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ORIGINAL RESEARCH

RELIABILITY, COMPARABILITY, AND VALIDITY OF FOOT INVERSION AND EVERSION STRENGTH MEASUREMENTS USING A HAND-HELD DYNAMOMETER

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ABSTRACT

Background: There are conflicting results with respect to the validity and reliability of lower extremity strength measurements using a hand-held dynamometer (HHD) in the healthy population. Previous studies exploring foot inversion and eversion strength using a HHD were carried out with predominantly clinically affected participants in different positions. The question arises whether HHD measurements of isometric foot inversion and eversion strength performed with participants in different positions are valid, reliable and comparable and can be used alternatively.

Purpose: The aims of this study were to investigate: a) the intra- and inter-tester reliability of measurements of foot inversion and eversion strength in different participant positions using a belt-stabilized HHD; b) the comparability of results obtained in different positions; and c) the concurrent validity of the aforementioned measurements using an isokinetic dynamometer.

Methods: Thirty adults (12 females and 18 males; mean age 22.5 ± 3.9 years) volunteered to participate in this study. Maximal isometric foot inversion and eversion torques (Nm) were measured with participants lying supine, sitting with knees extended and lying on their side using a belt-stabilized HHD. Measurements were performed independently by two physiotherapists over two days and were repeated using an isokinetic dynamometer. Validity and intra- and inter-tester reliability were determined using the intra-class correlation coefficient (ICC). A two-way ANOVA ($p < 0.05$) and post-hoc tests with Bonferroni correction were used to compare data from different positions. Bland-Altman plots were used to demonstrate the range of error and difference between HHD and isokinetic measurements.

Results: Intra-tester reliability for inversion and eversion torques was fair to excellent in all positions (ICC = 0.598–0.828). Excellent inter-tester reliability was found for eversion torques in all positions (ICC = 0.773–0.860). For inversion torques, inter-tester reliability was fair to excellent (ICC = 0.519–0.879). ICC values of 0.205 to 0.562 indicated a low to fair concurrent validity. A significant difference was observed between the torques of the supine and side-lying positions as well as sitting and side-lying positions ($p < 0.05$). Bland-Altman plots showed that the mean of the differences for inversion and eversion torques deviates considerably from zero, indicating that measurements with the HHD in the three positions produce lower values compared to using the isokinetic dynamometer.

Conclusions: Inversion and eversion strength measurements with subjects in different positions using HHD seem to be reliable, but consistently underestimated torque output when compared with measurements using isokinetic dynamometry. While the HHD outcomes measured in supine and sitting positions seem to be comparable, those measured in supine/sitting and side-lying positions differed.

Keywords: different test positions; dynamometry; eversion; inversion; reproducibility

Level of Evidence: Diagnostic study, Level 3

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INTRODUCTION

Ankle inversion and eversion muscle strength may become impaired as a result of disorders or acute injuries.[1-5] Physiotherapists need to use a practical method for identifying muscle strength deficits in the ankle and foot during examination. Strength measurements, usually expressed as force[6-8] or torque,[5,9-11] can be performed using commercially available isokinetic dynamometers, which are considered to be the gold-standard.[7] However, these time-intensive measurements require large and expensive equipment. As an alternative, hand-held dynamometers (HHD) have been used for clinical muscle strength examinations and research with demonstrated reliability and validity.[12-15]

There are conflicting results with respect to the reliability of lower extremity strength measurements using a HHD in the healthy population. A wide range of correlation coefficients (r = -0.20 to 0.96) was found for hip extension, hip abduction, knee flexion, and ankle dorsiflexion in a small sample of only four healthy subjects.[16] On the contrary, high correlations (>0.80) for muscle strength measurements of ankle dorsi- and plantarflexion as well as knee and hip flexion and extension within and between raters were determined in 55 healthy students.[17] For strength measurements of the ankle plantarflexors and dorsiflexors, ICC values of 0.31-0.79 were found between measurements using a HHD and a fixed KinCOM electromechanical dynamometer, demonstrating poor to good concurrent validity.[18] These results were similar to those of Marmon et al who used a KinCOM dynamometer and a HHD.[7] Insufficient data for isometric strength measurements of foot inversion and eversion using a HHD in the healthy population are available in the literature. To investigate the influence of ankle orthoses, Paris & Sullivan[19] measured rearfoot inversion and eversion strength with the participants sitting at the edge of the bench or table with the knee flexed and the lower leg hanging down, fixed with a padded and adjustable device. Under these conditions, gravity may have had an important influence on force development.

However, high intra-tester reliability has been determined for isokinetic inversion (ICC = 0.92-0.96) and eversion (ICC = 0.87-0.94) torque measurements at 60 and 180 degrees/s angular velocities in healthy people.[20] An ICC value of 0.95 demonstrated high inter-tester reliability in the same study. Test-retest reliability with ICC values between 0.87 and 0.96 have also been reported for isometric inversion and eversion strength measurements using an isokinetic dynamometer.[21]

In the clinically affected population, strength measurements of foot inversion and eversion using a HHD were carried out with participants in different positions. Foot inversion and eversion muscle strength in subjects with Type I myotonic dystrophy and healthy controls was measured with the participants lying supine in order to reduce the influence of gravity.[3] Docherty et al.[6] tested the foot eversion strength, and Hall et al.[22] measured eversion and inversion strength in patients with chronic instability of the ankle with the participants lying on their side. Carroll et al.[1] assessed foot inversion and eversion strength in patients with rheumatoid arthritis and healthy controls, with the subjects sitting on the treatment bench with their knees extended. Thus, the question arises whether HHD measurements of foot inversion and eversion strength performed with participants in different positions are valid, reliable and comparable and can be used alternatively. Furthermore, different testing procedures using a HHD may influence internal validity. Results from previous studies indicate that the rater's gender, body weight, grip strength[23] and various strength levels of different testers[24] can have an impact on reliability of testing with a HHD. The experience of the raters was considered to not affect reliability of strength measurements using a HHD.[25] However, a decisive factor was the strength of the tester to withstand the force generated by the tested person. When forces above 120 Newton (N) are applied, the tester's strength appears to determine the magnitude and reliability of the forces measured with the HHD.[24] This may lead to an underestimation of the muscle strength. Therefore, a fixation of the HHD using a belt/strap or a steel frame during measurements has been recommended.[13,26,27] To the authors knowledge to date, strength measurements of foot inversion and eversion have not been investigated using a belt-stabilized HHD. Finally, the angle of the talocrural joint during testing appears to affect muscle strength measurements. Foot inversion and eversion torques were found to be greater at 10° of plantarflexion than those generated at neutral dorsiflexion and plantarflexion as well as 10°- dorsiflexed foot positions during isokinetic testing.[28]

Reliability and validity of foot inversion and eversion muscle strength measurements using a HHD in healthy participants and the comparability between measurements with participants in different positions have not been determined previously. Therefore, the aims of this study were to investigate: a) the intra- and inter-tester reliability of measurements of foot inversion and eversion strength in different participant positions using a belt-stabilized HHD; b) the comparability of results obtained in different positions; and c) the concurrent validity of the aforementioned measurements using an isokinetic dynamometer.

It was hypothesized that the measurements of foot inversion and eversion muscle strength in different participant positions would be reliable but not comparable when measured twice by the same tester and when measured by different testers. Furthermore, it was expected that the measurements using HHD would be valid compared to the isokinetic method considered to be the gold standard.

METHODS

Participants

Thirty healthy participants (12 females and 18 males) volunteered to participate in the study. Their mean age was 22.5 (± 3.9) years, their mean height was 176.0 (± 11.6) cm, their mean body mass was 71.7 (± 2.6) kg, and their mean body mass index was 23.1 (± 2.6) kg/m^2. The participants were recruited from a local school of physical therapy and occupational therapy education. A questionnaire was used to select participants for the study. Inclusion criterion was being between the ages of 18 and 35 years. The following exclusion criteria were utilized:

- A history of a traumatic injury of the lower extremity, the pelvis, and/or trunk within the previous 12 months
- A chronic disorder of the lower extremity, e.g., chronic instability of the ankle joint or Achilles or patellar tendinopathy
- Acute, sub-acute or chronic low back pain with and without radiating symptoms
- Acute pain and dysfunction of the lower extremity
- Neurological diseases or disorders

All of the participants gave written informed consent prior to participation and were able to withdraw from the study at any time without any consequences. The study was approved by the Ethik-Kommission der Deutschen Sporthochschule Köln.

Procedures

Maximal isometric foot inversion and eversion torques of one foot were measured by two experienced physiotherapists (one female and one male) independently over two days in three different subject test positions using a belt-stabilized hand-held dynamometer (Commander™ Muscle Tester, JTECH Medical, Salt Lake City, USA). This HHD consists of a transducer used to record peak force (in Newtons), which is connected to a console that collects, stores, and displays data from the transducer. The belt was used for stabilization because of the expectation that the forces generated by healthy subjects would exceed the withstanding force of the tester, which is necessary to perform "make" tests precisely.[26] Furthermore, using a belt is convenient[29] and reduces the influence of the testers' different strength levels during HHD strength measurements.[27,30]

Participants were first positioned supine on a treatment bench with the head and neck supported by a foam therapy half roll with the feet off the end of the treatment bench (Fig. 1). The tester stood beside the participant's tested foot. The HHD was stabilized using a non-elastic belt that was placed around the pelvis of the tester. The pelvis, thighs, and tibias of both legs of the subjects were fixed on the bench with non-elastic belts to limit unwanted movements of the tested leg. Next, the participants sat on a treatment bench with their hands placed behind the back on the bench, their legs extended, and their feet off the end of the bench (Fig. 1). Again, the HHD was stabilized using a non-elastic belt that was placed around the pelvis of the tester. The thighs and the tibias of both legs of the participants were secured with non-elastic belts.

Figure 1. *Testing maximal isometric foot eversion torque while supine and sitting with knees extended. The HHD was stabilized using a non-elastic belt that was placed around the pelvis of the tester.*

Figure 2. *Testing maximal isometric foot eversion torque while lying on the side. The HHD was stabilized using a non-elastic belt that was vertically applied around the forefoot of the subject and the foot of the tester standing on the ground.*

Finally, participants were positioned on their side, again with the measured foot off the end of the treatment bench and with the tibia and thigh of the tested leg fixed with non-elastic belts (Fig. 2). The knee was supported by a rolled towel. The HHD was stabilized using a non-elastic belt that was vertically applied around the forefoot of the subject and the foot of the tester standing on the ground.

In all test conditions, the foot was positioned at 10° of plantarflexion.[28] For testing foot eversion strength, the transducer of the hand-held dynamometer was positioned at the lateral border of the forefoot directly below the fifth metatarsal head. For measuring foot inversion strength, the transducer of the hand-held dynamometer was placed at the medial border of the forefoot directly below the first metatarsal head. These points were marked with a waterproof pen for the retest. The recorded force in Newton (N) was converted to torque and expressed as Newton-meters (Nm) by multiplying it by the corresponding lever arm (in meters). The functional axis of rotation for eversion and inversion enters the front superior part of the talus on the medial side and crosses downwards to the lateral rearfoot.[31,32] For testing inversion strength, the lever arm was defined as the distance between the first metatarsal head (dynamometer placement) and the superior part of the sustentaculum tali, and for eversion strength between the fifth metatarsal head (dynamometer placement) and the superior part of the cuboid.

Isometric "make" tests were performed.[1,3] During the make test, the participant applies a maximal force against the HHD, that is stabilized by the examiner[8] or a belt. In contrast, the break test is performed by the examiner pushing the HHD against the participant's extremity until the participant's maximal muscular exertion is exceeded and the joint gives way.[8] Resistance was held for three seconds.[6] After one trial of a submaximal contraction was used to familiarize the subject with the task, three consecutive maximal contractions were performed by the subject which were recorded by an independent assessor. The tester, the subject and the assessor were blinded to the results from the previous day and to the results of the other tester. The mean of the three trials was used for further analysis.[3] Participants rested for approximately one minute when changing between the test positions and for approximately three minutes between groups of inversion and eversion measurements. All participants were measured barefoot. The foot (right/left) of the participant, the foot movement (inversion/eversion), and the position of the subject (supine, sitting, side-lying) were tested in a random order to avoid any effects of fatigue and habituation. Furthermore, the first tester (of the two testers) was selected at random. The participants were tested consecutively. The order of testing could not be randomized because of subjects' individual availability. This testing procedure was preserved for the retest session. All data collection using the HHD took place at medicoreha Welsink Akademie GmbH, a school of physiotherapy education in the city of Neuss (Germany).

In order to investigate the validity of the measurements of hand-held dynamometry, isometric foot inversion and eversion strength was tested using an isokinetic dynamometer (Cybex II®, USA) and recorded by the corresponding software (HUMAC® 2008v8.5.3 Norm™, CSMi Medical Solutions, 101 Tosca Drive, Stoughton, MA). The Cybex II® is considered to be reliable and valid for strength testing of the lower extremity.[33-35] Here, only 26 of the subjects participated and were considered for comparisons between HHD and isokinetic dynamometer measurements. Four participants were not available for this part of the study due to personal reasons. Participants were positioned according to the manufacturer's recommendations. They sat on the chair with the chair's backrest tilted (60°). The popliteal fossa of the tested leg lay on a cushion of a fixture and was fixed with a strap. The foot was placed on the ankle inversion-eversion footplate attachment at 10° of plantarflexion[28] and fastened using hook-and-loop closures to avoid movement between the sole of the shoe and the surface of the footplate (Fig. 3). Participants wore their own athletic shoes. The midline of the foot was aligned with the midline of the patella when adjusting the dynamometer and the chair,[5] positioning the calf in a nearly horizontal orientation. Data collected using the isokinetic dynamometer were performed at medicoreha Welsink Rehabilitation GmbH, an outpatient rehabilitation center in the city of Neuss (Germany).

Figure 3. *Testing maximal isometric foot inversion and eversion torques using isokinetic dynamometry.*

Statistical analysis

Data were examined for the normal distribution using the Kolmogorov-Smirnov test and histograms, and normal distribution of data was confirmed, allowing use of parametric tests for analysis. For testing the homogeneity of variance of the dependent variable isometric muscle strength of foot inversion and eversion, the Levene test was performed. Intra-class correlation coefficients (ICC, model 2, k) and 95% confidence intervals (CI) were then used to determine intra- and inter-tester measurement reliability. Values < 0.50 represented poor reliability, values > 0.50 and < 0.75 indicated fair to good reliability, and values > 0.75 marked excellent reliability.[15]

A two-way repeated measures analysis of variance (ANOVA) was used to test the interaction between the factors of test position and tester on measurements of isometric foot inversion and eversion torques using the HHD. The level of statistical significance was set a priori at $\alpha < 0.05$. Post hoc tests with Bonferroni adjustment of *p*-values were used for multiple pairwise comparisons of maximal inversion and eversion torques between test positions (supine, sitting and side-lying) within testers. Concurrent validity between measurements detected by hand-held dynamometry and isokinetic dynamometry was determined by calculating the intra-class correlation coefficient (ICC, model 3, k) and 95% confidence intervals (CI) between measurements of both testers using HHD and the measurement using the isokinetic dynamometer. Furthermore, Bland-Altman plots were used to demonstrate the range of error and difference between HHD and isokinetic measurements. Statistical analysis was conducted with commercial software (IBM SPSS Statistics 21.0).

RESULTS

Intra-tester reliability

For the maximal isometric inversion torque, intra-tester reliability for Tester 1 and Tester 2 was excellent in the supine position (Tester 1: $ICC_{2,k}$ = 0.815, 95% CI: 0.615-0.912, $p<0.001$; Tester 2: $ICC_{2,k}$ = 0.813, 95% CI: 0.608-0.911, $p<0.001$), good to excellent in the sitting position (Tester 1: $ICC_{2,k}$ = 0.784, 95% CI: 0.551-0.897, $p<0.001$; Tester 2: $ICC_{2,k}$ = 0.739, 95% CI: 0.455-0.876, $p<0.001$), and good in the side-lying position (Tester 1: $ICC_{2,k}$ = 0.675, 95% CI: 0.319-0.845, $p=0.002$; Tester 2: $ICC_{2,k}$ = 0.677, 95% CI: 0.336-0.844, $p=0.001$) (Fig. 4).

For the maximal isometric eversion torque, intra-tester reliability for Tester 1 and Tester 2 was good to excellent in the supine position (Tester 1: $ICC_{2,k}$ = 0.625, 95% CI: 0.221-0.821, $p=0.005$; Tester 2: $ICC_{2,k}$ = 0.813, 95% CI: 0.605-0.911, $p<0.001$), good to excellent in the sitting position (Tester 1: $ICC_{2,k}$ = 0.645, 95% CI: 0.247-0.832, $p=0.004$; Tester 2: $ICC_{2,k}$ = 0.819, 95% CI: 0.617-0.914, $p<0.001$), and fair to excellent in the side-lying position (Tester 1: $ICC_{2,k}$ = 0.828, 95% CI: 0.641-0.918, $p<0.001$; Tester 2: $ICC_{2,k}$ = 0.598, 95% CI: 0.146-0.810, $p=0.009$) (Fig. 4).

Inter-tester reliability

For the maximal isometric inversion torque, inter-tester reliability was good to excellent in the supine position when measured over two days (day 1: $ICC_{2,k}$ = 0.656, 95% CI: 0.215-0.843, $p<0.001$; day 2: $ICC_{2,k}$ = 0.824, 95% CI: 0.634-0.916, $p<0.001$). In the sitting position, inter-tester reliability was fair on day one ($ICC_{2,k}$ = 0.519, 95% CI: -0.045-0.777, $p=0.005$) and excellent on day two ($ICC_{2,k}$ = 0.879, 95% CI: 0.731-0.944, $p<0.001$). Measurements in the side-lying position revealed excellent inter-tester reliability on day one ($ICC_{2,k}$ = 0.812, 95% CI: 0.604-0.911, $p<0.001$) as well as day two ($ICC_{2,k}$ = 0.835, 95% CI: 0.655-0.921, $p<0.001$) (Fig. 5).

For the maximal isometric eversion torque, inter-tester reliability was excellent in the supine position

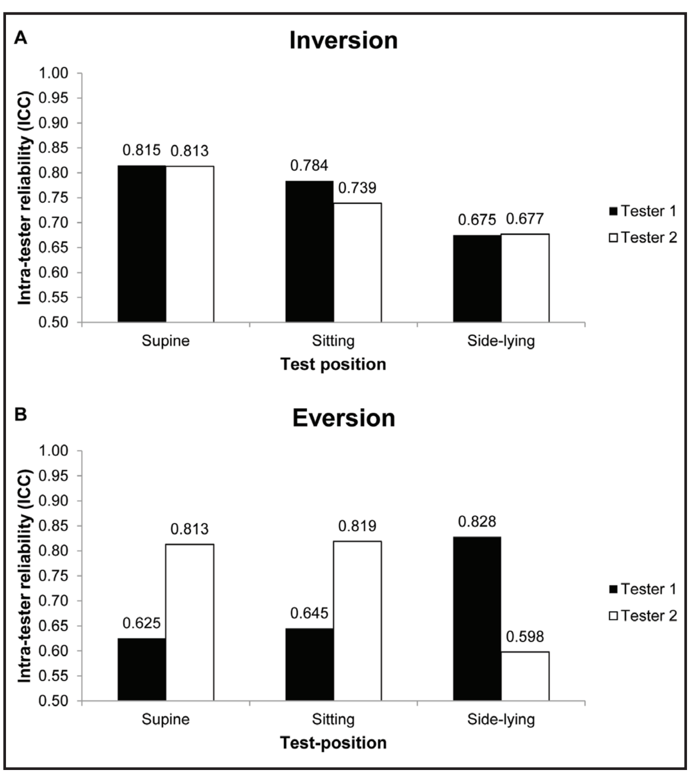

Figure 4. *Intra-tester reliability of inversion (A) and eversion (B) strength measurements using a belt-stabilized hand-held dynamometer over two days in three different positions. ICC = Intraclass correlation coefficient (model 2,k).*

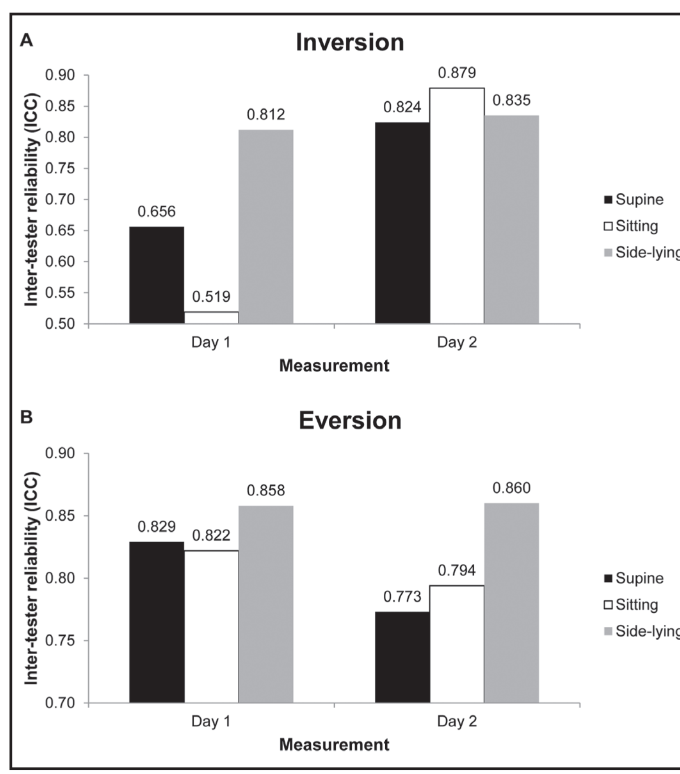

Figure 5. *Inter-tester reliability of inversion (A) and eversion (B) strength measurements using a belt-stabilized hand-held dynamometer over two days in three different positions. ICC = Intraclass correlation coefficient (model 2,k).*

Table 1. *Mean ± standard deviation (SD) and standard error of measurement (SEM) for maximal isometric torques (Nm) of foot inversion and eversion in different subject positions using the HHD. Significance of differences (Bonferroni adjusted p-values) of post hoc tests of measurements in different test positions (ab = supine vs. sitting, ac = supine vs. side-lying, bc = sitting vs. side-lying) within testers on days one and two*

Measurement		**Test condition, Tester 1, day 1**		**Significance of differences between test positions, within tester**
	HHD supine (a) [Mean ± SD (SEM)]	HHD sitting (b) [Mean ± SD (SEM)]	HHD side lying (c) [Mean ± SD (SEM)]	*p*-values (ab; ac; bc)
Inversion	7.3 ± 2.6 (0.5)	8.0 ± 2.4 (0.4)	8.9 ± 2.8 (0.5)	*p* =0.004; *p* <0.001; *p* =0.001
Eversion	6.2 ± 2.1 (0.4)	6.2 ± 2.2 (0.4)	11.0 ± 3.7 (0.7)	*p* =1; *p* <0.001; *p* <0.001
		Tester 2, day 1		
	HHD supine (a) [Mean ± SD (SEM)]	HHD sitting (b) [Mean ± SD (SEM)]	HHD side lying (c) [Mean ± SD (SEM)]	*p*-values (ab; ac; bc)
Inversion	5.9 ± 2.3 (0.4)	6.1 ± 2.3 (0.4)	8.8 ± 2.8 (0.5)	*p* =0.257; *p* <0.001; *p* <0.001
Eversion	5.8 ± 2.1 (0.4)	5.7 ± 2.2 (0.4)	10.4 ± 3.4 (0.6)	*p* =1; *p* <0.001; *p* <0.001
		Tester 1, day 2		
	HHD supine (a) [Mean ± SD (SEM)]	HHD sitting (b) [Mean ± SD (SEM)]	HHD side lying (c) [Mean ± SD (SEM)]	*p*-values (ab; ac; bc)
Inversion	7.0 ± 2.5 (0.5)	7.6 ± 2.7 (0.5)	9.4 ± 3.9 (0.7)	*p* =0.004; *p* <0.001; *p* =0.001
Eversion	5.8 ± 1.7 (0.3)	6.1 ± 2.1 (0.4)	10.5 ± 3.6 (0.7)	*p* =1; *p* <0.001; *p* <0.001
		Tester 2, day 2		
	HHD supine (a) [Mean ± SD (SEM)]	HHD sitting (b) [Mean ± SD (SEM)]	HHD side lying (c) [Mean ± SD (SEM)]	*p*-values (ab; ac; bc)
Inversion	6.5 ± 2.5 (0.5)	6.9 ± 2.6 (0.5)	9.8 ± 4.0 (0.7)	*p* =0.257; *p* <0.001; *p* <0.001
Eversion	5.8 ± 1.7 (0.3)	5.7 ± 1.9 (0.3)	10.2 ± 3.2 (0.6)	*p* =1; *p* <0.001; *p* <0.001

when measured on two days (day 1: $ICC_{2,k}$ = 0.829, 95% CI: 0.643-0.918, $p<0.001$; day 2: $ICC_{2,k}$ = 0.773, 95% CI: 0.519-0.892, $p<0.001$). In the sitting position, inter-tester reliability was excellent on day one ($ICC_{2,k}$ = 0.822, 95% CI: 0.626-0.915, $p<0.001$) and on day two ($ICC_{2,k}$ = 0.794, 95% CI: 0.573-0.901, $p<0.001$). Measurements in the side-lying position demonstrated excellent inter-tester reliability on day one ($ICC_{2,k}$ = 0.858, 95% CI: 0.705-0.923, $p<0.001$) as well as day two ($ICC_{2,k}$ = 0.860, 95% CI: 0.706-0.933, $p<0.001$) (Fig. 5).

Comparability of the measurements in different test positions

The mean, standard deviation, and standard error of measurement for maximal isometric torques of foot inversion and eversion in different participant positions using the HHD are shown in Table 1. Two-way repeated measures analysis of variance (ANOVA) demonstrated significant tester X test position interaction effects for inversion and eversion torques ($p<0.001$). Figure 6 shows the significance of simple effects (the effect of test position for each tester) on both days.

Furthermore, a significant day X test position interaction effect was noted for inversion torques measured by Tester 2 ($p<0.05$). The significant differences (*p*-values) between the post hoc tests of measurements in different test positions within testers on days one and two are presented in Table 1.

Concurrent validity

Strength measurements using the isokinetic dynamometer revealed considerably higher inversion [mean: 20.1 ± SD 6.1 Nm (SEM 1.2)] and eversion torques [mean: 18.9 ± SD 8.3 Nm (SEM 1.6)] than torques measured with the HHD in all positions.

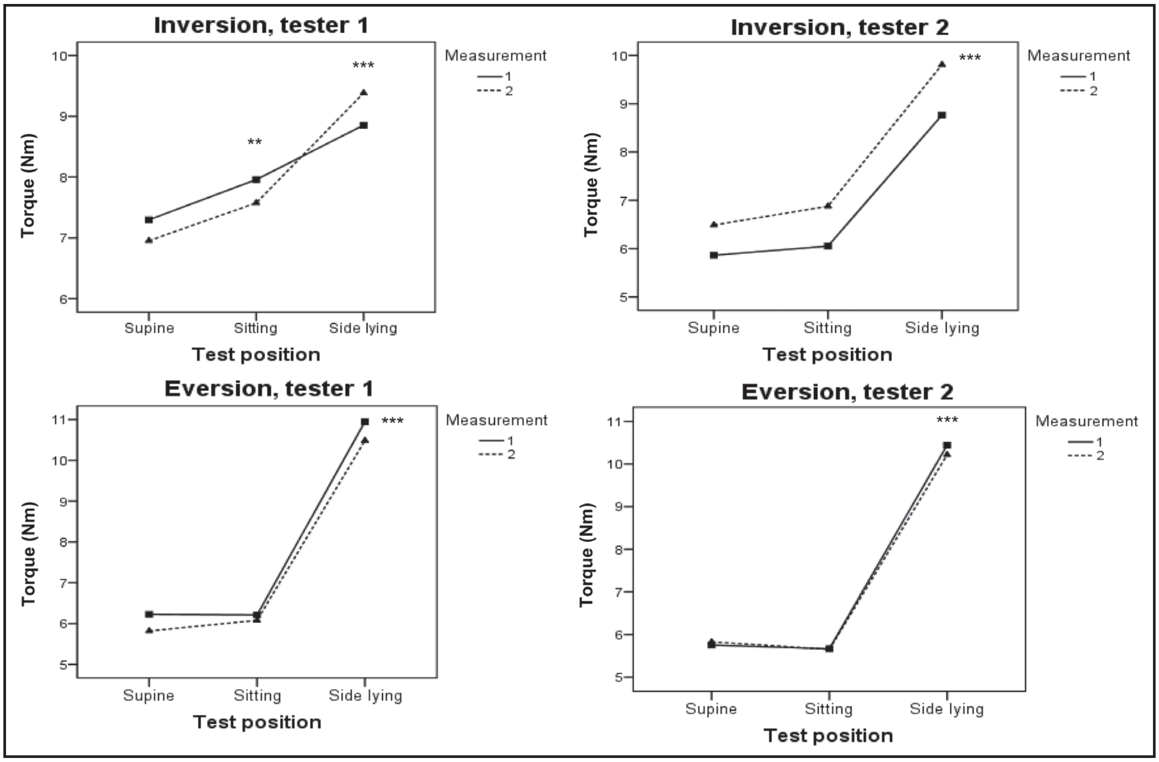

Figure 6. *Significance of the simple effects (the effect of test position for each tester) of inversion and eversion torques (Nm = Newton-meters) tested in 3 different positions on both days, **p<0.01, ***p<0.001. Between measurement 1 (day 1) and measurement 2 (day 2), no significant differences were found.*

Accordingly, little agreement between measurements using the HHD and isokinetic dynamometer was observed for maximal isometric inversion torques. The HHD measurement in the supine position vs. isokinetic dynamometry revealed an $ICC_{3,k}$ = 0.303 (95% CI: -0.555-0.687, $p=0.187$). The HHD measurement in the sitting position vs. isokinetic dynamometry showed an $ICC_{3,k}$ = 0.347 (95% CI: -0.457-0.707, $p=0.147$). A fair correlation was demonstrated between the measurement using the HHD in the side-lying position vs. the isokinetic dynamometer ($ICC_{3,k}$ = 0.562, 95% CI: 0.024-0.804, $p=0.022$). For the maximal isometric eversion torque, similar results were observed for the comparison between the HHD measurement in the supine position, and the isokinetic dynamometer ($ICC_{3,k}$ = 0.205, 95% CI: -0.772-0.644, $p=0.285$). Low correlations between HHD and isokinetic measurements were observed in the sitting position ($ICC_{3,k}$ = 0.241, 95% CI: -0.693-0.660, $p=0.248$) and the side-lying position ($ICC_{3,k}$ = 0.427, 95% CI: -0.278-0.743, $p=0.085$). Bland-Altman plots show that measurements using the HHD do not agree with those using the isokinetic dynamometer (Fig. 7). The mean of the differences of measurements for inversion and eversion torques deviates considerably from zero, indicating that measurements using the isokinetic dynamometer produce higher values than measurements using the HHD. Furthermore, the plots consistently show that the greater the torques, the greater the deviation from zero. The difference in inversion torques using the HHD and the isokinetic dynamometer varied extensively with the 95% limits of agreement between 1.7 Nm and 24.9 Nm measured in supine position, between 1.5 Nm and 24.3 Nm assessed in sitting and between 0.4 Nm and 20.8 Nm measured in side-lying. The difference in eversion torques using the HHD and the isokinetic dynamometer varied similarly with the 95% limits of agreement between -2.7 Nm and 28.7 Nm measured in supine position, between -2.7 Nm and 28.7 Nm measured in sitting and between -6.4 Nm and 23.0 Nm assessed in side-lying.

A post hoc power analysis on the basis of $\alpha < 0.05$, the lowest identified effect size (η^2 = 0.44, i.e., f = 0.89) from two-way ANOVA comparing measurements

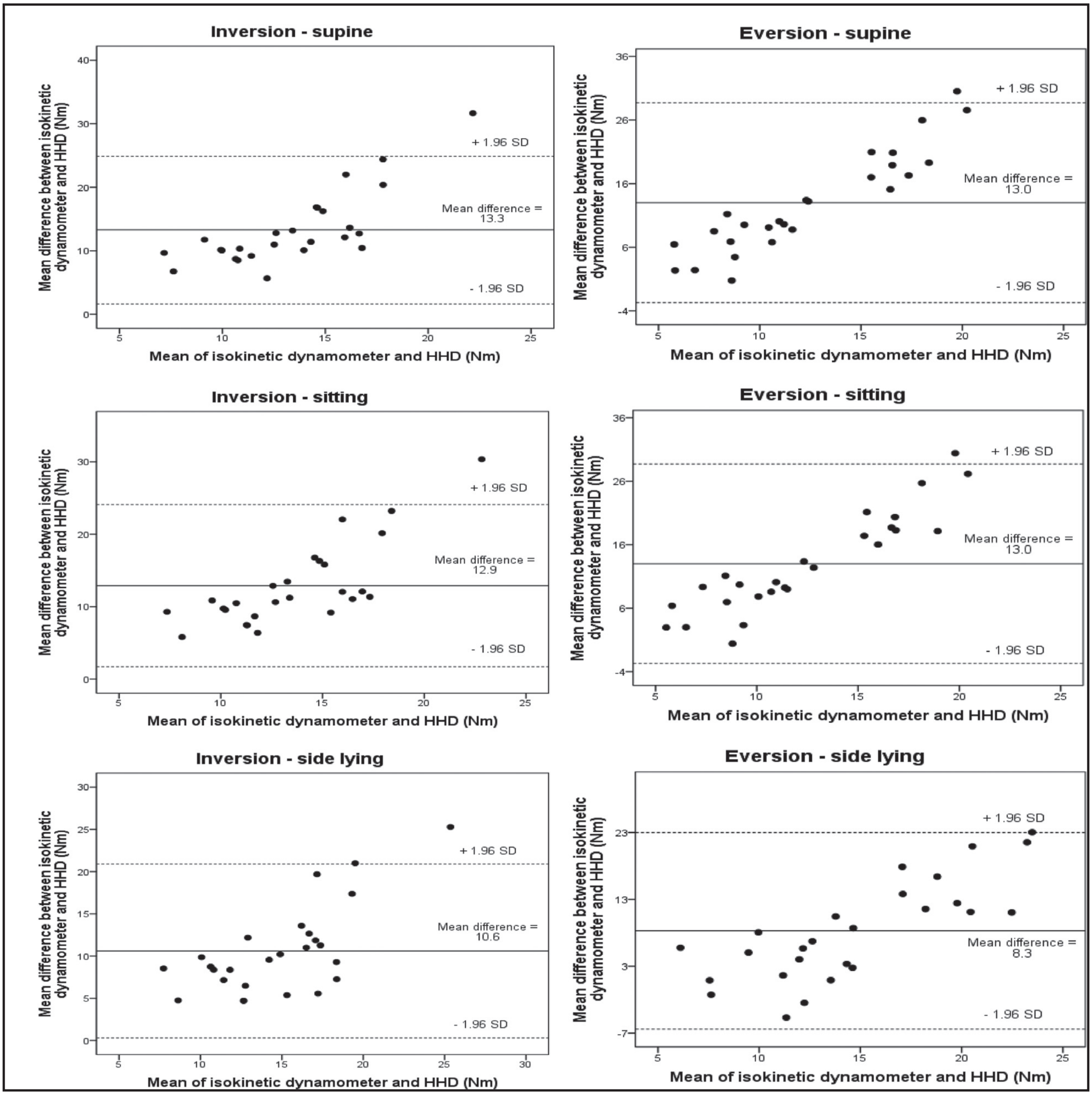

Figure 7. *Bland-Altman plots illustrating the difference (y-axis) compared with the mean (x-axis) of foot inversion and eversion torques (Nm) using a hand-held dynamometer (HHD) and isokinetic dynamometer. The middle line characterizes the mean difference between the HHD and isokinetic dynamometer. The upper and lower dashed lines demonstrate the 95% limits of agreement.*

using HHD in different test positions, and a sample size of n = 30, revealed a test power of > 90%.

DISCUSSION

The main findings of the present study were that measurements of foot inversion and eversion torques in different test positions using a belt-stabilized HHD were reliable when repeated by the same tester and when measured by different testers. While the maximal torques between supine and sitting with the knees extended test positions were comparable, those carried out with supine/sitting and side-lying positions differed. When compared to measurements using an isokinetic dynamometer, the maximal torques differed as well.

The analysis of the reliability of foot inversion and eversion strength testing in healthy subjects is similar to that reported in a previous study.[36] ICC values of 0.74 for foot inversion and 0.84 for foot eversion strength measurements are presented here. For inversion strength measurements, there was a higher agreement within testers in the supine and sitting test positions than in the side-lying position. For eversion strength measurements, Tester 2 showed similar results, while the results of Tester 1 showed a higher agreement between measurements in side-lying than in supine and sitting positions. This suggests that foot inversion and eversion strength measurement methods should not be used alternatively by the same tester in evaluating patients' treatment progress. Furthermore, different testers should agree upon the test method before testing the same patient. Highly reliable measurements of foot inversion and eversion strength using HHD are only ensured using the same subject position with the same test method in pre- and post-measurements, as previously reported.[15]

Analysis of the inter-tester reliability of measurements demonstrated a higher agreement between the results of testers on the second day compared with the first day for the supine and sitting test positions, suggesting a learning effect for testers. For eversion torques, correlations between testers were excellent on both days for all of the test positions, especially for side-lying position. In this position, the belt was fixed with the foot of the tester standing on the ground, ensuring a total static resistance without the influence of resistance applied by the tester's body or body parts. This suggests that a belt-fixated method, where stabilization is provided by a static object, should be used for inversion and eversion strength testing.

Force values of measurements using a HHD have been previously reported to range from 19.5 kg (≈ 191.3 N) to 22.0 kg (≈ 215.8 N) for inversion and from 19.5 kg (≈ 191.3 N) to 22.4 kg (≈ 219.7 N) for eversion in healthy participants with a slightly higher mean age of 28.1 years.[36] In the present study, the strength values in all positions are considerably lower. Furthermore, they differ similarly to the values reported for the healthy controls in the study by Carroll et al.[1] (inversion: 127.5 N; eversion: 121.7 N). This is in contrast to the suggestion that forces or torques measured with a belt-stabilized HHD would reveal higher values than assessed manually as previously reported for the knee and the hip.[30,37-39] Therefore, stabilizing the HHD using a non-elastic belt may not be optimal for replacing the manual resistance applied by the tester in HHD foot inversion and eversion measurements. However, this should be investigated in further studies.

The peak eversion torques of control subjects with a mean age of 43.1 years (subjects from Quebec) and 45.7 years (subjects from Lyon) in the study of Hébert et al.[3] ranged from 17.9 Nm to 19.6 Nm. Furthermore, isometric pronator and supinator torques that were measured using a specific foot apparatus ranged from 17.5 Nm to 18.5 Nm and from 13.3 Nm to 14.8 Nm, respectively.[9] However, the lever arm was not defined in either of the previous studies, so that differences might have been caused by a larger lever arm. Furthermore, the different position of participants[9] might be another reason for different torque outputs.

The peak forces measured with the HHD in the present study were lower than foot inversion and eversion force values in patients with chronic ankle instability measured with a HHD prior to a training intervention.[22] The force values in the study of Hall et al.[22] ranged from 157.2 N to 187.5 N for inversion and from 141.2 N to 175.5 N for eversion. Therefore, it appears that results of inversion and eversion strength measurements using HHD depend on the test method rather than on the existing ankle instability.

In the present study, the torques tested in the supine and sitting positions were consistently lower than those measured in the side-lying position, indicating that gravity is not the crucial factor in strength measurements using HHD. The fixation of the dynamometer and the applied resistance appeared to be most reliable in the side-lying position. It is therefore obvious that the muscles need a constant static resistance in order to generate high forces and torques, which is consistent with the results of the aforementioned studies of the knee and hip.[30,37,38]

Isometric eversion torques measured with the isokinetic dynamometer revealed lower values than eversion torques of healthy controls in the study of Kaminski et al. (30.14 Nm)[11] who only tested male students, which could account for the higher values.

The SEMs for the measurements using HHD and isokinetic dynamometer in the present study were low, indicating that differences of strength levels between subjects appear to be identifiable. As previously reported for the shoulder, testing techniques with low SEM are considered to be important for accuracy of measurements, especially to predict risk of injury.[40]

Concurrent validity of inversion and eversion strength was low to fair compared with results of isokinetic dynamometry. This is consistent with the results from a study investigating plantarflexion strength.[7] Measurements using HHD in a side-lying position demonstrated higher validity than measurements in supine and sitting positions, which supports the theory that strength testing could be better controlled in this position. Furthermore, Bland-Altman plots showed that the discrepancy between HHD measurements and measurements using the isokinetic dynamometer increased with higher torques produced by the stronger subjects, especially when carried out with subjects in supine and sitting positions. Consequently, it seems that both testers were not able to control the torques generated by stronger subjects, although the HHD was stabilized using a belt around the tester's pelvis. The findings of 95% limits of agreement support these assumptions and are similar to those previously determined for plantarflexion force values.[7] It seems that the torques measured with the belt-stabilized HHD with participants lying on the side are more similar to the torques obtained with the isokinetic dynamometer because the tester could stabilize the belt to a fixed object, the floor. Based on these findings from Bland-Altman analysis, physiotherapists should not use the HHD and the isokinetic dynamometer alternatively to identify deficits of foot inversion and eversion strength. The validity results should be interpreted with caution, however, because the isokinetic test position differed from the position used for measurements with HHD. Furthermore, during measurements with the isokinetic dynamometer, the participants wore their own shoes to ensure a safe fixation of the foot on the footplate of the device while strength measurements using HHD were performed barefoot to ensure comparability with results presented in literature.

There are further limitations of the study that need to be addressed. In measurements using the HHD, a limitation was that the dynamometer was fixed with the belt around the pelvis of the tester with the subject in the supine and sitting positions; therefore, the applied resistance depended on the tester. However, as this technique is often used in manual therapy interventions, it was expected that resistance could be controlled more effectively with the body weight of the tester than with resistance applied with the hand.[26] For future investigations, a device to stabilize the belt to a fixed object introduced by Thorborg et al[30] may help to improve the test methods and reduce variation.

CONCLUSION

Inversion and eversion strength measurements using HHD in different subject positions demonstrate good to excellent intra- and intertester reliability but only poor to fair validity when compared with isometric strength measurements using an isokinetic dynamometer. While the outcomes assessed in supine and sitting positions seem to be comparable, those measured in supine/sitting and side-lying positions differed. These results may be relevant for the measurement of foot inversion and eversion strength during the recovery from common and prevalent foot and ankle injuries.

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