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Validity and intra-session reliability of a low-cost device for assessing isometric mid-thigh pull force

original paper
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DIEGO COUTO[1], RAFAEL CUNHA[1], VICTOR LAGE[1], VALDINAR ROCHA-JUNIOR[1,2], WANDERSON SANTOS[3], JOÃO B. FERREIRA-JUNIOR[4], JAMES TUFANO[5], AMILTON VIEIRA[1]

[1] Strength and Conditioning Laboratory, Faculty of Physical Education, University of Brasilia, Brasília, Brazil
[2] National Police Academy, Federal Police, Brasília, Brazil
[3] Faculty of Physical Education and Dance, Federal University of Goiás, Goiás, Brazil
[4] Federal Institute of Sudeste of Minas Gerais, Rio Pomba, Brazil
[5] Faculty of Physical Education and Sport, Charles University, Prague, Czech Republic

ABSTRACT

Purpose. The isometric mid-thigh pull (IMTP) test is a strength test usually requiring expensive equipment like a force platform. Low-cost alternatives could make IMTP testing more accessible. Previous research reported high systematic bias when comparing low-cost devices with more expensive criterion devices (force platforms). This study investigated the concurrent validity and intra-session reliability of a custom-built low-cost IMTP device using a load cell.

Methods. Overall, 17 recreationally resistance-trained men (25 ± 6 years, 83 ± 14 kg, 178 ± 7 cm, 5 ± 3 years of resistance training experience) first visited the laboratory to be familiarized with testing protocols and returned 2–3 days later for IMTP testing with the low-cost device and a laboratory-grade force platform.

Results. The overall bias was trivial (–0.8%, 95% CI: –5.7 to 4.3%). The typical error of the estimate was moderate (10.2%, 95% CI: 7.4–16.2%). A strong correlation of 0.91 (95% CI: 0.76–0.97) was found between peak force values from both devices; the low-cost IMTP device accounted for 81.3% of the variation in force platform. The low-cost IMTP also demonstrated acceptable scores for reliability and agreement (ICC = 0.96, 95% CI: 0.89–0.98; typical error = 5.0%, 95% CI: 3.7–7.7%), similar to the criterion (ICC = 0.97, 95% CI: 0.91–0.99; typical error = 4.5%, 95% CI: 3.3–7.1%).

Conclusions. The low-cost IMTP device using a load cell was valid and reliable for maximal force production in recreationally trained men and provided results comparable with those of a force platform.

Key words: muscular fitness, muscular strength, isometric mid-thigh pull, agreement, accuracy, precision

Introduction

The neuromuscular ability to produce force (i.e., muscular strength) is fundamental for daily tasks and sports activities [1]. Furthermore, muscular strength level is associated with health status [2] and athletic performance [3]. Considering athletic performance, stronger athletes may not only display a performance advantage over their weaker counterparts, but also present a reduced injury risk [4]. In this context, increasing maximal strength is often desirable, which highlights the importance of strength testing. Therefore, monitoring maximal strength should be considered an important aspect in exercise prescription in order to target optimal training stimuli and health benefits [3].

Although muscular strength can be assessed in a variety of ways, the one-repetition maximum test (1RM) has traditionally been considered as one of the most popular tests since the required equipment is readily available in gyms and similar facilities [5]. 1RM is a dynamic test that includes progressive loading which culminates in the lifter performing single repetitions with increasing loads, a process that continues until concentric muscle failure. Despite 1RM testing being popular and safe when performed correctly, it requires multiple maximal effort dynamic attempts, which carries some degree of risk and a pos-

Correspondence address: Amilton Vieira, Strength and Conditioning Laboratory, Faculty of Physical Education, University of Brasilia, 70910-900, Brasília, DF, Brazil, e-mail: amiltonvieira@unb.br, https://orcid.org/0000-0002-6027-4367

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sibility of fatigue. Furthermore, 1RM testing is a time-consuming task, which is especially hard to complete when many individuals need to be tested in a short period. Although the results of submaximal tests can be extrapolated to estimate 1RM, it is still time-consuming and requires a certain degree of dynamic technique mastery. Therefore, coaches and practitioners may prefer a less time-consuming and more static maximal strength test that is less fatiguing and can be implemented with large groups of athletes.

One example of a quick static maximal effort test is the isometric mid-thigh pull (IMTP), which has been successfully used for strength testing in weightlifting athletes since early 1990s [6]. IMTP requires a body posture similar to the second pull position of the clean movement (reported as the instant of the highest force output [7]), while participants push the floor with feet and try to pull an immovable bar upwards. This test is often performed while standing on a force platform that records the ground reaction force. Being a short-duration (ca. 5-s) isometric test, IMTP can be completed for multiple 'maximal trials,' which may reduce measurement error [8, 9] and may be safer, quicker, and easier to implement than 1RM testing [10].

Despite the advantages of IMTP testing, it traditionally requires expensive force platforms, leading coaches and practitioners to seek out less expensive devices, such as the use of a load cell. Researchers reported strong correlations ($r \geq 0.88$) between IMTP strength values assessed with force platforms and a load cell [11], a dynamometer [12, 13], and even a crane scale [14], but these studies usually also demonstrated a large systematic error (≥ 10%). As a result, this large error may problematically suggest that data from low-cost devices like load cells are not valid and cannot be directly compared with those from force platforms. Nevertheless, this issue might be overcome by a more robust methodological approach including a familiarization session. Considering these points, this study aimed to perform a regression analysis comparing data from a custom-built IMTP testing device using a load cell (i.e., low-cost) with a laboratory-based configuration utilizing a force platform (i.e., criterion). Secondarily, we sought to compare the intra-session reliability of both the low-cost and criterion testing devices. Since we provided a robust familiarization session for participants with some experience in resistance training, we hypothesized that the low-cost device would provide valid (with trivial to small systematic error) and reliable results for peak force produced during the IMTP test.

Material and methods

Participants

A total of 19 adult men with recreational experience in resistance training participated in this study (25 ± 6 years, 83 ± 14 kg, 178 ± 7 cm, 5 ± 3 years of recreational resistance training experience). They were invited by posters displayed at high visibility locations in resistance training facilities and local universities, as well as by social media announcements. To be included, the individuals must have had at least 1 year of experience with resistance training and been free from musculoskeletal injuries or any other conditions that could have affected testing performance. They were asked to abstain from caffeine (12 hours) and alcohol (24 hours) consumption, as well as vigorous physical activities, including their resistance training routine (for 48 hours prior to testing). Two subjects were excluded: 1 had a large bruise on his hand (not related to the study) and 1 was not able to maintain the required body posture for testing. The participants were informed about the risks and benefits of the research.

Experimental design and procedures

The study procedure is depicted in Figure 1. To complete this validity and intra-session reliability study, the participants visited the laboratory on 2 non-consecutive days (2–3 days apart). During the first day, the eligibility criteria were confirmed by completing health and training routine forms. Body mass, stature, and body posture (i.e., knee and hip angles) were recorded for the IMTP test, and the subjects were familiarized (ca. 20 minutes) with the load cell and force platform testing protocols. Prior to testing, the participants performed a standardized warm-up protocol consisting of general and specific exercises [15]. The general warm-up (ca. 5 minutes) of squats, lunges, and jump exercises was followed by a specific warm-up, including 3 submaximal (50%, 75%, and 90% of the perceived effort) IMTP trials, each for 5 s (1 minute apart). During the second day, the 'testing session,' the participants performed the same warm-up protocol and, after 3 minutes, they underwent the IMTP testing with a load cell or the laboratory-based configuration utilizing a force platform in a counterbalanced fashion; an online generated spreadsheet was applied (www.randomization.com). The individuals performed 2–5 maximal trials with a 2-minute rest interval between the trials and a 10-minute rest between the devices.

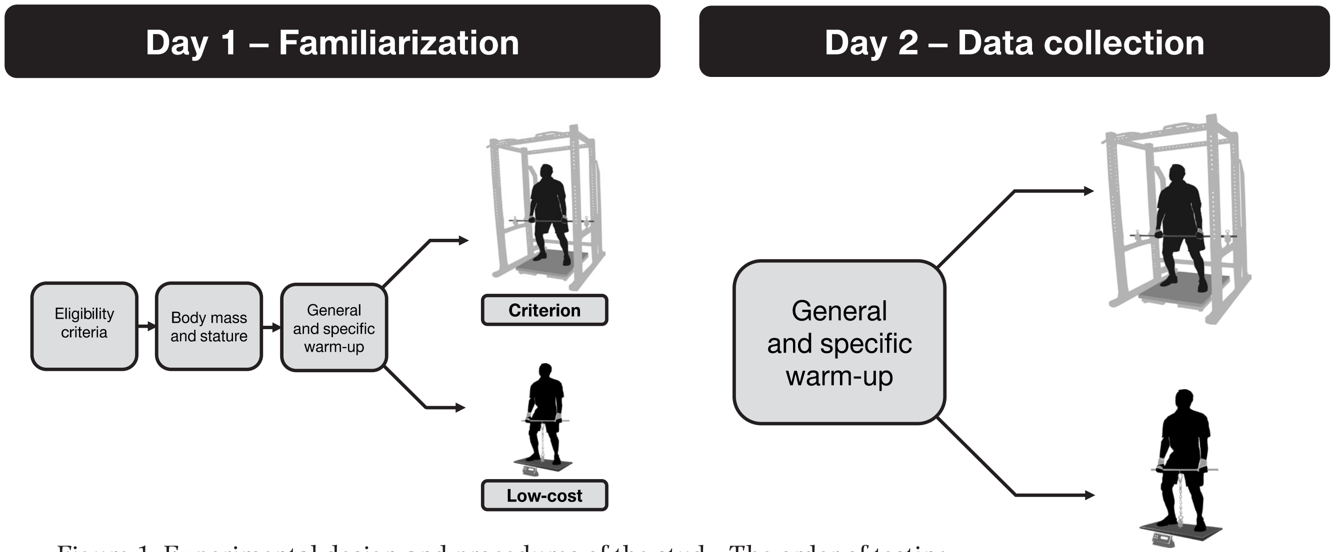

Figure 1. Experimental design and procedures of the study. The order of testing was counterbalanced between the criterion and low-cost isometric mid-thigh pull

For the IMTP test, the participants were positioned with their feet approximately hip width apart and hands approximately shoulder width apart. The bar height was adjusted to correspond to the second pull position of the clean exercise. This procedure resulted in knee and hip angles of 130 ± 6° and 140 ± 6°, respectively (180° = full extension) [15]. Joint angles were measured with a handheld goniometer, while feet and hand distances were determined with an anthropometric measuring tape. These measurements were performed on the first day and repeated on the second day. The subjects were verbally encouraged to produce a maximal effort in each attempt by a single rater.

The criterion test (Figure 2A) was performed in a custom-made rack (Select Fit, Brasília, Brazil), with the participants standing on a 101 × 80 cm force platform (AccuPower portable force plate; AMTI, Watertown, MA, USA). The rack allowed for adjustments in the bar height with a precision of 1 mm. Force data (1000 Hz) were recorded by using commercial software (AMTI NetForce, version 3.5.3; AMTI, Watertown, MA, USA). Data were then analysed *a posteriori* with a custom-made script (MATLAB R2018; MathWorks, Inc., Natick, MA, USA) following a well-established procedure [15]. The net force (overall force minus system force) was established and digitally filtered at 20 Hz.

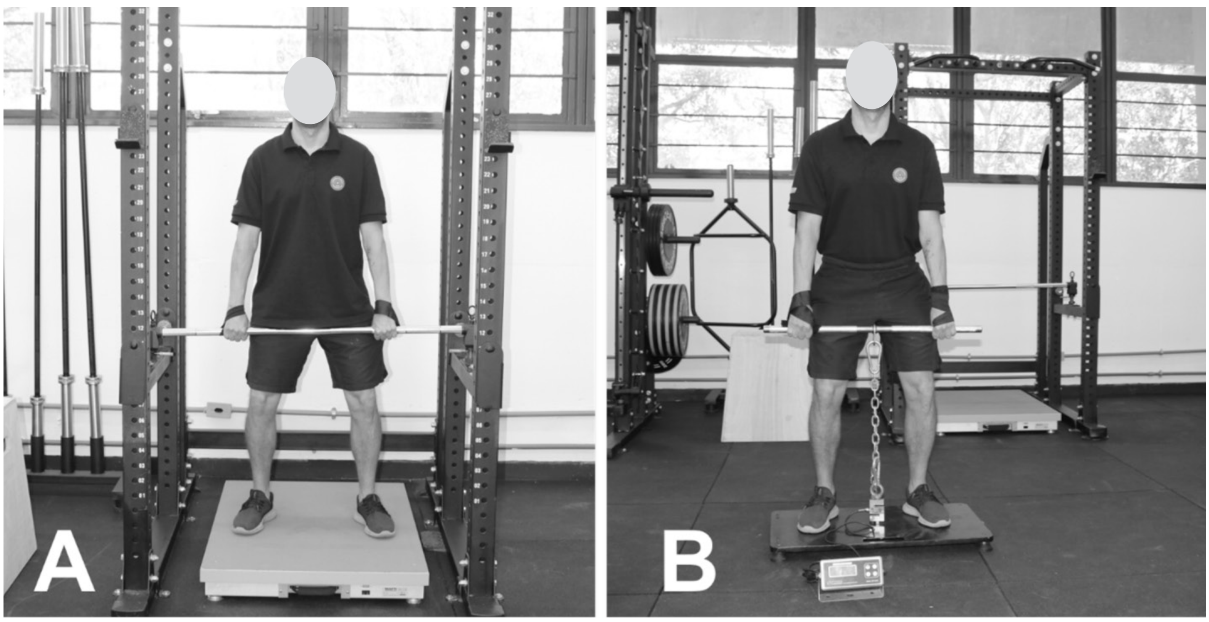

Figure 2. Isometric mid-thigh pull test. (A) Laboratory-based setup utilizing a force platform ('criterion'). (B) Portable custom-made setup utilizing a load cell ('low-cost')

The initiation of the pull was set as the time when the force rose to 5 times the standard deviation of body weight [16]. Pre-tension was controlled not to exceed 50 N, and data without a stable period of at least 1 s or presenting a countermovement (i.e., force below body weight) immediately prior to the force rise or presenting the maximal force only in the last second (≥ 4 s of the trial) were excluded [15].

The IMTP test with the low-cost device (Figure 2B) was performed over a custom-made 75 × 45 cm metal plate that was attached to a stainless-steel S-type load cell (AmCells Corp., Vista, CA, USA). The load cell was attached to a steel chain allowing for adjustments of 2.5 cm. Data from the load cell were collected at 10 Hz, and the maximum force was displayed with a digital indicator (OP-902; Optima Scale, Rancho Cucamonga, CA, USA).

Statistical analyses

The means of peak force values were used to determine the criterion validity and the intra-session reliability of both the force platform and load cell. The normality of the residuals and the presence of outliers were assessed by visual inspection of a normal probability plot and histogram. To investigate the criterion validity, a regression analysis was performed using a custom-made spreadsheet available online [17, 18] and the SPSS software (version 26; IBM, Chicago, IL, USA). The regression analysis included: (a) the overall bias (systematic error) and the typical error of estimate (random error); (b) determination of a linear equation to estimate the net force of the force platform from the load cell force (i.e., calibration equation); (c) Pearson correlation between the force platform and load cell data and adjusted r^2; and (d) uniformity of error by plotting residuals (predicted values minus 'real' values obtained from the force platform) against predicted values and then calculating a Pearson correlation between the residuals and predicted values.

To analyse the intra-session reliability of data from both the load cell and force platform, the following parameters were calculated from the repeated trials (i.e., trial 2–1 and trial 3–2): (a) the change in mean (absolute and percentage) values; (b) intraclass correlation coefficient (ICC3,1); (c) typical error of measurement (TEM), derived from the standard deviation of the difference scores for each participant divided by √2; and (d) TEM as percentage (TEM%). These calculations were performed in a custom-made spreadsheet, which is available online [18]. The magnitudes of standardized differences for change in means between repeated trials could be interpreted as trivial (< 0.20), small (0.20–0.59), moderate (0.60–1.19), large (1.20–1.99), and very large (≥ 2.0). TEM and TEM% could be interpreted as trivial (< 0.10), small (0.10–0.29), moderate (0.30–0.59), large (0.60–0.99), and very large (≥ 1.0) [18]. ICC with 95% confidence interval (CI) were interpreted as poor (< 0.50), moderate (0.50–0.75), good (0.751–0.90), and excellent (> 0.90) [19]. The final analysis was the within-participant coefficient of variation (CV) (as percentage), obtained by dividing the individual standard deviation by the mean (i.e., standard deviation / mean × 100), which was interpreted as low (< 5%), moderate (5–10%), and large (> 10%) [20].

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the UDF University Center Ethics Committee (approval No.: 2.878.364).

Informed consent

Informed consent has been obtained from all individuals included in this study.

Results

The final sample of 17 participants were tested; among these, 9 self-reported as practitioners of traditional resistance training, 6 reported practising weightlifting, and 2 regularly performed CrossFit routines. The majority of the individuals required 3 trials with each device (i.e., between-trial differences ≤ 250 N), except a single participant in the criteria test who required only 2 trials to meet the required precision.

Validity

The force obtained with the load cell (low-cost) was able to predict the force obtained with the force platform (criterion) (F(1,15) = 70.58, p < 0.001). The load cell accounted for 81.3% (adjusted r^2) of the variation in the force platform. The slope of the regression was 0.96 (95% CI: 0.72–1.21) and the intercept was 121.58 N (95% CI: –485 to 728 N). The Pearson correlation coefficient demonstrated a strong positive correlation of 0.91 (95% CI: 0.76–0.97) between the force platform and load cell (Figure 3A). These results allowed a linear equation to estimate the net force that would be obtained on the force platform from a load cell value:

$$\text{force}_{\text{plataform}} = 0.9621 \times \text{force}_{\text{loadcell}} + 121.58$$

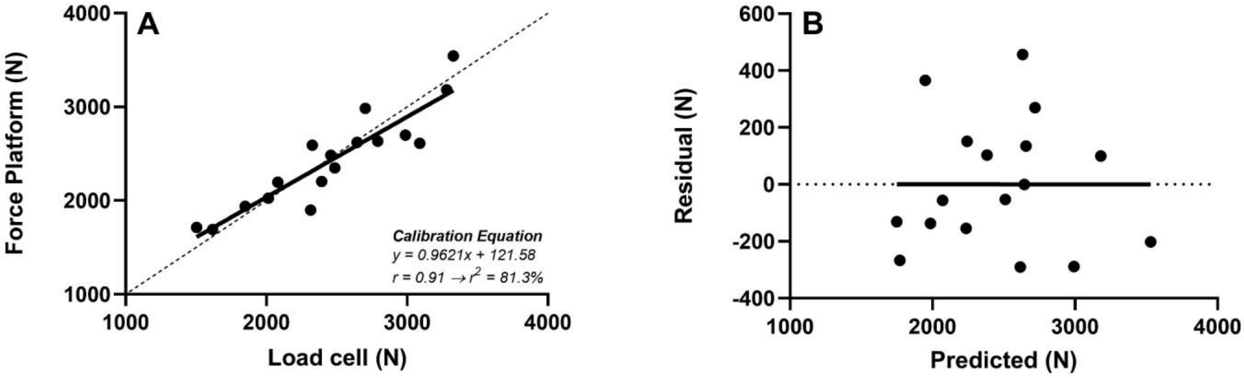

Figure 3. Regression analysis.(A) Relationship between the net force obtained during the isometric mid-thigh pull test performed on a force platform (criterion) and using a load cell (low-cost). (B) Scatter plot for heteroscedasticity (non-uniformity of error) examination

The overall bias (i.e., systematic error) was –29.33 N (95% CI: –146 to 88 N) and the typical error of estimate (i.e., random error) was 234.01 N (95% CI: 173–362 N). No evidence of heteroscedasticity (i.e., non-uniformity of error) was found (p = 1.00, slope < 0.001; Figure 3B) since the Pearson correlation approached zero.

Intra-session reliability

Table 1 presents the intra-session reliability of the net force obtained during IMTP from both the load cell and force platform. Similarly, both devices demonstrated acceptable scores of reliability (e.g., ICC ≥ 0.92, TEM% ≤ 7%). Trivial changes in mean net force between trials (i.e., trial 2 vs. 1 and trial 3 vs. 2) were observed (data not shown for the sake of concision), while ICC increased and typical error decreased from moderate to small when trials 3 vs. 2 were compared with trials 2 vs. 1.

No substantial differences in within-participant CV were observed. Overall, 7 out of the 17 and 9 out of the 17 participants demonstrated a low CV score for the force platform and load cell, respectively. Only a single individual obtained a large CV score (10.5%) for the load cell (Figure 4).

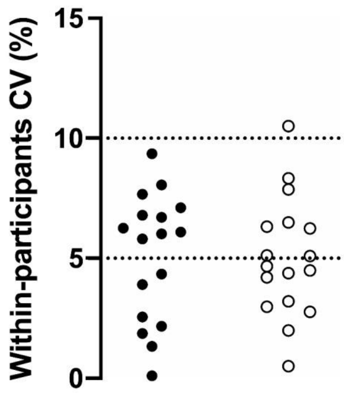

Figure 4. Individual coefficient of variation (CV%) for the force platform (●) and the load cell (○)

Table 1. Intra-session reliability of the net force obtained during the isometric mid-thigh pull test from a force platform and from a load cell. Data are presented as mean and its respective [95% confidence interval]

Device	Trial comparisons	Change in mean (N)	Change in mean (%)	ICC	ICC (%)	TEM (N)	TEM (%)
Force platform	2–1	–101.5* [–225 to 22]	–3.6* [–8.2 to 1.2]	0.92 [0.79–0.97]	0.93 [0.82–0.97]	169.9$^{\beta}$ [127–259]	7.0$^{\alpha}$ [5.1–10.8]
	3–2	83.2* [–3 to 169]	3.4* [0.0–6.9]	0.96 [0.89–0.99]	0.97 [0.91–0.99]	114.3$^{\alpha}$ [84–177]	4.5$^{\alpha}$ [3.3–7.1]
Load cell	2–1	41.6* [–81 to 164]	2.1* [–2.1 to 6.5]	0.92 [0.80–0.97]	0.95 [0.86–0.98]	168.8$^{\beta}$ [126–257]	5.9$^{\alpha}$ [4.4–9.1]
	3–2	–48.4* [–140 to 43]	–1.9* [–5.3 to 1.6]	0.95 [0.87–0.98]	0.96 [0.89–0.98]	125.8$^{\alpha}$ [94–192]	5.0$^{\alpha}$ [3.7–7.7]

ICC – intraclass correlation coefficient from absolute values and from percentage values
TEM – typical error of measurement from absolute values and from percentage values
* trivial, $^{\alpha}$ small, $^{\beta}$ moderate magnitude of standardized differences

Discussion

The present study compared the criterion validity and intra-session reliability of a custom-built IMTP testing device using a load cell (i.e., low-cost) and a laboratory-based configuration utilizing a force platform (i.e., criterion). As hypothesized, the current findings suggest that when the participants were properly familiarized with the testing procedures, the low-cost device provided a valid measure of the net force with trivial systematic error and an acceptable level of reliability, which were similar to the values obtained from the force platform.

The subjects produced similar net force values using the load cell and force platform, as data from the load cell were slightly lower than those from the force platform (–29.3 N, ca. 1%), only presenting a trivial difference. It is also important to note that the random error was moderate (227.4 N, ca. 10%), suggesting that any direct comparison between the load cell and force platform data may benefit from the calibration equation (Figure 3A). A possible explanation for this moderate amount of random error may be the moveable open-chain design of the low-cost setup compared with the rigid closed-chain design of the criterion setup. While the custom-made apparatus for criterion measurement does not allow for any undesirable movement, the participants may have involuntarily performed anteroposterior and/or mediolateral movements when conducting IMTP with the load cell. Although the subjects were strongly advised to apply their effort only longitudinally (e.g., feet against the floor with the trunk upright), it could not be ruled out that some may have slightly leaned backward, for example.

Indeed, some amount of error is quite common, as has been reported in previous studies [11–14] comparing robust or laboratory-based structures utilizing force platforms with those less robust instruments including load cells, dynamometers, or crane scales. These studies have demonstrated good-to-excellent reliability and agreement scores (ICC: 0.91–0.96, CV: 3–6%); however, larger systematic bias was presented in those studies when compared with the current study (173–229 N, ca. 10–20% vs. 29 N, ca. 1% of the current study). For example, using a crane scale, one study revealed acceptable values for both validity and reliability [14], but a low systematic error of 50 N and acceptable scores of reliability (ICC = 0.93, CV 4.9%) were present. It should be noted, though, that only 8 participants were included in that study. Another limitation of that study [14] may be the use of a crane scale, which is usually not able to maintain and display the maximum value – requiring the crane scale display to be recorded with a high-frequency camera (e.g., 120 Hz). Therefore, these results indicate that the low-cost testing device used in the current study is likely a similar, or even slightly better, alternative for the IMTP test as compared with other low-cost devices.

In the present study, the low-cost device provided reliable results, which were similar to values obtained from the force platform (Table 1 and Figure 4). It is worth noting that the smallest worthwhile change from trials 3–2 for both devices was 105 N, which is less than the error of the test (114 and 126 N for force platform and load cell, respectively). Therefore, the ability of both devices to detect a small magnitude of effect may be compromised. When comparing trials 2–1 with trials 3–2, it was noted that error was reduced from moderate to small (Table 1), which indicates that more trials (i.e., even more familiarization) may reduce the amount of error for both testing protocols. Thus, it is possible that 4 or 5 trials could benefit the sensibility of the IMTP test, but this notion requires further investigation.

Although the present study demonstrated that a simple load cell provided valid and reliable values of strength during an IMTP test in recreationally resistance-trained men, it is not free of limitations. Firstly, the data are only valid for a specific sample of resistance-trained men, which also applies to the calibration equation provided. Thus, future studies recruiting a more heterogeneous sample of participants are required to formulate a more general equation, which can be useful for those seeking to compare data from load cells and force platforms. Despite the positive results reported herein, further studies are warranted to cross-validate the present findings in a different sample of individuals. Moreover, although assessing the rate of force development could be a valuable metric, the low-cost device only collects data at 10 Hz and only displays the peak force output, both of which are limitations of the instrument that do not allow for the rate of force development to be collected.

Conclusions

The criterion validity and intra-session reliability of a load cell for IMTP force was investigated. The findings demonstrated that the low-cost device using a load cell provided valid and reliable measurement of the net force obtained during the IMTP test under these experimental conditions when the participants were familiarized with the testing procedures. Furthermore, although the resultant data from the load cell itself are valid and reliable, an equation ($force_{plataform} = 0.9621 \times force_{loadcell} + 121.58$) is suggested when trying to estimate the force that would be obtained in a laboratory-based structure including a force platform.

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Disclosure statement

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Conflict of interest

The authors state no conflict of interest.

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