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Poster 7

RELIABILITY AND VALIDITY OF UNILATERAL AND BILATERAL ISOMETRIC STRENGTH MEASURES USING A CUSTOMISED, PORTABLE APPARATUS.

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INTRODUCTION

The ability to produce high levels of muscular force and power are considered to be essential determinants in successful athletic performance across a broad range of sports (3,14,16,29). While conjecture continues to exist regarding the precise levels of strength required to optimise performance (25,36), the overriding conclusion drawn from a multitude of research upholds the positive relationship between maximal strength and athletic performance in sports reliant on strength, speed and power (8,14,25,29,36,37,38). In order to assess maximal strength, a variety of measures are available for use, including isotonic, isokinetic and isometric testing modalities (21,27,28); however, a lack of consensus remains concerning the most suitable mechanism to assess muscle function due to inherent limitations and varying situational contexts (8,16,27,28,30).

Despite muscular expressions of strength and power remaining contextually specific (2,10,16,27), measures of isometric strength have been shown to correlate well with dynamic strength when assessed within the same exercise domain (14,36,40). This isometric-dynamic relationship is primarily achievable by honouring the premise of positional specificity (13,40,41), which promotes the deliberate selection of exact joint angles and body positions in isometric protocols (15,27,34) that best correspond with the position of highest force production within the equivalent dynamic activity (15,30). As isometric strength testing has other notable advantages, including high test-retest reliability (23,25,39); greater task control (11,22); lower performance variability (23,25,39); lower injury risk, incidence and severity (4,11); and simple test administration and data analysis processes (4); this might explain the popularity of isometric strength measures frequently used in research, clinical and athletic contexts (4,14,25,31).

While isometric testing protocols have many advantageous characteristics, there are limitations which require acknowledgement. In particular, the relationship of isometric strength to athletic performance is not as strong as those exhibited by dynamic strength testing mechanisms (4,6,12). Furthermore, isometric protocols require a force-measuring device in order to acquire meaningful strength data (11,25). In spite of these limitations, muscle function tests using isometric protocols can provide necessary information regarding an athlete's capacity to produce maximal voluntary forces (4,6). This data can subsequently be used by coaches to produce a complete and proper assessment of an athlete's training status and so too the effectiveness of their training programs (6,12). In support of this, previous research has successfully demonstrated the importance of maximal isometric strength in a variety of athletically and recreationally trained populations (5,14,25,31,40), using peak force (PF) and rate of force development (RFD) as descriptive measures of performance.

Historically, these assessment outcomes have been determined using expensive, large-scale, fixated devices which are notably limited by a lack of transportability, customisability, and affordability; demonstrating an inherent lack of practicality to real training and testing scenarios (11). In response to these constraints, a portable and fully customisable isometric assessment device has been developed which is relatively inexpensive; highly transportable; easy to set-up and administer; and is able to be used in any location at any given time. Although the portable apparatus has many practical benefits, the decreased stability of the device presents as a potential limitation as there are no bar supports to prevent horizontal sway which might influence the athlete's ability to produce a true reflection of their maximal force capabilities (23). It is therefore the purpose of this paper to assess the validity and reliability of the newly developed portable and customisable isometric assessment device in order to determine whether it is able to facilitate and derive valid representations of maximal strength and rate of force development characteristics, and whether it is able to do so in a reproducible manner.

METHODS

Experimental Approach to the Problem

Maximal bilateral and unilateral lower body isometric strength measures were performed using the isometric squat at preset hip and knee angles of 140° using both fixated and portable isometric assessment devices, to allow for maximal force production at zero velocity (14,15,30,32). Specific measures (peak force (PF), mean force (MF), rate of force development (RFD) and time to peak force (TTP)) were identified using a portable force plate (400 series Performance Plate; Fitness Technology, Adelaide, Australia) sampling at 600Hz, and data acquisition software (Ballistic Measurement System (BMS); Fitness Technology, Adelaide, Australia).

Participants

Eleven recreationally trained men (age: 24.3 ± 2.2 years; mass: 81.1 ± 10.8 kg; height: 180.2 ± 2.8 cm) were recruited for participation in this study. For participation eligibility into this study, subjects were required to have a minimum of twelve months resistance training experience, and participate in a recreational football competition. All subjects were absent of injury, and contraindication at the time of testing, and did not perform any lower body resistance training or vigorous physical activity within 48 hours prior to their testing session. The study was approved by the human ethics committee of Edith Cowan University. All athletes were notified of any potential risks involved, and provided written informed consent prior to commencement.

Equipment

A uniaxial, portable force plate (dimensions: 795 x 795 mm; maximum load: 1000 kg (9810 N)); standard 20kg Olympic barbell (mass: 20 kg; Australian Barbell Company, Victoria, Australia); and BMS data acquisition software were required for use across both isometric devices. The fixated isometric squat trials were performed using a floor-bolted power rack (Power Cage, Cybex International, MN, USA), with height adjustable bar supports, as presented in Figure 1. The portable isometric squat trials were performed using only a load-bearing, fully customisable heavy duty strap (SureTie, Zenith, NSW, Australia) designed to resist high loads (max: 4218 N (430 kg)), with an anti-retractible locking mechanism to prevent undue movement (loosening or tightening), and hooks to affix the strap to the barbell as presented in Figure 2. The primary difference of equipment between the portable and fixated apparatus involves the exchange of the large-scaled immovable rack, with the more affordable and transportable heavy duty load-bearing strap.

Figure 1 - Set-up and operation of the fixated isometric apparatus.

Figure 2 - Set-up and operation of the portable isometric strength apparatus.

Procedures

Subjects were required to perform a total of eighteen lower body maximal isometric squat contractions, consisting of three bilateral (BL); and six unilateral (dominant (ULD) and non-dominant (ULN)) trials on each isometric assessment device (fixated and portable). The order of testing between both devices for all subjects was counterbalanced, with bilateral and unilateral trial-types fully randomised to negate the effects of muscular potentiation or fatigue (17,33). Subjects were provided with two minutes of passive recovery between each maximal effort, with a ten minute period of passive recovery during the changeover of isometric devices. Subjects were required to complete a sub-maximal familiarisation session one hour prior to the official testing procedure in order to determine subject-specific bar height settings for each apparatus, and to acclimatise them with the testing conditions of each isometric device.

At the commencement of the official testing period, participants had their height (cm) and weight (kg) measured using a wall-mounted stadiometer and electronic weighing scale. A general dynamic warm-up was provided, prior to a specific warm-up which included additional familiarisation efforts on each isometric strength device. A five minute recovery period was subsequently enforced. Prior to testing commencement, subjects were required to stand on the force plate while holding the barbell and remaining stationary, in order to offset the total mass of the system to zero within the BMS software. During official trials, the starting position for each device required the subjects to place slight upward pressure on the bar so that it is pressing against the supports (fixated device); or is pulling the straps taught (portable device). This was to ensure that no change in joint-angle was evident during maximal contraction, thus controlling the maximal contraction to commence at zero velocity (with no slight countermovement or jolting actions permitted).

For each bilateral trial, subjects adopted a traditional back squat position under the pre-set height of the bar, eliciting a hip and knee angle of 140° flexion (Figure 4) using a manual handheld goniometer. For each unilateral trial, subjects were required to reposition the active leg under their centre of mass, while removing their inactive leg from the force plate by flexing it at the knee (Figure 4). Due to unilateral repositioning, hip and knee angles of the active leg must be re-assessed using the goniometer to ensure the current bar-height settings meet the 140° joint angle criteria. Once subjects were in position, they were instructed to “push as hard and as fast as you can, until I stay stop” in order to produce a rapid and sustained maximal contraction for five seconds in duration (6,42), and were provided with time to balance themselves. Once balanced and set in position, subjects were required to state “ready” to the researcher, prompting a 3-second verbal countdown: “3, 2, 1, GO” as test recording commenced. The researcher, and two research assistants, provided verbal encouragement to promote maximal efforts; visually monitored athlete technique during each trial to ensure postural and mechanical compensatory adjustments did not occur; and ensured athlete safety was maintained. This is particularly important when using the portable device, as there are no bar supports preventing undesirable horizontal movement or potential loss of balance during unilateral trials.

Figure 3 - Adopted subject positioning between bilateral (left) and unilateral (right) testing conditions.

For each bilateral and unilateral condition, two trials needed to produce peak force outputs within 5% of each other to be considered legitimate representations of the subjects maximal force production. If, within the 3 trials provided this was not achieved, a 4^{th} and 5^{th} trial per condition was permitted, with two minutes recovery provided per trial. No subject required more than 3 trials during this study, as adequate familiarisation was provided. For analysis purposes, the best trial for each condition across both devices was chosen to compare each athlete's performance between both isometric apparatus, identified by the trial with the greatest peak force (PF) output. In addition, within the portable isometric device, the best two trials for each trial-type were chosen using the same selection criteria in order to assess its reliability in measuring all dependent variables.

The dependent variables that were chosen for analysis were supplied by the BMS data acquisition software. The program, using the collected force-time data, identifies peak force (PF) as the highest force value produced during the maximal isometric contraction, with mean force (MF) and time to peak force (TTPF) determined from the point of curve inflection (onset of maximal contraction) to the moment of peak force production. Peak rate of force development (RFD) was also determined as the highest rate of force development produced within a 30ms window (epoch) between the onset of contraction and the peak force value.

Statistical Analysis

Isometric strength outputs, identified as peak force (PF), mean force (MF), rate of force development (RFD) and time to peak force (TTPF) were exported for analysis to Microsoft Excel (Microsoft, Redmond, WA) and analysed using a statistical analysis package (SPSS, Version 17.0; Chicago, IL). The portable isometric device was validated by using an independent t-test to examine whether significant differences were prevalent between the isometric strength outputs obtained from the fixated and portable isometric devices. Statistical significance was set at an alpha level of $p \leq 0.05$ (with a 95% confidence level).

Intra-tester reliability and within-subject reliability for the portable isometric device were assessed by calculating the coefficient of variation (CV) and intraclass correlation coefficient (ICC). The strength of relationship for ICC coefficients was classified in accordance with Hopkins (18,19,36): $r \approx 0.3$ is moderate; $r \approx 0.5$ is strong; $r \approx 0.7$ is very strong; $r \approx 0.9$ is nearly perfect; and $r \approx 1.0$ is perfect. Coefficients of variation below 10% were considered reliable in accordance with other studies analysing biomechanical, and strength based human movement data (1,7,9,20).

RESULTS

The portable isometric device was only able to reliably determine peak force (CV < 4.7%; ICC > 0.961) and mean force (CV < 9.3%; ICC > 0.831) outputs under all bilateral and unilateral conditions. The portable device was therefore unable to reliably assess the peak rate of force development. Bilateral and dominant-leg unilateral conditions nearly reached reliable limits (CV < 15.2; ICC > 0.931), while surprisingly large variability was evident within non-dominant limb, unilateral trials (CV < 45.5; ICC > 0.360). This is likely due to the recreational training status of subjects, coupled with the reduced stability of the portable device. The portable device might be suitable for athletes of sub-elite or elite status, though this requires further investigation.

Table 1 - Between trial variance, and intra-tester reliability for peak force (PF), mean force (MF), and rate of force development (RFD) between each trial type using the portable isometric device.

	Bilateral Squat			Unilateral Squat (N.Dom)			Unilateral Squat (Dom)		
	PF [a,b]	MF [a,b]	RFD [b]	PF [a,b]	MF [a,b]	RFD	PF [a,b]	MF [a,b]	RFD [b]
CV	3.6	8.4	15.2	3.6	9.3	45.5	4.7	6.1	14.5
ICC	0.973	0.906	0.943	0.980	0.831	0.360	0.961	0.950	0.931

[a] Variables within CV criteria (CV < 10%).
[b] Variables with very strong ICC criteria (ICC > 0.7).

Table 2 - Statistical significance (p-levels) determined between fixated and portable isometric devices for peak force (PF), mean force (MF), rate of force development (RFD), and time to peak force (TTPF).

	Bilateral Squat				Unilateral Squat (N.Dom)				Unilateral Squat (Dom)			
	PF	MF	RFD	TTPF	PF	MF	RFD	TTPF	PF	MF	RFD	TTPF
P	0.737	0.681	0.366	0.545	0.859	0.739	0.434	0.000[a]	0.928	0.907	0.794	0.001[a]

[a] Statistically significant difference (p ≤ 0.05) found.

Additionally, the portable isometric device was able to accurately determine all descriptive measures when compared with the previously validated fixated apparatus (Blazevich et al, 2002). No significant differences ($p \leq 0.05$) were found between all strength outputs (peak force, mean force and peak rate of force development), or between the time to reach peak force during the more stable, bilateral condition. The only statistical difference noted between the two devices were found when comparing the times taken to peak force under both unilateral isometric trials ($p < 0.001$), with athletes requiring an extra second to produce maximal strength when using the portable device.

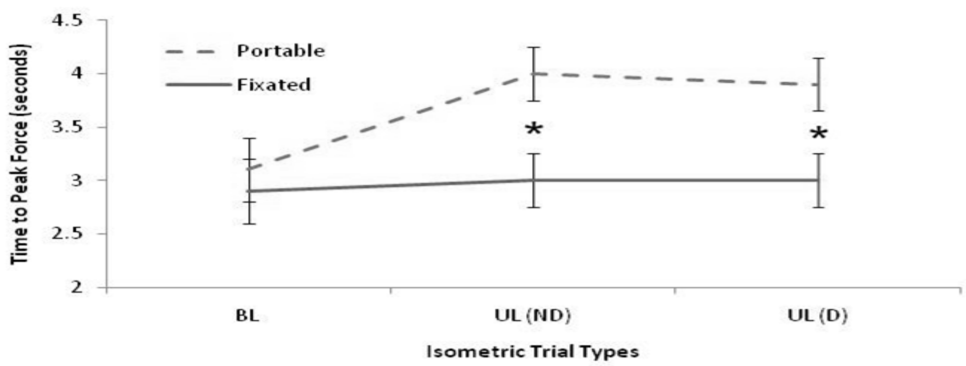

Figure 4 - Time taken (in seconds) to produce peak force (PF) for each isometric apparatus, when performing bilateral, and unilateral (non-dominant (ND) and dominant (D) leg) maximal isometric contractions.

DISCUSSION

Maximum isometric strength is an important physical characteristic, contributing to successful performance in a variety of sporting contexts (3,5,14,29,38). Previous research has demonstrated the importance of maximal isometric strength (peak force (PF)) and the development of power (rate of force development (RFD)) in a variety of athletic (5,8,14,30) and recreationally trained (25) populations, with these studies demonstrating high correlations between isometric strength tests and 1-repetition maximum (1RM) tests (4,39,41). However, these outcomes have been assessed using expensive, large-scale, fixated devices. As there is a need for portable testing devices, it was the purpose of this study was to assess the validity and reliability of force measurements produced when using a new, portable and customisable isometric strength device. This was examined through using the isometric back squat exercise to illicit maximal isometric strength under bilateral and unilateral performance conditions across both portable and fixated isometric apparatus.

The results of this study successfully validate the new portable device when comparing obtained performance variables against a previously validated isometric device (4,25). In particular, all descriptive measures (peak force, mean force and rate of force development) were statistically even, with no significant differences ($p \le 0.05$) between the two devices, producing P-values above 0.737, 0.681 and 0.366 respectively. Interestingly, time taken to reach peak force under unilateral conditions were significantly different between the two devices with athletes requiring an extra second of time to achieve peak force production (3 seconds using fixated; 4 seconds using portable). This was expected as the portable device requires additional balance, with the initial period of time used by the athlete to stabilise under the bar prior to producing maximal leg drive. In this regard, athletes using the portable device should be given an extra second of time to derive their peak force outputs under maximal testing conditions.

Furthermore, the portable isometric device has upheld the high reliability of maximal isometric strength protocols (25,39), producing very strong correlations (ICC > 0.831) for all descriptive measures. The rate of force development for the non-dominant limb, during unilateral trials, was the main exception, with a moderate correlation (ICC > 0.360) that was additionally confirmed by the high coefficient of variation (CV < 45.5) in this trial type. The typical error prevalent within the data, which represents a useful measure of reliability within athletic performance (4,18), was also determined, demonstrating high reliability for peak force and mean force outputs across both isometric devices (CV < 9.3). The rate of force development during bilateral and dominant-leg unilateral conditions was only able to approach acceptable limits (CV < 15.2), however this may have been confounded by the training status of the recreationally trained men used within this study, who routinely produce greater performance variability within human movement (35). Similar volatility in rate of force development outputs have also been noted in previous research featuring maximal isometric strength assessments (24,25,26), highlighting the need for a cautious approach when interpreting or using rate of force development measurements under this isometric testing scenario.

The portable isometric apparatus was shown to be an efficient, convenient, valid and reliable assessment tool for maximal isometric strength, which is able to be used as an effective indicator of dynamic performance within this population. The findings of this study substantiate that this new, fully customisable and portable device can be used to accurately and reliably assess peak force, and mean force outputs under bilateral and unilateral testing conditions, with rate of force development measures to be interpreted with caution. Users of this device should provide their athletes with an extra second of maximal effort during unilateral strength trials to ensure the peak is achieved; and should allow substantial familiarisation to allow the athlete to adapt to the less stable nature of this new device. Future studies may wish to investigate the reliability of this apparatus when using the isometric mid-thigh pull or other potential isometric exercises. Further, the unstable nature of the portable testing apparatus may have application in measures of strength when balance is an important component of the target sport performance.

PRACTICAL APPLICATIONS

This apparatus provides strength and conditioning professionals with a more affordable, pragmatic, portable and easy-to-administer method to test, monitor and train unilateral and bilateral lower body isometric strength at any customisable joint angle, at any time, and in any location. In particular, it presents as a suitable alternative to the fixated apparatus during times when the large-scaled equipment is unavailable or unattainable. Coaches may wish to invest in portable, height-adjustable bar supports (if convenient) to increase the stability of the device in the applied, real-world environment. Furthermore, coaches may also wish to use this device to further assess and develop strength under less stable conditions as a tool to promote this component within their particular sport.

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