of the jumping mechanography in children with CP. The investigation was performed as a single two-legged jump (S2LJ) using a Leonardo Mechanograph GRFP®.

The calculated coefficients of variation for V_{max}, height, P_{max}/mass, EFI and Force Efficiency (FE) were higher than ones reported for healthy children (healthy: 2.3%-5%, Table 4)[4]. The highest coefficient of variation was observed in jump height. Only F_{max}/BW was lower to that of healthy children (healthy: 13.1%)[4]. A higher variability of the S2LJ parameters in subjects with movement disorders has already been assumed by Veilleux et al. and Matheson et al., probably attributable to the greater movement variability[4,5]. In addition, understanding of the task and the willingness to cooperate could be lower among children with CP than in healthy children. This is reflected by the fact that 30.4% of the S2LJ investigations (=97/319) could not be completed (three consecutive S2LJ assessments). The major reasons for incomplete S2LJ investigations were fatigue and unwillingness of the child.

The determination of intra-class correlation coefficients (ICC) is commonly used to indicate the reproducibility of S2LJ investigations. For the S2LJ parameters V_{max}, height, P_{max}/mass, EFI and FE, ICC values indicated a very high reproducibility. They were slightly lower compared to ICC values in healthy children (healthy: 0.90-0.99, Table 4)[4]. The ICC for F_{max}/BW revealed a good reproducibility and was again slightly lower than ICC values in healthy children (healthy: 0.8)[4].

The S2LJ investigations were carried out by one of three raters. The S2LJ parameters V_{max}, height, P_{max}/mass and F_{max}/BW showed no systematic differences between the raters (Table 5). FE and EFI were significantly higher for rater A in comparison to rater B. A different way of guiding the child to perform the S2LJ could be the reason for this finding.

In 319 S2LJ investigations, no adverse effects or injuries occurred in our study population.

In summary, our data showed that the S2LJ investigation on the Leonardo Mechanograph GRFP® was a safe assessment and provided good reproducible results in children with CP, especially for V_{max} and P_{max}/mass. The reproducibility was slightly lower compared to healthy children.

As already mentioned in Methods, the present study determined reproducibility for a mechanography protocol that uses only one jump to produce a final result. Therefore, it must be highlighted that this study did not in fact determine the reproducibility of S2lJ as it is usually done.

As we know, the reason to perform three individual jumps per S2LJ investigation is to get reliably the maximum jumping performance. In accordance, our data showed that the jump parameters (except F_{max}/BW and FE) increased significantly between the first and third jump, but not between the second and third. The "best" jump was in approximately 80% of the cases either the second or third jump. Suitably, the reproducibility of the two most reliable parameters (V_{max} and P_{max}/mass) of the first two jumps was less than that of the second and third jumps (Data not shown). Therefore, it can be assumed that the reproducibility estimated with our evaluation form is less than the reproducibility of the S2LJ as it is usually done.

When comparing two S2LJ results of one child, e.g. the values

Table 6. Validity of the S2LJ parameters used in the present study.

Selecting jump with the best parameter in	Spearman rho for GMFM-66 Score and					
	V_{max}	Height	F_{max}/BW	P_{max}/mass	pP_{max}/mass (EFI)	Efficiency
V_{max}	0.748 (<0.001)	0.706 (<0.001)	0.030 (0.731)	0.732 (<0.001)	0.591 (<0.001)	0.607 (<0.001)
Height	0.751 (<0.001)	0.677 (<0.001)	-0.008 (0.931)	0.720 (<0.001)	0.602 (<0.001)	0.625 (<0.001)
F_{max}/BW	0.730 (<0.001)	0.661 (<0.001)	0.095 (0.273)	0.707 (<0.001)	0.554 (<0.001)	0.563 (<0.001)
P_{max}/mass	0.750 (<0.001)	0.726 (<0.001)	0.022 (0.803)	0.731 (<0.001)	0.585 (<0.001)	0.607 (<0.001)
pP_{max}/mass (EFI)	0.749 (<0.001)	0.724 (<0.001)	0.023 (0.795)	0.729 (<0.001)	0.585 (<0.001)	0.607 (<0.001)
Efficiency, %	0.741 (<0.001)	0.721 (<0.001)	0.056 (0.521)	0.737 (<0.001)	0.611 (<0.001)	0.603 (<0.001)
	Partial correlation (adjusted for age) for GMFM-66 Score and					
	V_{max}	Height	F_{max}/BW	P_{max}/mass	pP_{max}/mass (EFI)	Efficiency
V_{max}	0.696 (<0.001)	0.583 (<0.001)	0.091 (0.294)	0.654 (<0.001)	na[a]	na[a]
Height	0.697 (<0.001)	0.554 (<0.001)	0.057 (0.510)	0.647 (<0.001)	na[a]	na[a]
F_{max}/BW	0.679 (<0.001)	0.561 (<0.001)	0.150 (0.083)	0.638 (<0.001)	na[a]	na[a]
P_{max}/mass	0.700 (<0.001)	0.603 (<0.001)	0.096 (0.272)	0.658 (<0.001)	na[a]	na[a]
pP_{max}/mass (EFI)	0.700 (<0.001)	0.600 (<0.001)	0.099 (0.255)	0.545 (<0.001)	na[a]	na[a]
Efficiency, %	0.692 (<0.001)	0.602 (<0.001)	0.124 (0.155)	0.667 (<0.001)	na[a]	na[a]

Data presented as Spearman correlation coefficient.
P values presented in brackets, significance level was < 0.05 for italic values.
BW body weight.
[a]The Esslinger Fitness Index (EFI) and Efficiency are already adjusted for age.
na not applicable, S2LJ single two-legged jump.

prior to and following any intervention or medical therapy, LSC% may be used to decide whether a significant change had occurred (Table 4). A percentage increase or decrease of a S2LJ parameter in comparison to the corresponding value for LSC% indicates a statistically significant difference. Whether the difference is also clinically relevant shall be decided after taking into consideration other clinical data.

According to the assessment protocol, there were three individual S2LJs per investigation. We identified small, but significant differences in V_{max}, height, P_{max}/mass and EFI between the first and third S2LJ of the investigations (Table 3). F_{max}/BW and FE showed no significant difference between the three S2LJ. This result can be interpreted as a learning effect. We assume that the first and second S2LJ served to practice the jump sequence, so that higher power could be achieved with the same force for third S2LJ. This reflects the paradigm that motor learning leads to an increase in performance with the same or even less force. Lower forces not only lead to energy savings, but also protect body structures from harm[5].

No significant differences were identified between the second and third S2LJ. It seems that in children with CP often already two S2LJ are sufficient to retrieve the maximum power during S2LJ investigation.

To evaluate the validity of the S2LJ, the correlation of the S2LJ parameters with the results of the GMFM-66 was examined. Among the parameters considered, V_{max} and P_{max}/mass had the highest correlation coefficient with the GMFM-66 score, followed by jumping height, EFI and FE (Table 6). To rule out a mock correlation, the partial correlation coefficient between the S2LJ parameters and the GMFM-66 score was adjusted for the age. The correlation coefficients were only slightly lower, despite the age-adjustment (Table 6). The square of the correlation coefficient R2 (= measure of the linear regression) was just over 0.50 for V_{max} and P_{max}/mass. This implies that approximately 50% of the GMFM-66 variance can be explained by the variance of V_{max} or P_{max}/mass. This can be interpreted as an indication that both measurement methods (S2LJ and GMFM-66) at least measure to a certain extent different motor skills. Therefore, we estimate that both methods complement each other with regard to assessment of the motor performance in children with CP. To compare our results with literature, there are only few comparable studies. Buehring et al. reported a correlation of proximal femur lean mass measured by DXA with P_{max}/mass in older individuals (R^2=0.27)[6]. Siglinsky et al. reported a correlation of grip strength and chair rise time with P_{max}/mass in adults (n=332, mean age= 65.4; R^2=0.32-

0.33)[29]. Recently, Vill et al. found good correlations between S2LJ and clinical tests such as 6-minute walk test (r = 0.64) or the time to run 10 m (r=0.74) in children with hereditary motor and sensory neuropathy (CMT). They assumed that Leonardo mechanography was a good additional tool for the assessment of pediatric CMT patients[14].

Our data also showed that it made no significant difference which S2LJ parameter was used to select the "best" S2LJ out of the three individual S2LJ. Although in most publications the jumping height was used as selection criterion, V_{max} or P_{max}/mass showed a better reproducibility[4,5,17]. Since the coefficient of variation of V_{max} was slightly better than of P_{max}/mass and the calculation of V_{max} is less error-prone than the calculation of P_{max}/mass, we would recommend to use of V_{max} in children with CP, when selecting the "best" S2LJ.

Limitations

The study population consisted of participants in the rehabilitation concept "Auf die Beine". Although the authors did not identify any selection bias, it can still not be excluded.

A further limitation is that the values for the coefficient of variation given in the literature have been calculated using two S2LJ investigations within a week (inter-day, intra-rater)[4]. The coefficients of variation in our study were calculated by means of three single S2LJ, which were performed within a few minutes (intra-day, intra-rater). Therefore, it must be highlighted that this study did not in fact determine the reproducibility of S2IJ as it is usually done. Further research is needed to confirm the reproducibility and validity of jumping mechanography using S2LJ in children with CP.

Conclusion

This study revealed that the single two-legged jump (S2LJ) investigation on a Leonardo Mechanograph GRFP® is a sufficiently reliable measurement method to determine the motor performance in children with CP GMFCS levels I and II. We recommend an assessment protocol with at least three individual S2LJs to assess the highest motor performance. The criterion according to which the best single jump is determined seems to be of minor importance. Due to the higher reproducibility (intra-day/intra-rater and inter-rater), we recommend the use of V_{max}. Further, V_{max}, and P_{max}/mass show the strongest correlation with the GMFM-66 score in combination with a good reproducibility. Therefore, we supposed that these parameters were the most relevant evaluation criteria. F_{max}/BW did not correlate with the GMFM-66 score. This fact indicates that the ability to generate high forces seems to have a subordinate importance in motor performance. The presented least significant change (LSC%) values shall be considered as a basis when evaluating whether two S2LJ results are statistically significant different.

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