Validity and Reliability of a Portable Isometric Dynamometer to Measure Strength Performance Variables in Athletes

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Isometric dynamometer | **Field testing** | **Force-time curve** | **Isometric mid-thigh pull**

Headline

This study assessed the validity and reliability of force-time curve variables obtained from an dynamometer compared to a force platform during an isometric mid-thigh pull test. Eighteen athletes (age=18.7±6.12 years) participated in two sessions held one week apart. Peak force, rate of force development, and force at specific time points were compared within and across devices. The study found high validity (ICC=0.99, CV=4.0%) and sufficient relative reliability (ICC=0.81, CV=21.2%) for peak force measurements. The isometric dynamometer is recommended as a highly valid and sufficiently reliable tool for measuring peak force, but not for alternative force-time curve variables.

Introduction

The isometric mid-thigh pull (IMTP) test using a force platform is a popular and common method used in sporting populations to measure and quantify maximal strength amongst athletes (1–4). Maximal force production was observed in the pull at the mid-thigh position adopted during Olympic weightlifting movements such as the clean and snatch (5). The force platform is traditionally used in the IMTP test to derive force-time curve variables, such as peak force, rate of force development (RFD), and force at specific time points through the collection of ground reaction force data. Past analysis of force-time curve variables has been shown to be highly correlated to sporting performances such as the 10-m sprint (6), shot-put (7) and golf swing (8). However, using force platforms to conduct the IMTP test is highly costly and lacks portability due to the nature of the size and set-up of the testing rigs. This limits its utility in only laboratory settings and not out in sporting environment, where field testing provide a practical and ecological way to assess an athlete's physical fitness and performance in real-world conditions (9). In recent years, there has been an increase in the utility of commercial isometric dynamometers to measure force-time curve variables in the field, as the devices are portable and affordable in comparison to that of the force platform (10). However, there is limited research in the validity and reliability of these devices in the field of sport science. The aim of this study was to investigate the criterion validity and test-retest reliability of force-time curve variables derived from a portable isometric dynamometer in an IMTP test.

Methods

Experimental Approach to the Problem

The study was designed to assess the the criterion validity and test-retest reliability of an IMTP test performed on an isometric dynamometer against a force platform. All athletes were familiar with the IMTP protocol as it was periodically administered as part of the strength test battery at the sports institute. Two separate test sessions were conducted a week apart, with testing consistency maintained with subjects being assessed at the same time of the day (± 2 hours) (11). Activity levels (i.e. Strength and sport training sessions) were maintained in between test session. The highest force value at any time point during the IMTP trial was reported as the absolute peak force. Rate of force development (RFD) was calculated as the mean from the initiation of the pull (identified as the time corresponding to three standard deviations from baseline) to the identified peak force. Force at given time points was also measured at 100, 200 and 300 milliseconds (F_{100}, F_{200} and F_{300}). All recorded data was post-processed by a custom-designed Python (3.11, Python Foundation, USA) script.

Subjects

National-level athletes (n = 18; age: 18.7 ± 6.12 years; height: 168 ± 11.0 cm; weight: 61.2 ± 14.3 kg) from various sporting backgrounds (i.e., athletics, sailing, sport climbing, windsurfing, wrestling, wushu, and volleyball) and ≥ 2 years resistance training experiencer were recruited for this study. All athletes were currently undertaking a structured resistance training program conducted by Certified Strength and Conditioning Specialists. Subject recruitment and testing were conducted at the strength and conditioning facility in the National Youth Sports Institute (NYSI). Subjects were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study. A parental or guardian signed consent was obtained for subjects who were under the age of 21 years of age. This study was approved by the Singapore Sports Institute (SSI) Institutional Review Board (IRB Approval ID: BM-EXP-031) and was performed in accordance with the Helsinki Declaration.

Procedures

The setup for the IMTP test was configured within a traditional squat rack, where a heavy duty chain was used to attach the isometric dynamometer (GStrength, Exsurgo Technologies, LLC) and handle bar to the bottom frame. The dual force platform (Forcedecks, VALD Performance, Newstead, Queensland Australia) was placed across the frame to complete the experimental set-up (Figure 1.). Before each testing session, subjects performed 3 minutes of warm-up on the cycle ergometer, followed by a series of general dynamic stretches. The IMTP test required subjects to position themselves on the force platform, with feet approximately hip width apart. The subjects adopted the second pull position of the Olympic clean lift, with the height of the handle bar adjusted so that the hip and knee flexion angles were maintained at 140 – 150° and 125 – 135° respectively (12). Subjects used wrist straps to grasp the handlebar with an overhand grip. Subjects were familiarised with the IMTP test through 2 submaximal attempts at 50% and 80% maximal effort. Thereafter, subjects performed 3 trials of the IMTP protocol, with a rest interval of 2 minutes between each repetition. During each trial, subjects were instructed to pull on the handle bar "as fast and hard as possible" and maintain the maximal tension for 5 seconds (13). Strong verbal encouragement for maximal effort was given for all trails.

Fig. 1. **"Open-chain" configuration of the isometric mid-thigh pull (IMTP) test.**

Statistical Analysis

Validity and reliability for peak force, rate of force development (RFD), and force at time-specific point values of 100 – 300ms (F_{100}, F_{200} and F_{300}) were calculated by means of the intraclass correlation coefficient (ICC), coefficient of variation (CV), and 90% confidence intervals (CIs). Acceptable and high ICC values were determined at cut-offs of $\geq$ 0.8 and $\geq$ 0.9 respectively (4). Acceptable and high CV values were determined at cut-offs of $\leq$ 10% and $\leq$ 5% respectively (4). Pearson's correlation coefficient (r) was used to calculate criterion validity between both devices. The values for r were classified as little or no relationship (0.00 – 0.24), fair relationship (0.25 – 0.49), moderate to good relationship (0.50 – 0.74), and good to excellent relationship (0.75) (14). The standard error of measurement (SEM) was used as a measure of the precision of the two devices, and it was calculated as SEM = SD * $\sqrt{(1-r)}$, with SD being the standard deviation and r being the Pearson product-moment correlation (15). Bland-altman plots were used to display visual representations of the errors against true values by plotting the difference between force-time curve variables obtained between testing sessions and devices. Data was analysed using the Statistical Package for Social Sciences (version 28; IBM, New York). A p-value of $<$0.05 was considered statistically significant.

Results

Peak force derived from the isometric dynamometer demonstrated high validity (ICC = 0.99, 90% CI: 0.98 – 1.00; CV = 4.0%, 90% CI:2.96 – 5.04) (Table 1), when compared to the force platform. A low standard error of measurement (SEM) (40.6 N) with a systematic bias of -57.2N was observed (Figure 2). The isometric dynamometer also reported sufficient relative reliability (ICC = 0.82, 90% CI:0.64 – 0.91; CV = 21.2%, 90% CI:19.9 – 22.4) results between both test sessions (Table 2). Rate of force development did not reach acceptable validity (ICC = 0.03, 90% CI = -0.41 – 0.36; CV = 32.2%, 90% CI = 30.1 – 34.3) or reliability (ICC = -0.21, 90% CI = -0.55 – 0.20; CV = 42.8%, 90% CI = 40.2 – 45.4) for the isometric dynamometer (Table 3). Force at time-specific point values of 100 – 300ms (F_{100}, F_{200} and F_{300}), did not reach acceptable validity or reliability for the isometric dynamometer (Table 4). This was represented by a wide range of CV values, from 30.5 (90% CI = 27.5 – 33.5) to 32.1 (29.3 – 34.9), and ICC values ranging from -0.03 (90% CI = -0.13 – 0.13) to -0.01 (90% CI = -0.09 – 0.12). The isometric dynamometer showed proportional bias compared to the force platform when measuring force values at time specific points (Figure 3).

Table 1. Criterion validity for the measurement of peak force between the isometrtic dynamometer and force plateform in the isometric mid-thigh pull (IMTP) test.

Isometric dynamometer (mean ± SD)	1363 ± 464 N
Force platform (mean ± SD)	1308 ± 444 N
ICC (90% CI)	0.99 (0.98 – 1.00)
CV% (90% CI)	4.0 (2.96 – 5.04)
SEM	40.6 N
r	0.99

SD = standard deviation; ICC = intraclass correlation coefficient; CV = coefficient of variation; CI = confidence interval; SEM = standard error of measurement

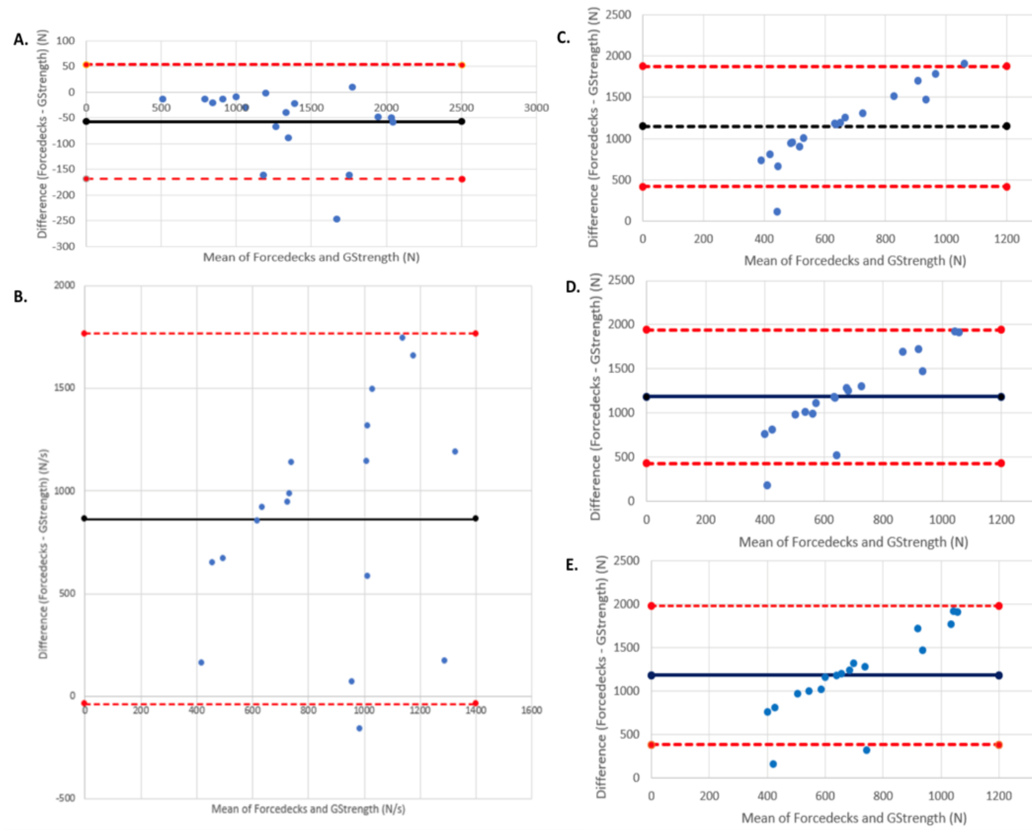

Fig. 2. Bland-Altman plots for the measurement of (A) peak force, (B) rate of force development (RFD), (C) force at 100ms, (D) force at 200ms, and (E) force at 300ms from the isometric dynamometer and force platform. The bold lines represent the mean difference between the two devices, and the dotted lines represent the 90% limits of agreement for the mean difference.

Table 2. Test-retest reliability for the measurement of peak force from the isometrtic dynamometer in the isometric mid-thigh pull (IMTP) test.

Session 1 (mean ± SD)	1363 ± 464 N
Session 2 (mean ± SD)	1345 ± 376 N
ICC (90% CI)	0.82 (0.64 – 0.92)
CV% (90% CI)	21.2 (19.9 – 22.4)
SEM	186 N
r	0.83

SD = standard deviation; ICC = intraclass correlation coefficient; CV = coefficient of variation; CI = confidence interval; SEM = standard error of measurement

Table 3. Criterion validity and test-retest reliability for rate of force development (RFD) measurements in the isometric mid-thigh pull (IMTP) test.

	Validity	Reliability
ICC (90% CI)	0.03 (-0.41 – 0.36)	-0.21 (-0.55 – 0.20)
CV% (90% CI)	32.2 (30.1 – 34.3)	42.8 (40.2 – 45.4)
SEM	489 N/s	331 N/s
r	-0.03	-0.21

ICC = intraclass correlation coefficient; CV = coefficient of variation; CI = confidence interval; SEM = standard error of measurement

Table 4. Criterion validity and test-retest reliability for force at time-specific point values in the isometric mid-thigh pull (IMTP) test.

	Validity			Reliability		
	100 ms	200 ms	300 ms	100 ms	200 ms	300 ms
ICC (90% CI)	-0.01 (-0.09–0.13)	-0.02 (-0.11–0.12)	-0.03 (-0.13–0.13)	-0.09 (-0.50–0.33)	-0.26 (-0.63–0.17)	-0.10 (-0.51–0.32)
CV% (90% CI)	32.1(29.3–34.9)	30.5(27.5–33.5)	30.9(27.9–33.9)	93.4(48.8–109)	88.8(59.7–128.1)	1023(66.2–163)
SEM	256 N	268 N	295 N	112 N	78.5 N	181 N
r	0.01	-0.25	-0.25	-0.12	-0.11	-0.08

ICC = intraclass correlation coefficient; CV = coefficient of variation; CI = confidence interval; SEM = standard error of measurement

Discussion

The study investigated the criterion validity and test-retest reliability of force-time curve variables (i.e., Peak force, rate of force development (RFD), and force at time-specific points of 100 – 300ms (F_{100}, F_{200} and F_{300})) derived from a portable isometric dynamometer in an IMTP test. High validity and sufficient relative reliability were reported in the measures of peak force.

A high validity for peak force was reached by the isometric dynamometer (ICC = 0.99; CV = 4.0%), but the device slightly over-reported peak force measures compared to the force platform with a systematic bias of 40.6 N. However, high relative (ICC = 0.82) but low absolute (CV = 21.2%) reliability representations suggested that changes in the peak force needed to be cautiously interpreted when assessing improvements in the strength profile of individuals. The smallest worthwhile change in this sampled population is 92.8 N, which is less than the standard error of measurement for the device (186 N). Thus, the isometric dynamometer is not able to detect a small magnitude of effect in profiling the absolute strength of an athletic population. For the other force-time curve variables, the RFD, F_{100}, F_{200} and F_{300} derived from the isometric dynamometer were not valid and reliable for the IMTP test, as the measures exceeded acceptable thresholds. This showed that only the measure of peak force derived from the isometric dynamometer can be used to accurately assess the absolute strength of athletes, but caution should be used in monitoring other intrinsic measures of neuromuscular performance such as RFD in strength development.

The validation of peak force measures obtained from the isometric dynamometer gives confidence for practitioners to assess the strength profile of the athletes under their charge. A previous study had shown that the device was found to report content validity when compared to the calibrated weights (5-, 25-, 50-, 100-, 200-, 250-kg) (16). A perfect relationship (r = 1.00, $p<0.001$) between the device and known loads was reported, albeit a small overestimation error with no fixed or proportional bias (16). The low absolute reliability of the peak force measure from the isometric dynamometer may be due to the "open-chain" configuration of the experimental set-up (17–19). As the handle bar is attached in space to the isometric dynamometer by a heavy-duty chain, there may be slight anterior-posterior and medio-lateral deviations by the athlete in the direction of the applied force pulled during the IMTP test (4). This may systematically result in inconsistent results generated for measures of the peak force values.

The results of this study also reported that measures of RFD, F_{100}, F_{200} and F_{300} derived from the isometric dynamometer were not valid and reliable for the isometric mid-thigh pull (IMTP) test. The 83.3 hertz sampling rate of the device may have inadequately captured the quick ramp in force development observed in the fast pull of the IMTP protocol. The results corresponded to a similar a study that recruited recreationally active males to perform an IMTP test with an attached S-type load cell (100 hertz sampling rate) (4). The same force-time curve variables did not reach acceptable levels of validity or reliability in the experimental condition (4). When a force platform (1000 hertz sampling rate) was used, other studies reported that the corresponding measures were reliable components to be assessed among professional rugby league players (6), elite Olympic weightlifters (13) and Division I collegiate athletes (20). As a result, appropriate devices (i.e. force platforms with a high sampling rate) need to be used when measures of rapid force production (i.e., RFD) is needed to be monitored in an athletic population.

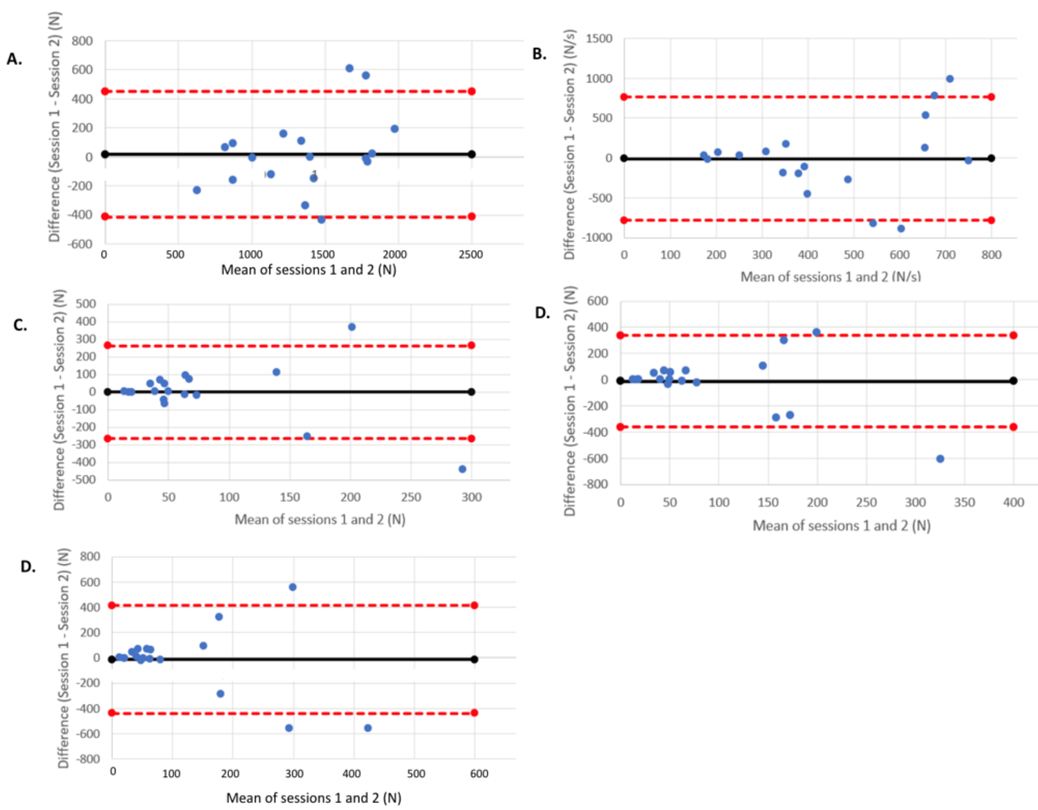

Fig. 3. Bland-Altman plots for the measurement of (A) peak force, (B) rate of force development (RFD), (C) force at 100ms, (D) force at 200ms, and (E) force at 300ms from the isometric dynamometer. The bold lines represent the mean difference between the testing sessions, and the dotted lines represent the 90% limits of agreement for the mean difference.

Limitations

- The limitations of this study include the lack of recruitment of well-trained participants. The discrepancy in the results may be due to the recruitment of youth athletes in the current study. The lower training age and limited familiarization with the IMTP test of the subjects may have influenced the desired technical execution required for the investigation (4). Future investigations should recruit senior athletes with both a higher training age and strength levels.
- In addition, the "open-chain" configuration of the experimental condition may have influenced the consistency of the results being captured. A customised sliding column, alike a smith machine, may limit any anterior-posterior and medio-lateral deviations of the pulling vector. In order to minimise the mentioned effects in the current protocol, it is important that researchers and coaches emphasise the testing instruction for athletes to "pull upright as hard and fast as possible" during the IMTP test (21).

The primary aim of this investigation was to determine whether the isometric dynamometer can be used as an alternative to the force platform for an IMTP test. Although measures of RFD, F_{100}, F_{200} and F_{300} failed to meet the acceptable thresholds needed, the peak force obtained from the isometric dynamometer met adequate validity and sufficient relative reliability for testing in an athletic population. This finding is aligned to other studies that assessed the force-time curve variables derived from various customised strain gauges (4,12,17).

Practical Applications

- The isometric mid-thigh pull (IMTP) test is a common method to assess the strength profile of athletes, as research has reported a high relationship between isometric strength variables and sporting performance.
- Due to the low cost and portability of isometric dynamometers, practitioners have been readily utilizing such commercial devices instead of the traditional force platforms.
- Their portability also allows strength testing, that were once traditionally limited within the laboratory settings, to be administered in the field.
- In this study, peak force measures derived from the isometric dynamometer (GStrength, Exsurgo Technologies, LLC) displayed high validity and sufficient relative reliability to for the IMTP test.
- This gives confidence for practitioner to utilize the device to assess the relevance of maximal strength for a given athlete population or sport.
- Although, the device also displays alternative force-time curve variables such as rate of force development (RFD) and force at specific time intervals (100 – 300ms), caution should be used in their interpretation for training as the measures exceeded acceptable thresholds of validity and reliability.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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