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REPRODUCIBILITY OF ISOKINETIC MAXIMAL CONCENTRIC STRENGTH IN THE CLOSED CHAIN OF THE LOWER EXTREMITIES, HAND AND LEG BILATERAL ASYMMETRY

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ABSTRACT

The comparison of maximal concentric strength between the affected and unaffected leg is a criterion for assessing the rehabilitation progress after unilateral injury. In healthy individuals and as a result of sport specific load (soccer) left/right leg strength differences may occur. Aim of the present study was to determine the relative and absolute reproducibility of a double legged isokinetic concentric test protocol for maximal strength (two sets of three reps in a leg press with 180 mm/s) separately measured for the left and right leg in healthy physically active men (N = 30, age = 26.5 ± 3.5 years) by use of the ICC (3.1) and Bland Altman method. The absolute reproducibility of the average maximal strength was for the group comparison 118 N and 127 N (10.1 and 11.3 %) and for the individual comparison 231 or 249 N (20 and 22 %) for the left and right leg. Significantly higher values of the left leg were found (from 3.6 to 3.2 %). The test protocol is suitable for the diagnosis of the isokinetic maximal concentric strength considering leg asymmetries. The differences in footedness must be considered in rehabilitation after unilateral injury and for comparisons of athletes with a specific leg asymmetry.

Keywords: unilateral injuries, double legged isokinetic, symmetry index, reproducibility

INTRODUCTION

The concentric maximal strength (17, 12, 23), power or work (13, 14) measured on isokinetic dynamometers are used to document the training progress during rehabilitation to restore normal functional muscular performance. An important criterion for the decision on the rehabilitation progress after unilateral injury represents the comparison between the affected and unaffected leg (14). The clinician must take into account that even in healthy people left/right leg strength differences (footedness) exist. Footedness is defined as role differentiation of both feet and legs in movement. The dominant foot or leg is preferred to execute a manipulative or mobilizing action like kicking a ball while the non-dominant leg provides stabilizing support or is the jumping leg (14, 7). The left leg tends to be longer and stronger than the right leg owing to this support function (25) in adult right-handers.

In various sports, such as soccer (26), jumping in track and field, sweep rowing (30), baseball, etc., the sport specific load is associated with a typical left-right leg asymmetry. This asymmetry has to be optimal to provide a high level of athletic performance in the respective sport. At the same, an excessive asymmetry is associated with increased susceptibility to injury (26, 8). Even in cycling as an externally circular motion, differences were found in the amount of strength between the strong and weak leg for the benefit of the stronger leg (about 13-17 %), which can lead to an early fatigue of the leg (4). Consequently, the aim of rehabilitation is not only a reduction in differences in leg strength, but must also differentiate between the dominant and non-dominant leg to minimize secondary injuries effectively.

The findings on strength asymmetry depend on the type of testing and the test device, whereby differences occur during isokinetic or isometric contractions in an open or closed chain, as well as during single or double legged measurement. The test results vary accordingly and underline strength asymmetries or show non-significant differences in strength between both legs, taking account of the leg dominance.

McCurdy and Langford (20) investigated the one repetition maximum for single legged squat and found a non-significant side-difference of 2.8 % in healthy young men. According to the authors, the data showed no differences in the concentric maximal strength in single legged squat between the dominant and non-dominant leg in healthy men. Contrary, some bilateral differences between the lower extremities in inactive people as well as most athletes were found in isokinetic concentric tests in the open kinetic chain (23). A greater average force (7.0 % to 10.6 %) and work (7.4 % to 11.3 %) in the kicking leg was observed in unilateral isokinetic concentric testing in the closed chain at three stretching speeds (10, 15, and 20 s) (14).

Exercises in the closed kinematic chain are described as more specific, functional and safe due to their complexity (3, 31). Simon and Ferris (29) studied 12 neurologically healthy individuals (7 men and 5 women), who showed in double legged pre-test at maximal voluntary isometric contraction (MVC) in a leg press a bilateral leg asymmetry of at least 10 %, additionally under single legged conditions. They found a correlation between the maximum force data and the test conditions ($p = 0.04$), although, the MVC presented under single legged conditions no longer showed a significant difference between the stronger and weaker leg ($p = 0.38$). All participants demonstrated lower maximum force values under double legged conditions ($p = 0.00$) not only for the dominant but also for the non-dominant leg. Bilateral index or the double legged deficit was 35.3 ± 7.1 % ($p = 0.00$). Thus, the leg strength asymmetry proved more dependent on neural factors as the mechanical capacity of the muscles. This is consistent with other studies. If participants produce the isometric MVC of the extension group of the lower extremities over several joints (leg press) and isolated in only one joint (knee extension), then the bilateral index changes from a bilateral deficit to a bilateral surplus (28). Also, the bilateral index depends on training, whereas double legged training reduces the deficit (28, 33, 10).

Test data collected at different diagnosis devices for strength (etc. Biodex, Cybex, Lido) are not directly comparable due to the different mechanics of the devices. A relatively new test device is the IsoMed 2000 dynamometer, which allows testing in both the open as well as the closed chain.

Dirnberger et al. (5) investigated the absolute and relative reproducibility of the maximum torque at knee flexion and -extension in the open chain under isometric and isokinetic (60 and 120 °/s) conditions using the IsoMed 2000 dynamometer. They found a higher reproducibility of the maximum torque of knee extension in physically active young men under isokinetic compared to isometric conditions. Furthermore, the data showed, in accordance with Kues et al. (15), Li et al. (18) and Dirnberger et al. (6) a slightly better reproducibility at a higher angular velocity and were thus contrary to findings of Impellizzeri et al. (9), which determined a higher reproducibility at an angular velocity of 60 °/s compared to 120 °/s. Data reproducibility for double legged maximal extensor strength tests in the closed chain of the lower extremities using the IsoMed 2000 dynamometer have not been published to the authors' knowledge. Since exercises are used in the closed chain generally for strengthening and rehabilitation of the lower limbs (3, 16, 34), thus there is a need for reliable muscle function tests under these conditions for this equipment (14).

The aim of this study was 1) an evaluation of the relative and absolute reproducibility of a standardized isokinetic testing protocol for the concentric maximal strength in the closed extension chain of the lower extremities using the IsoMed 2000 dynamometer and 2) the double legged collection of data for the concentric maximal strength of the left and right leg, as well as 3) testing the maximal hand grip strength in healthy sporting men. Furthermore, the hypothesis was tested 4) whether healthy, athletic active young men have a left/right asymmetry of hand grip strength and additionally show a contralateral asymmetry of the muscles of the extensor chain of the lower extremities.

METHODS

Participants

Healthy male athletic participants (*N*=30) volunteered in the study (Table 1). The sample consisted of 26 right-handed and 4 left-handed, who practice fitness, hand-ball, martial arts, gymnastics or other sports since 10 ± 6 years in mean four times a week. All participants signed a written informed consent to participate in the study. Each was asked about their preferred leg, which was checked by juggling a soccer ball before the motoric tests. The study was approved by the local ethic committee of the Faculty of Psychology and Human Movement Science of the University of Hamburg.

Test-design and procedures

Reproducibility was collected in a repeated measures design by the same tester. The retest was conducted within five to seven days. After a 10-minute warm up on the treadmill, participants performed first a grip strength test to determine the stronger hand (only test 1 without repeated measures), followed by the test of the lower extremities.
The grip strength test was realized in a standing position with the arms vertically next to the body. Both hands were tested twice and the mean value of both measurements was noted as the result. The measuring instrument was previously adjusted to the individual's hand size. The volunteers could use chalk on their hands if necessary to ensure the grip control in case of slippery hands.

Testing in the leg press was conducted in a double legged seating position (Fig. 1). The feet were placed at the bottom of the foot stretcher, the heels laid down whereby a comparable distance from heel to gluteal resulted. The foot stretcher was inclined forwards for 15° (second hole from above; Fig. 1), the backrest had an angle of 78° in the horizontal axis.

Table 1. Overview of the participants, *N*=30

Age [years]	Body mass [kg]	Body height [cm]	Squat Best result [kg]	Handedness		Preferred leg	
				Right	Left	Right	Left
26.5 ± 3.5	78.5 ± 8.9	180.1 ± 5.6	105 ± 30	26	4	26	4

Figure 1. Measuring position of the knee joint in 90°-flexion position (positioning: seated, 45°/90°/85°, hip/knee/ankle angle).

Positions and settings were noted and saved by the test device for all areas in 0.5° steps. The progress of the knee angle in the starting positing was 80°. During repeated measurements, servomotors reproduced the settings and test position. The range of motion (ROM) was in two directions 45°. Participants performed two submaximal concentric contractions to get used to the test conditions. After a three-minute-rest, the isokinetic concentric maximal strength test started with a movement speed of 180 mm/s for two sets of three repetitions with three minutes of rest between sets. During the test, the tester motivated the participants verbally and with visual feedback to obtain their personal maximal performance (11). An experienced tester supervised the entire test procedure. The total duration of the tests in the leg press was about five minutes.

Measuring instruments

The handgrip strength was measured with the JAMAR Jamar® Hydraulic Hand Dynamometer (Model 5030J1, J.A. Preston Corporation, Clifton, NJ). Studies showed a high reliability (ICC (3.1) = 0.98) and validity (ICC (2, K) = 0.99) for measuring the hand grip strength (2).

For the double legged measurement of maximal extension strength an IsoMed 2000-linear ergometer (D & R Ferstl GmbH, Hemau, Germany) was used. Strain gauges were integrated into the foot stretcher to capture the normal strength for the left and right leg separately (Fig.1). Accuracy of the measurement was 0.25 % at a measuring frequency of 200 Hz. To minimize the risk of injury of the participants, mechanical limits were installed in the linear ergometer so that an emergency stop button could be pressed in case of a dangerous situation. However, this situation never occurred. Data recording was conducted with the manufacturers' computer software, IsoMed analyze 2008.

Data analysis

The results of the maximum strength test were exported from the manufacturer's soft-ware (IsoMed 2008) in csv files and processed in Excel. The degree of asymmetry between the left and right leg and grip strength was determined using the symmetry index (SI) (27) according to the formula:

$$SI = \frac{(X_R - X_L)}{0{,}5(X_R + X_L)} \cdot 100\ \%$$

with X_R for the values of the right and X_L for the values of the left side (leg or hand). Statistical analysis included descriptive statistics with arithmetic mean and standard deviation. Mean differences between the two tests were checked using an analysis of variance with repeated measures (general linear model) and the within-subject-factor "Test" (Table 2).

Normal distribution and homogeneity of variance was checked with the Kolmogorov-Smirnov and Levene test. The relative reproducibility was described with the Intra-class Correlation Coefficient (ICC (3,1)) and rated according to Weir (35) with limits of ICC> 0.9 high, 0.8-0.9 moderate, <0,8 low (Table 3).

The absolute reproducibility was determined using the Bland-Altman method with xl-STAT in Excel. To rate the homoscedasticity visually, both tests were displayed with Bland-Atman plots (Fig.2) (22).

To determine the random error, the standard deviation of the individuals mean differences from test 1 and 2 as well as the differences between the limits of agreement were considered. The standard error of measurement (SEM) was calculated using the formula SEM=SD·√(1-ICC) (35, 24). Level of significance was for all tests $p \leq 0.05$. SPSS 20.0 (Chicago, IL, USA) was used for all statistical analysis.

Table 2. Comparison of hand grip strength (FG) left versus right, Symmetry Index of hand grip strength (SIFG), (*N* = 30).

Hand	F_G [N]	F	Sig.	Partial Eta^2	SI_{FG} [%]
Left	422 ± 108	5.724	.023	.165	5.0 ± 12.1
Right	442 ± 106				

Table 3. Mean force (F), work (W), power (P), maximum force (F_x), and symmetry index (SI) of parameters, mean ± standard deviation, intra-class correlation coefficient (ICC), mean (M), and the difference of standard deviation (Δsd) of test 1 and test 2, confidence interval (CI), lower (u) and upper (o) limits of Agreement (LOA), Standard Error of Measurement (SEM)

Rotation	Characteristic [Unit of measurement]	Test 1	Test 2	ICC	95 % CI	M	Δsd	bias	uLOA	oLOA	LOA-bias	SEM
Sum of left+right	F [N]	2286 ± 432	2302 ± 436	0.92	0.82 - 0.96	2294	242	16	-457	490	473	70
	W [J]	648 ± 131	656 ± 135	0.92	0.83 - 0.96	652	73	8	-135	151	143	21
	P [W]	412 ± 78	415 ± 79	0.92	0.82 - 0.96	414	44	3	-82	88	85	13
	F_x [N]	3219 ± 627	3291 ± 656	0.90	0.79 - 0.95	3255	383	72	-679	823	751	120
Left	F [N]	1164 ± 222	1170 ± 217	0.92	0.84 - 0.96	1167	118	6	-224	237	231	33
	W [J]	330 ± 68	333 ± 68	0.93	0.85 - 0.96	332	36	3	-66	73	70	10
	P [W]	210 ± 40	211 ± 39	0.92	0.84 - 0.96	210	21	1	-40	43	42	6
	F_x [N]	1639 ± 324	1673 ± 331	0.91	0.81 - 0.96	1656	190	34	-338	406	372	58
Right	F [N]	1122 ± 217	1132 ± 227	0.91	0.81 - 0.96	1127	127	10	-239	259	249	38
	W [J]	318 ± 65	322 ± 69	0.91	0.82 - 0.96	320	38	4	-70	79	75	11
	P [W]	202 ± 39	204 ± 41	0.91	0.82 - 0.96	203	23	2	-43	47	45	7
	F_x [N]	1612 ± 320	1654 ± 343	0.89	0.77 - 0.95	1633	207	42	-364	447	406	68
Symmetry Index	SI_F [%]	-3.8 ± 7.8	-3.7 ± 8	0.95	0.9 - 0.98	-3.7	3.4	0.2	-6.4	6.8	7	1
	SI_W [%]	-3.9 ± 7.8	-3.6 ± 8	0.95	0.9 - 0.98	-3.7	3.4	0.2	-6.5	6.9	7	1
	SI_P [%]	-3.8 ± 7.8	-3.7 ± 8	0.96	0.91 - 0.98	-3.7	3.3	0.2	-6.3	6.6	6	1
	SI_{Fx}[%]	-1.8 ± 7.6	-1.3 ± 7.1	0.75	0.47 - 0.88	-1.5	6.5	0.4	-12.3	13.2	13	3
ROM	ROM [mm]	282 ± 17	282 ± 17	0.82	0.61 - 0.91	282	13	1	-25	27	26	6

Figure 2. Bland-Altman plots of mean force (F in N). Comparison of Test 1 and Test 2, extension left (left figure) and right (right figure), confidence interval (CI).

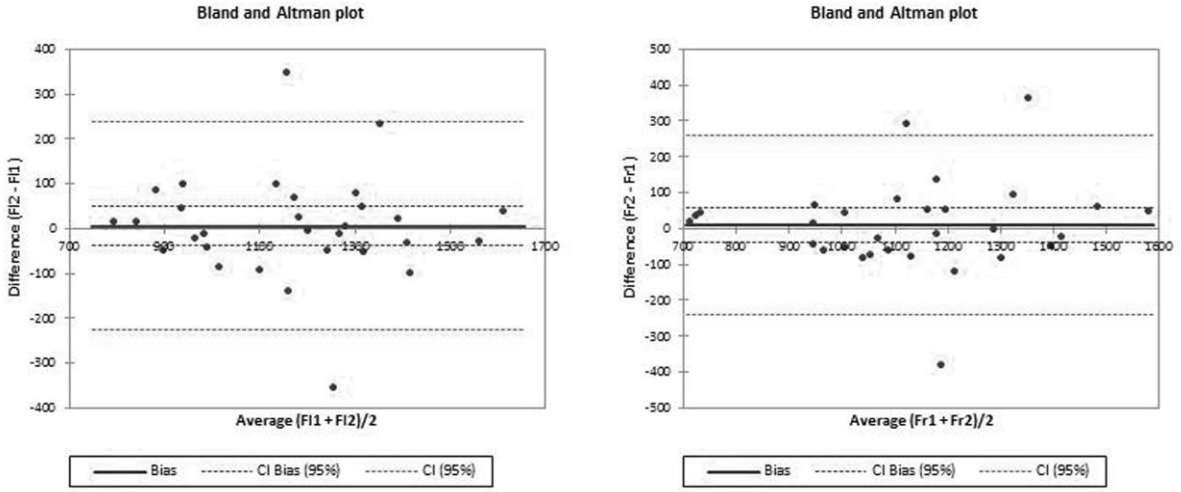

Table 4. Comparison of the measured data of test 1 and 2, mean force (F), work (A), power (P) and maximum force (F_x) in the left-right comparison and the corresponding symmetry index (SI), mean ± standard deviation, and F - and p-value of the analysis of variance with repeated measures, $N = 30$

Test	Characteristic [Unit of measurement]	Sum of Left + Right	Left	Right	F	Sig.	Partial Eta^2	SI
1	F [N]	2286 ± 432	1164 ± 222	1122 ± 217	7.567	.010	.207	-3.8 ± 7.8
	A [J]	648 ± 131	330 ± 68	318 ± 65	7.753	.009	.211	-3.9 ± 7.8
	P [W]	412 ± 78	210 ± 40	202 ± 39	7.287	.011	.201	-3.8 ± 7.8
	F_x [N]	3219 ± 627	1639 ± 324	1612 ± 320	1.545	.224	.051	-1.8 ± 7.6
2	F [N]	2302 ± 436	1170 ± 217	1132 ± 227	5.768	.023	.166	-3.7 ± 8
	A [J]	656 ± 135	333 ± 68	322 ± 69	5.824	.022	.167	-3.6 ± 8
	P [W]	415 ± 79	211 ± 39	204 ± 41	6.149	.019	.175	-3.7 ± 8
	F_x [N]	3291 ± 656	1673 ± 331	1654 ± 343	.847	.365	.028	-1.3 ± 7.1

RESULTS

The maximal grip strength of the right hand was significantly greater resulting to a positive symmetry index (Tab. 2).

The parameter of the isokinetic concentric maximal strength for the right and left leg fulfilled the normal distribution and homoscedasticity. There was no dependence of the distribution of strength values from the mean of the two tests. Figure 2 shows the Bland-Altman plots of double legged testing for the left and right leg separately.

Table 3 shows the data for relative and absolute reproducibility of the concentric maxi-mal strength of the lower extension chain. No significant differences were found for all investigated parameters between the means of both test series. The values in Test 2 were slightly higher than in Test 1 as illustrated by the consistently positive bias values. Relative reproducibility with ICC values from 0.75 to 0.96 was found. The highest relative reproducibility of all parameters was reached with the various symmetry indices from the data for the mean force, work and power and force maxima. In contrast, a low relative reproducibility indicated the ROM and the symmetry index of the maximal force.

Significant left-right differences were found for mean force, work and power with higher values for the left body-side in both tests, but not the maximal power (Tab. 4). The higher values of the left body-side were also reflected with the negative symmetry index.

DISCUSSION

The determination of intra-rater reliability of an isokinetic double legged test protocol for bilateral concentric maximal strength in the closed extensor chain of the lower limbs at the IsoMed 2000 dynamometer was a major aim of the study. A high relative reproducibility with ICC values of in mean 0.9 or greater was found in accordance with Weir (35) for mean force, work and power left and right, their symmetry index as well as for the force maximum of the left side. A moderate relative reproducibility was found for maximal force on the right side and ROM with ICC values of 0.89 to 0.82. The lowest relative reproducibility was determined for the symmetry index of the force maxima.

With the aid of the data for the absolute reproducibility, ranges can be specified for a reliable interpretation of differences or changes in the bilateral concentric maximal strength using the test protocol. The test protocol identifies changes in the group comparison, if the data for mean force exceed 118 N and 127 N (10.1 and 11.3 %) for the left and right leg in the pre-post-test comparison. Intra-individual differences in mean force must exceed 231 or 249 N (LOA-bias), a SEM of 33 or 38 N for the left and right leg. Comparable differences in percent as found for the mean force were found for mean work (10.7 and 11.7 %) and power (10.1 and 11.3 %) in the group comparison and in the intra-individual comparison with 21 and 23 % for mean work 20 and 22 % respectively for power of the left and right leg. A major reason for the compliance of the percentage values for mean force and power is the predetermined constant speed of movement of isokinetic concentric tests because it is included in the determination of the power (force multiplied by speed). The mean force during the isokinetic phase of contraction, in comparison to the maximum force, showed a slightly higher relative and absolute reproducibility.

The consistently positive bias values represent slightly higher test results in the

case of repetition (Test 2) and can be seen as a habituation to the test conditions. Although the differences i.e. for the mean force only reached 6 or 10 N for the left or right side, it remains unclear whether in case of a new retest, further habituation effects occur or not. The findings support the suitability of the test protocol for the diagnosis of the double legged isokinetic maximal concentric strength considering leg asymmetry within clinical studies. With that, a comparably high reproducibility of test data using the IsoMed 2000 Dynamometer for the knee flexion and –extension (6) as well as for the isometric and isokinetic plantar and dorsalflexion (19) was found also for the double legged isokinetic maximal concentric strength measured with the leg press.

A significant asymmetry with higher values of maximal concentric strength for the left leg was found in both, Test 1 and Test 2 for the mean force, work and power, but not for the maximum force. The performance dominance of the left leg was also expressed with the negative values of the symmetry index. The mean values for the right leg showed in Test 1 and Test 2 for the mean force 3.6 or 3.2 %, work 3.4 or 3.3 % and power 3.8 or 3.3 % lower values com-pared to the left body-side. With that, a higher and at the same time significant side difference was shown compared to McCurdy and Langford (20).

The higher side difference between the strong and weak leg can also be explained with the double legged measurement in the leg press, whereas McCurdy and Langford (20) determined the one repetition maximum during one-legged squat. In comparison to Kovaleski et al. (14), who revealed higher differences in the mean force and work in favor of the dominant right leg during one legged isokinetic testing in the closed chain, in this study lower side differences were found with the stronger left leg.

In the sample examined, the right-handed (n = 26) outnumbered the left-handed (n = 4). This finding was expected, because in the German (European) population right-handedness dominates (21). The predominance of right-handedness explains the greater average maximal grip strength of the right hand. Both the significantly higher right hand grip strength and the higher maximal force for the left leg, amongst the population, are consistent with the hypothesis. The healthy, physically active young men with an asymmetry of the handle power in favor of the right hand, therefore, have a contralateral asymmetry of the muscles of the extensor chain of the lower extremities with higher values of the left side. The findings also confirm the statement that in adult right-handers the left leg tends to be stronger than the right leg (25).

In test protocols to determine the maximal strength, the average force and not the maximal force should be used. Although both parameters showed a comparable repeatability, minor differences were reported for the average force, but not for the maximal force.

We investigated a heterogeneous sample of young, physically active male subjects without acute symptoms who participated voluntarily in the study. The people were directly addressed in the gym by the test administrator. A positive approach to weight training and –tests was thus created. Because right-handed subjects with a stronger left leg were the significant majority in the sample (N = 26), the comparative analysis was conducted for the left and right leg and the comparison of dominant and non-dominant leg was dispensed with. The findings cannot be applied to left-handers.

Another limitation was the test procedure because it was only tested at one movement speed (180 mm/s) in a sitting position double legged in the closed chain. Owing to their complexity exercises in a closed kinetic chain are described as more specific and functional (3, 31). The knee angle was set only initially at 80°, but in the subsequent repetitions, the subject could freely choose the knee angle for the starting position. Further normalization of the ROM was not performed. The leg length determines the ROM and depends on body height, which had a range of 20 cm within the sample, and also on inter-individual differences in body height. The test administrator checked the full leg extension. Initial tension of the muscles and also the development of power could have been influenced by angular deviations in the initial position.

CONCLUSION

The results showed that double legged testing of the isokinetic maximal concentric extension strength of the lower extremities in the closed chain using the Isomed 2000 dynamometer shows a high reproducibility. The test protocol describes the limits for clinical evaluation of differences between the participants, and changes in the maximal force as a result of exercise interventions for groups as well as for individuals. In healthy, physically active male participants with greater grip strength of the right hand, a higher concentric maximal strength of the left leg is likely. These side differences have to be considered in rehabilitation after unilateral injury, and for comparisons of groups of athletes in which a sport-specific leg asymmetry is expected.

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