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The reliability, variability, and minimal detectable change of multiplanar isometric trunk strength testing using a fixed digital dynamometer

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Abstract:

Objective Trunk strength plays a vital role in athletic performance, rehabilitation, and general health, however, current assessment methods are expensive, non-portable, or unreliable. This study aimed to investigate the within- and between-session reliability, variability, standard error of measurement and minimal detectable change (MDC) of trunk strength in the sagittal (flexion and extension) and frontal planes (left and right lateral flexion) using a fixed digital dynamometer.

Methods 18 participants (ten men; eight women) attended two sessions separated by seven days. Participants were fitted with a trunk harness which was secured to an immovable base via a digital dynamometer. Three maximal voluntary isometric contractions were completed across four positions (prone, supine, left-side recumbant, and right-side recumbant, respectively) on a glute-hamstring raise machine.

Results All positions demonstrated *excellent* reliability and low variability within session (ICC: 0.95–0.98; CV: 5–7%) and between sessions (ICC: 0.98–0.99; CV: 4–6%), across all positions. The between-session MDC ranged from 8% (prone) to 13% (right-side recumbant), translating to absolute values between 2.9 to 3.2 kg across all positions.

Conclusion Maximal isometric force testing using a fixed digital dynamometer provides reliable measurements of multiplanar trunk strength, providing a practical method for use in clinical practice.

Key Words

Force, Trunk Flexion, Trunk Extension, Lateral Trunk Flexion

Introduction

Trunk strength has an important role to play in athletic performance (Rodríguez-Perea[27]), facilitating different movement control strategies (Vleeming et al[33]) and transferring forces between the upper and lower limbs (Martin et al[12]; Rodriguez-Perea[26]). Trunk muscle weakness has been shown to be associated with spinal disorders, such as low back pain and disability (Gabr and Eweda[4]; Reyes-Ferrada[24]). The point prevalence of low back pain is between 18-65% in elite athletes based on the sport they perform (Trompeter et al[32]) and accounts for 21% of all causes of global disability (Hoy et al[8]). Accurately measuring multiplanar trunk muscle strength, therefore, is vital in both performance and clinical settings.

Both the intra- and inter-session reliability need to be established prior to implementing a new method of measuring trunk strength. This will inform the practitioner of the repeatability or consistency of a test both within a single testing session and between different testing sessions, allowing practitioners to understand if alterations in strength over time reflect true changes or are due to measurement error (Hopkins[7]).

The most common method of assessing the physical qualities of the trunk musculature in clinical practice is through isometric endurance holds. Participants maintain a fixed position against gravity where either the anterior, lateral, or posterior trunk is biased until muscular failure is achieved and the position can no longer be maintained (Reiman et al[21]). Isometric endurance holds are correlated with back pain (McGill et al[14]), reliable (intraclass correlation coefficient [ICC] 0.79–0.95), and require minimal equipment (Reiman et al[21]). Furthermore, the importance of isometric trunk endurance ratios was first highlighted by McGill et al[14], who suggested a contributing factor to low back pain is an imbalance between the flexion-extension trunk endurance. They specifically suggested when the trunk extensors have a lower endurance than the trunk flexors, individuals are predisposed to developing back pain. Isometric endurance holds, however, assess the endurance characteristics of the trunk musculature and not the maximal strength characteristics. The physiological mechanisms between muscular endurance and maximal strength are different and the assessment of both qualities may yield valuable insights that direct the focus of any training interventions.

Several methods of measuring trunk maximum strength exist, namely isokinetic dynamometry, handheld dynamometry, and manual muscle testing (Althobaiti et al[1]), however, these approaches all have considerable limitations (Trajkovi´c et al[31]). Manual muscle testing has inconsistent reliability (ICC 0.55−0.93) and low sensitivity, limiting its application in groups such as athletes, where precise scores are needed (Trajkovi´c et al[31]). Hand-held dynamometry provides a valid (De Blaiser et al[3]) and sensitive measure of strength, however, mixed reliability (ICC 0.24−0.93) has been observed when measuring trunk flexion and extension strength (De Blaiser et al[3]; Moreland et al[17]). Isokinetic dynamometry is considered the gold-standard for assessing trunk muscle strength (Reyes-Farrada[23]), demonstrating both reliability (ICC 0.87–0.95) and validity ($r > 0.99$) when correlated to cross sectional area of the trunk musculature assessed using MRI and surface EMG muscle activity (Guilhem et al[5]). The feasibility of using isokinetic dynamometry in clinical practice is of limited benefit as the device can cost upwards of £40,000, is time-consuming to operate, and immobile, meaning they are typically only found in research settings (Althobaiti et al[1]). Classical models also commonly assess strength in unnatural positions and movements, questioning their specificity to athletic performance (Reyes-Ferrada[23]).

Fixed digital dynamometry is a relatively novel method of measuring muscle strength, wherein a belt-stabilised dynamometer is used to connect the individual to a fixed object, which they pull against isometrically. It has shown *good* to *excellent* reliability (ICC 0.76–0.91) when assessing strength at the shoulder, knee, and hip (Trajković et al[31]), and is inexpensive (£100–£1000), quick to use, and highly portable (Trajković et al[31]). Fixed digital dynamometry also facilitates multiplanar trunk strength testing (i.e., across flexion, extension, and lateral flexion), which has been overlooked in most trunk strength research. Insufficient multidirectional stability of the spine may lead to increased forces imparted onto the passive structures of the spine, and subsequently, a greater risk of pathology (Vleeming et al[33]). To date, however, no study has investigated the use of a fixed digital dynamometer to assess trunk strength in any plane.

To facilitate clinical reasoning, rehabilitation, and performance programming, there is a need for a practical, inexpensive, and reliable method of assessing multiplanar trunk strength. The first aim of the study is, therefore, to establish the within- and between-session reliability, variability and minimal detectable change (MDC) of trunk muscle strength in the sagittal and frontal planes using a fixed digital dynamometer. The second aim is to establish a descriptive data set of trunk strength measurements within a population of healthy participants. The final aim is to provide a comparison of strength data across positions.

Methods

Study Design

A within-subject test-retest design was adopted to examine the reliability, variability, SEM, and MDC of trunk strength tests. The testing was carried out in the Ballet Healthcare suite at the Royal Opera House, London, United Kingdom in July 2023. All data collection was carried out by the same Chartered Physiotherapist, who had more than ten years' experience working within elite sport. Testing was carried out at the same time of day (± 1 hour) for each participant, within an air-conditioned gymnasium, with temperature set at 21 °C.

Participants

An *a priori* power analysis was conducted, identifying a minimum sample of 18 participants needed to calculate the ICC ($\alpha = 0.05$, $\beta = 0.80$), established on three trials recorded per participant in each testing position, with a minimum acceptable reliability (ρ_0) of ≥ 0.7 and an expected reliability (ρ_1) of ≥ 0.9 (Brady et al[2]; Walter et al[34]). A convenience sample of 18 healthy participants volunteered to take part in this study. Anthropometric measurements were performed following the guidelines of the International Society for the Advancement in Kinanthropometry (ISAK) (Stewart et al[30]). Measurements were taken prior to testing with the participants barefoot. Bodyweight (kg) was measured using a SECA scale, (SECA, Hamburg, Germany) with 100 g precision and standing height (cm) was measured using a SECA stadiometer (SECA, Hamburg, Germany) with 0.1 mm precision.

Participants were recruited through poster and email advertisements. They were required to be physically active but did not need to have previous experience in strength testing. All participants were free from musculoskeletal injury, had no previous history of spinal or trunk injury, were able to adopt the testing positions, and were not pregnant. All participants gave written informed consent following a full explanation of the study protocol and the rights of participants were protected. Ethical approval was granted from the local ethics committee in accordance with The Declaration of Helsinki.

Protocol

The study consisted of two testing sessions separated by seven days. A standardised and graduated warm-up was conducted prior to testing. The warm-up consisted of five minutes on a cycle ergometer maintaining a rate of perceived exertion of 6/10 effort, followed by five minutes of hip, lumbar and thoracic spine mobility exercises. Finally, three sets of 15 second front planks, side planks and glute bridges were completed. Participants completed three submaximal efforts at 50%,75% and 90% of self-perceived maximal voluntary contraction in each of the four testing positions prior to data collection to familiarise themselves with the testing requirements.

Participants were positioned in prone, supine, left-sided recumbant and right-side recumbant positions on an adjustable glute-hamstring raise machine (Pro-D Glute/Ham Hyper Station, Pullum Sports, Leighton Buzzard, UK). Within each position, the participant was parallel to the ground, with their feet secured within the foot supports of the glute-hamstring raise machine, knees in five degrees flexion, arms folded across chest, hands resting on their opposing acromion process, and iliac crests level with the edge of the glute-hamstring raise machine (**FIGURE 1**). A 10 Hz fixed digital dynamometer (EasyForce digital dynamometer, Meloq, Sweden) was attached to the participant using a harness and carabena system (**FIGURE 2**) and connected to the base of the glute-hamstring raise machine with a ratchet strap. A box was placed in front of the participant, allowing them to rest between contraction efforts.

For each position, testing consisted of three five-second isometric maximal voluntary contractions (MVCs). Within each position, the participant maintained maximal comfortable posterior pelvic tilt throughout. To minimise possible fatigue (Harding et al[6]), a 30-second rest period was given between each trial, and a two-minute rest period was given between each position (Mattiussi et al[13]). Testing position order was randomised for each participant, with the same order repeated when conducting the retest to reduce systematic error and minimise the effects of fatigue and potentiation on results. An assistant recorded scores to ensure blinding of the primary tester from the results to reduce observer bias. The dynamometer was zeroed between each trial. Peak force values were measured in kilograms and the mean and maximum peak force value over three trials in each position was calculated.

Participants were briefed to “pull-up maximally against the dynamometer” prior to each attempt. Each attempt was started by the lead author, telling the participant to adopt the starting position and then counting down “3, 2, 1, pull” (Mattiussi et al[13]). In prone, participants pulled up against the fixed digital-dynamometer, attempting to extend the spine. In supine, participants pulled up against the fixed digital-dynamometer, attempting to flex the spine. In left and right-side recumbent, participants pulled up against the fixed digital-dynamometer, attempting to right and left side-flex the spine, respectively. Testing was stopped and an additional trial was conducted if any compensatory patterns of movement were observed (e.g. hyperextension through the lumbar spine), an inability to maintain the appropriate test position, any pain was experienced, or the participant voluntarily discontinued the test.

Data Analysis

Following the completion of data collection, relative force was calculated by dividing the absolute force by body mass. The mean ± standard deviation (SD) of the absolute and relative force was calculated from the three trials in each position. The maximum ± standard deviation (SD) of the absolute and relative force was also calculated from the mean of each participant’s maximum trial in each position. In addition, strength ratios between opposing directions of movement were calculated by dividing the mean absolute prone force by the mean absolute supine force, and by dividing the mean absolute left-side force by the mean absolute right-side force.

Statistical Analysis

Within-session (2, 1) and between-session (2, k) reliability were evaluated using ICCs (Mokkink et al[16]; Weir[35]), calculated using two-way random effects models, with 95% confidence intervals. Shapiro-Wilk tests were used to verify the normality of data distribution. Within-session reliability was calculated using the three trials in each position, collected during the second testing session. Between-session reliability was calculated using the mean and maximum score in each position over the two testing sessions. The ICCs were interpreted as follows (Koo and Li[10]): *Poor* < 0.50, *Moderate* 0.50−0.75, *Good* 0.75−0.90, *Excellent* > 0.90.

The SEM was determined using the equation:

$$SEM = SD_{baseline} \times \sqrt{1 - ICC_{between}}$$

The MDC was determined using the equation:

$$MDC = 1.96 \times SEM \times \sqrt{2}$$

The CV was determined using the equation:

$$CV = \frac{\sqrt{MSE}}{\bar{y}}$$

All statistical analysis was carried out using R (version 4.0.3, R Foundation for Statistical Computing, Vienna, Austria). Significance was set at $p < .05$.

Results

The characteristics of the participants were 10 male (age: 37.7 ± 9.7 years, height: 1.81 ± 0.1 m, weight: 79.1 ± 9.1 kg) and 8 female (age: 36.5 ± 8.5 years, height: 1.69 ± 0.1 m, weight: 62.3 ± 11.3 kg).

Within-session reliability was *excellent* in all four positions (ICC 0.95–0.98), with relative force MDC ranging from 14% to 18% and variability ranging from 5% to 7%. Between-session reliability was *excellent* in all four-positions (ICC 0.98–0.99), with relative force MDC ranging from 8% to 13% and variability ranging from 4% to 6%. Within and between-session reliability statistics are presented in **TABLE 1**.

Descriptive statistics of absolute and relative force data across all testing positions are presented in **TABLE 1**, whilst box plots of individual participant test-retest absolute and relative force data are presented in **FIGURE 3**. The forces in the prone position across all participants were almost two-fold that of all other positions (prone mean = 41.8 ± 17.7 kg), whilst all other positions were similar (supine mean = 23.1 ± 10.8 kg; left mean 24.1 ± 10.1 kg; right mean = 21.9 ± 8.4 kg). The relative strength ratio of prone:supine position was 1.8 in males and 1.7 in females; whilst the left: right side-recumbant position strength ratio was 1.1 in males and 1.0 in females.

Discussion

This study investigated the reliability, variability, SEM and MDC of fixed digital dynamometer multi-planar trunk strength tests for the first time. The results demonstrated *excellent* within- and between-session reliability (ICC ≥ 0.95) with low variability (CV ≤ 7%) and MDC of up to 6.3kg for absolute and relative force across all four testing positions. Based on these results, the testing protocol investigated in all four positions can be considered to provide consistent measurements of isometric trunk muscle strength in both the sagittal and frontal planes. For ease, practitioners may want to use only one measure of force (i.e., absolute or relative force) in clinical practice due to comparable reliability and variability.

In line with previous investigations into fixed digital dynamometry for the assessment of isometric strength of the shoulder (ICC 0.91), knee (ICC 0.83), and hip (ICC 0.89) (Trajkovi´c et al[31]), we observed *excellent* reliability using the same method to assess multiplanar trunk strength. These results were consistent, both within and between sessions, and across all four testing positions. Furthermore, these results demonstrated higher between-session reliability than when using a handheld dynamometer (ICC 0.67−0.93) (De Blaiser et al[3]) and similar between-session reliability to using an isokinetic dynamometer (ICC 0.87−0.95) (Guilhem et al[5]) when measuring trunk strength. This study, therefore, provides clinicians with a method that is not only cost-effective, but is as reliable as gold-standard approaches, making it preferable in applied environments.

The between-session MDC for absolute force ranged from 8% (prone) to 13% (right-side recumbant) of the group mean during the four different positions of trunk strength; translating to absolute values between 2.9 to 3.2 kg across all positions. The MDCs observed in the present study are slightly greater than those previously reported using isokinetic dynamometry (9%) (Guilhem et al[5]), and considerably greater than similar research using a bespoke measurement system (3.1 N) (Loss et al[11]). It is plausible that the lower MDCs observed in the aforementioned studies are explained by the equipment used, which restricted movement to a single plane and involved more points of stabilisation, making them more robust against small variations in participant position. Conversely, the between-session MDCs of trunk testing using handheld dynamometry were larger than those observed in this study (5.2−7.5 kg; Kahraman et al[9]). Studies employing handheld dynamometry to measure trunk strength have failed to adequately stabilise participants, with fixation either not being used at all or only being used at one region of the body potentially leading to erroneous results (e.g. across the hips) (Newman et al[19]). The present method, therefore, offers a middle ground between the excessive degrees-of-freedom present using a handheld dynamometry approach, and the low degrees-of-freedom but low practicality of isokinetic dynamometry/bespoke equipment approaches.

Peak forces in this study are approximately 10% lower than when testing with an isokinetic dynamometer (Zouita et al[36]). This may be explained by the reduced fixation employed in this study compared to when using an isokinetic dynamometer, resulting in decreased force production. Increased fixation during strength testing has been shown to lead to increased force output when testing other regions of the body (Michailov et al[15]), however, it may curtail specificity and compromise the clinical applicability of the test. In contrast, the testing method chosen may not isolate the trunk musculature, and, as such, there may be contributions from other muscles within the body. This is more akin to real life where trunk muscles work in combination with muscles of the upper and lower limb to provide stability and transfer force through the kinetic chain (Martin et al[12]; Rodriguez-Perea[26]). The descriptive data set in this study, within the specific population recruited, provides insight into trunk strength and the ratios between opposing positions. The trunk extensors (prone position) demonstrated 1.7 and 1.8 times the force of the trunk flexors (supine position) in females and males respectively. This is consistent with past research that has shown the trunk extensors are stronger than the trunk flexors (Moussa et al[18]; Reyes-Ferrada[25]).

Strengths and Limitations

A strength of this study is the participant recruitment process. Unlike much research in the sports science literature (Paul et al[20]), it adopted a mixed sample of both males and females;

improving the generalisability of the results. This has been a limitation of recent research investigating trunk strength measurements (Rodriguez-Perea[28]; Reyes-Ferrada[22]). Also, the four testing positions ensured multi-planar trunk maximum strength assessment, a testing protocol lacking in the current literature base (Althobaiti et al[1]).

There are several limitations of this study. Firstly, participants were positioned using visual observation. Accurately measuring spinal position is complex, requiring specific equipment (Sonvico et al[29]). Further research may wish to implement more stringent measures of spinal position through technological advancements, such as the use of sensors and accelerometers (Sonvico et al[29]). However, the decision was made to aid the clinical applicability of this methodology and translate best to a practical setting in which time is finite and resources are limited. A further limitation of this set-up is that these positions do not isolate the trunk musculature, and, as such, there will be contributions from the entire kinetic chain. For example, during the supine position, the hip flexors will contribute to force generation and during the prone position, there will be involvement of the hip extensors (Moussa et al[18]). Therefore, future research could use the fixed digital dynamometer in a different static position to determine if a better method exists to measure trunk strength. Thirdly, practitioners should be cautious when extrapolating the findings beyond the current population group. Future research could perform the same testing protocol in other populations, for example individuals with low back pain, elite athletes or older adults. Lastly, large differences in between-participant SD of strength were observed indicating minimal homogeneity across the group which may have affected the MDC calculation. A more homogeneous group with more similar physical qualities may lead to smaller MDC values.

Practical Applications

The protocol adopted in this study was quick to administer and easy to standardise, making it appealing for practitioners working in clinical practice. Thereby allowing the effects of trunk strength training or rehabilitation to be better understood. The isometric nature of contractions may also mean this assessment method is better tolerated in individuals with low back pain than more dynamic through range maximum contractions (Rodriguez-Perea[28]). Based on the relative ease of testing, low-cost of equipment, excellent reliability and competitive MDC values, these results provide a strong justification for the use of the present methodology in future research and practice.

Conclusion

This is the first study to investigate the within- and between-session reliability, variability, and MDC of multiplanar isometric trunk strength testing using a fixed digital dynamometer. Based on the results of this study, the fixed digital dynamometer is a reliable tool to assess multi-planar trunk strength in the four chosen positions. In addition, when interpreting for a meaningful change, absolute values of between 8–13% (or 2.9 to 3.2 kg) of the group mean between the four trunk testing positions can be used as benchmarks. This offers clinicians a readily available, highly portable and cost-effective method of assessing all four quadrants of trunk strength. Practically, simple and reliable assessment of trunk strength will facilitate the identification of insufficient trunk strength, allow practitioners to track longitudinal changes in trunk strength, and aid in trunk-specific performance and rehabilitation programming.

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TABLE 1. Descriptive statistics, and within- and between-session reliability results for absolute and relative force tests.

Reliability	Variable	Aggregation	Position	Mean Force ± Standard Deviation			ICC (95% CI)	CV (%)	SEM (kg)	MDC	
				Session / Trial 1	Session / Trial 2	Session / Trial 3				kg	%
Between-Session	Absolute	Maximum	Prone	43.3 ± 18.0	43.6 ± 18.4	-	1.00 (0.99–1.00)	4%	1.1	3.2	7%
			Supine	24.6 ± 10.9	24.4 ± 11.0	-	0.99 (0.98–1.00)	5%	0.9	2.5	10%
			Left	24.8 ± 10.9	26.1 ± 10.6	-	0.99 (0.96–1.00)	5%	1.2	3.2	13%
			Right	22.9 ± 9.1	23.8 ± 8.8	-	0.98 (0.96–0.99)	7%	1.2	3.4	14%
		Mean	Prone	41.5 ± 17.9	42.1 ± 17.6	-	1.00 (0.99–1.00)	4%	1.2	3.2	8%
			Supine	23.2 ± 10.7	23.0 ± 11.1	-	1.00 (0.99–1.00)	5%	0.7	2.0	9%
			Left	23.5 ± 10.0	24.8 ± 10.2	-	0.99 (0.96–1.00)	5%	1.0	2.7	11%
			Right	21.4 ± 8.5	22.4 ± 8.4	-	0.98 (0.96–0.99)	6%	1.1	2.9	13%
	Relative	Maximum	Prone	0.60 ± 0.23	0.61 ± 0.23	-	0.99 (0.99–1.00)	4%	0.017	0.047	8%
			Supine	0.34 ± 0.14	0.34 ± 0.14	-	0.99 (0.98–1.00)	5%	0.012	0.035	10%
			Left	0.34 ± 0.13	0.36 ± 0.12	-	0.98 (0.94–0.99)	5%	0.016	0.044	13%
			Right	0.32 ± 0.10	0.33 ± 0.10	-	0.97 (0.94–0.99)	7%	0.016	0.045	14%
		Mean	Prone	0.58 ± 0.23	0.58 ± 0.22	-	0.99 (0.99–1.00)	4%	0.017	0.048	8%
			Supine	0.32 ± 0.13	0.32 ± 0.14	-	0.99 (0.99–1.00)	5%	0.010	0.028	9%
			Left	0.32 ± 0.11	0.34 ± 0.11	-	0.99 (0.94–0.99)	5%	0.014	0.038	12%
			Right	0.30 ± 0.10	0.31 ± 0.10	-	0.98 (0.95–0.99)	6%	0.014	0.038	13%
Within-Session	Absolute	-	Prone	41.6 ± 18.6	42.3 ± 16.7	42.4 ± 17.8	0.98 (0.97–0.99)	6%	2.3	6.3	15%
			Supine	23.4 ± 11.3	22.8 ± 11.4	22.9 ± 10.7	0.98 (0.97–0.99)	6%	1.4	4.0	17%
			Left	24.5 ± 9.7	24.5 ± 10.1	25.3 ± 10.9	0.98 (0.95–0.99)	6%	1.6	4.4	18%
			Right	22.3 ± 8.3	22.5 ± 8.7	22.3 ± 8.5	0.97 (0.94–0.98)	7%	1.5	4.2	19%
	Relative	-	Prone	0.58 ± 0.24	0.59 ± 0.21	0.59 ± 0.22	0.98 (0.97–0.99)	5%	0.030	0.082	14%
			Supine	0.33 ± 0.14	0.32 ± 0.14	0.32 ± 0.13	0.98 (0.95–0.99)	7%	0.021	0.058	18%
			Left	0.34 ± 0.11	0.34 ± 0.11	0.35 ± 0.12	0.96 (0.93–0.98)	7%	0.022	0.061	18%
			Right	0.31 ± 0.10	0.31 ± 0.10	0.31 ± 0.10	0.95 (0.92–0.98)	7%	0.020	0.057	18%

Note: ICC, Intraclass Correlation Coefficient; CV, Coefficient of Variation; SEM, Standard Error of Measurement; MDC, Minimal Detectable Change; CI, Confidence Interval.

FIGURE 1. Trunk Testing Positions. A - Prone, B - Supine, C - Left-Side Recumbant, D -Right-Side Recumbant

FIGURE 2. Harness and Carabena System (Power Pull, Perform Better)

FIGURE 3. Box plots of individual test-retest Mean Relative (A), Max Relative (B), Mean Absolute (C) and Max Absolute (D) force data within each testing position.

Note: BW, bodyweight; kg, kilograms