CORA Cork Open Research Archive
Cartlann Taighde Oscailte Chorcaí

| | |
|---|---|
| Title | Trunk strength and endurance testing in field-athletes: a reliability study |
| Authors | Dekkers, Thomas A.;Blake, Catherine;Collins, Kieran D.;McVeigh, Joseph G.;O'Sullivan, Kieran J. |
| Publication date | 2025-07-28 |
| Original Citation | Dekkers, T.A., Blake, C., Collins, K.D., McVeigh, J.G. and O'Sullivan, K.J. (2025) 'Trunk strength and endurance testing in field-athletes: a reliability study.', Physical Therapy in Sport. https://doi.org/10.1016/j.ptsp.2025.07.012 |
| Type of publication | Article (peer-reviewed) |
| Link to publisher's version | 10.1016/j.ptsp.2025.07.012 |
| Rights | © 2025, Elsevier Inc. All rights reserved. This manuscript version is made available under the CC BY-NC-ND 4.0 license. - https://creativecommons.org/licenses/by-nc-nd/4.0/ |
| Download date | 2026-11-01 21:13:09 |
| Item downloaded from | https://hdl.handle.net/10468/17779 |

UCC
University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

# TRUNK STRENGTH AND ENDURANCE TESTING IN FIELD-ATHLETES: A RELIABILITY STUDY.

# TRUNK STRENGTH AND ENDURANCE TESTING IN FIELD-ATHLETES: A RELIABILITY STUDY.


## ABSTRACT

### Objectives

Despite the important role of the trunk muscles in athletic performance and the onset of injury, consensus is lacking as to the best methods to assess trunk strength and endurance in athletic populations in the field. This study aimed to examine the intra-rater reliability of a battery of trunk strength and endurance tests.

### Design

Test-retest reliability study.

### Setting

Isometric trunk strength using a hand-held dynamometer (HHD) and isometric trunk endurance using the McGill protocol and novel 'long-lever' tests were evaluated.

### Participants

Twenty-three male field-athletes.

### Main Outcome Measures

Intra-class coefficient (ICC) and standard error of measurement (SEM).

### Results

For relative reliability, good to excellent results were found for all HHD strength tests (ICC = 0.70-0.91). Relative reliability for trunk endurance tests showed excellent results for the McGill protocol (ICC = 0.80-0.89) and moderate to excellent reliability for the long-lever tests (ICC = 0.57-0.96). The V-Sit endurance test and the isometric lateral flexion strength test showed lower absolute reliability, with relatively high SEM values.

**Conclusions**

Therefore, we recommend practitioners assess athlete trunk function by using a HHD to evaluate isometric flexion, extension and rotation trunk strength and the Biering-Sørenson, and long-lever lateral flexion and flexion tests to assess trunk endurance.

Key words: Trunk; strength; endurance; soccer: football; hurling; tests; assessment,

## INTRODUCTION

The trunk muscles produce the force necessary to generate or prevent movements of the trunk (26). Given their central position in the body relative to the upper and lower limbs, they are thought to have an important role in the transfer of energy in the kinetic chain and thus contribute significantly to athletic function (24,49). As such training the trunk muscles to enhance athletic performance has long been considered a priority for conditioning programs in sporting populations with some evidence indicating that such training programs can lead to improvements in athletic performance (11,19,34,48). Although evidence exists that the trunk muscles may have a considerable influence on athletic performance (11,19,34) there is a lack of evidence for robust tests that practitioners can use to measure trunk muscle function.

Trunk muscle strength and endurance are thought to enhance athletic performance (14). Muscle strength is the maximum voluntary force that can be exerted by a muscle or muscle group under specific conditions (46). The gold standard for testing trunk strength is considered to be the isokinetic dynamometer (IKD) as it has high validity and reliability (14,20). However, the cost and size of IKD machines makes them prohibitive for day-to-day practice with athletes. The hand-held dynamometer (HHD) is a cost-effective and portable alternative to the IKD for assessing muscle strength (37).

For an instrument (such as a HHD) to be used in clinical practice or research its reliability, validity and responsiveness should be considered adequate, otherwise there is a risk of imprecise results and misdirected treatments (28). Reliability is the extent to which a measurement is free from measurement error which may arise from the instrument, participants, testers or the testing circumstances (28,43). Numerous methods using the HHD to

evaluate trunk strength have showed excellent relative reliability, measured by Intra-class coefficient (ICC), in different positions such as sitting (33) (ICC = 0.82), standing (18,22) (ICC = 0.83-1.0) or lying down (1,6) (ICC = 0.78 – 0.93). However, for sitting and standing the feet are in contact with the ground, thus it is conceivable that the lower limbs may contribute to force production in these positions making them less trunk specific.

De Blaiser et al (2018) found high correlations between HHD and IKD (r = 0.65–0.86) and excellent reliability for the HHD while testing trunk flexion at 30º and extension at 0º on a plinth (ICC = 0.90 and 0.93 respectively). The strength of the athlete's trunk muscles can make it difficult for the operator to prevent trunk movement with this technique to attain an isometic contraction. Hence movement can be restricted with external trunk fixation using straps (1). Trunk rotation has been assessed using a bar in both standing and sitting(1). Although good to excellent reliability (ICC 0.68-0.92) was found for both rotational methods, the use of the bar may preclude use in clinical environments. For the present study, multidirectional isometric trunk strength was assessed using only straps over the trunk and legs to ensure isometric contraction.

Muscle endurance is the ability of muscles to resist fatigue in response to sub-maximal resistance (17). Isokinetic dynamometry has been used for measurement, although as previously mentioned its use in the field is limited (14). Field tests for trunk endurance can be either dynamic (4,8) or isometric (5,12,27). McGill et al (1999) used a battery of four tests (including Biering-Sørenson, V-sit, and side bridge) which have been shown to have good to excellent intra and inter-rater reliability in non-athletic populations (12,20,31,44). To the authors knowledge, the reliability of this testing battery has not been examined in an exclusively field-athlete population. In addition, the upper and lower limbs may contribute

significantly to two of the tests. In the V-sit, the hips are flexed at 60° thus increasing the recruitment of the hip flexors (2). The side bridge position is maintained using the arm, with arm pain and/or fatigue commonly reported as the reason for test termination (16). Electromyographic studies have shown that variations of the side bridge recruit 29-63% of maximum voluntary contraction of the external oblique musculature (50). Hence, although the side-bridge test undoubtedly targets the lateral trunk musculature, the level of contribution of the upper limb to holding the position remains in doubt. To address these issues, we developed the "long-lever" tests which negate the use of upper limb for the side bridge test and place the participant with hips at 30º flexion with the intent of biasing muscle recruitment of the lateral and anterior trunk respectively.

In summary, the trunk muscles have been implicated as having an important function in athletic performance. However, there is no consensus on an optimal testing battery for trunk strength and endurance in athletes that can be performed by practitioners in the field. Therefore, the aim of the current study was to evaluate the intra-rater reliability of the following field tests in healthy athletes; (1) multi-directional isometric trunk strength using a HHD and straps; (2) the McGill trunk endurance test battery; (3) the 'long-lever' tests, in a cohort of healthy athletes.

## METHODS

### Subjects

Ethical approval was received through the Technological University Dublin Research Ethics and Integrity Committee (REIC-22-14). All study participants signed an informed consent form prior to data collection. Data were collected at two private clinics in Ireland between March 2023 and May 2024.

Participants were adult male field-sport athletes (18-40 years old) from soccer, Gaelic football and hurling who had participated in training and/or competed in their sport at a registered club in the last 12 months. Participants were recruited once ethical approval was gained. Recruitment was through social media, direct contact of Gaelic football, hurling and soccer clubs, coaches, and health professionals. If interested, participants contacted the research team for further information. A brief telephone interview was arranged to discuss the research aims and screen inclusion/exclusion criteria. If the individual was eligible and interested in participating, they were emailed an informed consent form. On receipt of the completed form they were included in the study.

Exclusion criteria were as follows; an episode of activity-limiting LBP in the last 12 months, defined as pain localised from T12 to the gluteal folds, resulting in time loss from sport that "prevents a player from taking full part in all training activities typically planned for that day and match play for more than 24 hours from midnight at the end of the day the injury was sustained" (7); thoracic or lumbar spine surgery in the past 18 months; previous fusion surgery of the lumbar or thoracic spine; LBP attributed to malignancy, rheumatological disorders, infections or acute vascular causes; any medical condition preventing them from engaging

177 safely in the physical testing procedures; LBP with dominant leg pain; inadequate ability to
178 speak and/or understand English.
179
180 **Procedures**
181 After written informed consent for each participant was received, physical testing of the athlete
182 was arranged. The test procedure was conducted a second time 2-5 days later, where possible
183 at the same time of day as the first session to limit the effects of circadian variation. All tests
184 were conducted by a state-registered Physiotherapist with 15 years of post-graduate clinical
185 experience in musculoskeletal and athletic environments, with a special interest in spinal
186 cohorts. There was no formal warm up advised as the testing battery was already quite
187 extensive. The following test procedures was carried out in the same order on both days.
188
189 **Strength testing**
190 Strength tests for flexion, rotation, lateral flexion and extension were performed. To minimise
191 trunk movement, three nylon straps were used (Figure 1). These straps were placed across the
192 participant's sternum, anterior superior iliac spine (ASIS) and 10cm superior to the lateral
193 malleoli for flexion, rotation and lateral flexion. For extension, a strap was placed across the
194 participant's thoracic spine at T4, posterior superior iliac spine (PSIS) and 10cm superior to
195 the lateral malleoli (Figure 2). In all movements, the HHD (MicroFET 2 handheld
196 dynamometer, Hoggan Scientific LLC, Salt Lake City) was affixed to the thoracic or sternal
197 strap using the hand attachment. The HHD was held in place by the tester. Participants were
198 asked to perform a maximal push into the dynamometer with their trunk for 5 seconds (6,40).
199 A single familiarisation repetition in each direction was conducted. Three maximal efforts in
200 each position were recorded with 15 seconds between contractions. A standard command of
201 "3, 2, 1 push as hard as you can" was given for each test with no encouragement given during

contraction. A 2-minute rest period was taken between each position. Tests were terminated if the position was not maintained, if pain was experienced, or if the participant voluntarily discontinued the test.

**Strength Tests**

*Flexion:* The participant was placed in supine with knees fully extended and the hips flexed to 30º with the trunk supported by the inclined portion of the bed. The HHD was placed on the sternum inferior to the supra-sternal notch.

*Rotation:* The participant assumed the same position as for flexion. The HHD was placed over the pectoral muscles, medial to the gleno-humeral joint and inferior to the clavicle, of the opposite side to which the participant was rotating.

*Lateral flexion:* The participant lay in side-lying, with both hips and knees in 0º flexion. The middle strap was placed over the ASIS and affixed to the centre of the bed (see Figure 1). The dynamometer was placed inferior to the acromion.

*Extension:* The participant was placed in prone at 0º extension with their hands to the side of their head and elbows not touching the bed. They were placed so that their head would fit into the head-cutout in the bed. The dynamometer was placed at T4.

**Figure 1: The trunk isometric strength tests**




1 (A) Flexion, (B) Rotation, (C) Lateral Flexion (D) Extension

**Figure 2: The hand-held dynamometer placements**




(A) Flexion, (B) Rotation, (C) Lateral Flexion, (D) Extension

**Endurance testing**

Participants were given a 5-minute rest period before endurance testing. The two endurance testing batteries (McGill and Long-lever) were separated by another 5-minute break. For all endurance tests participants were familiarised with the test position for a maximum of 5 seconds and then returned to a resting position. Participants were then asked to hold the position as long as they could and the time to test cessation (secs) was recorded. The test was stopped when participants could not maintain their position any longer, experienced pain or wished to stop the test.

**Endurance Tests**

McGill protocol (Figure 3)

*V-Sit Test:* The participant sat on the bed with knees at 90° and hips flexed to 60°. The arms were folded across the chest and a strap was placed across the feet.

*Side-bridge Test:* The participant lay in side-lying with the upper foot placed in front of the lower foot with knees extended. The underneath arm was flexed at the elbow and the body was maintained in a neutral position.

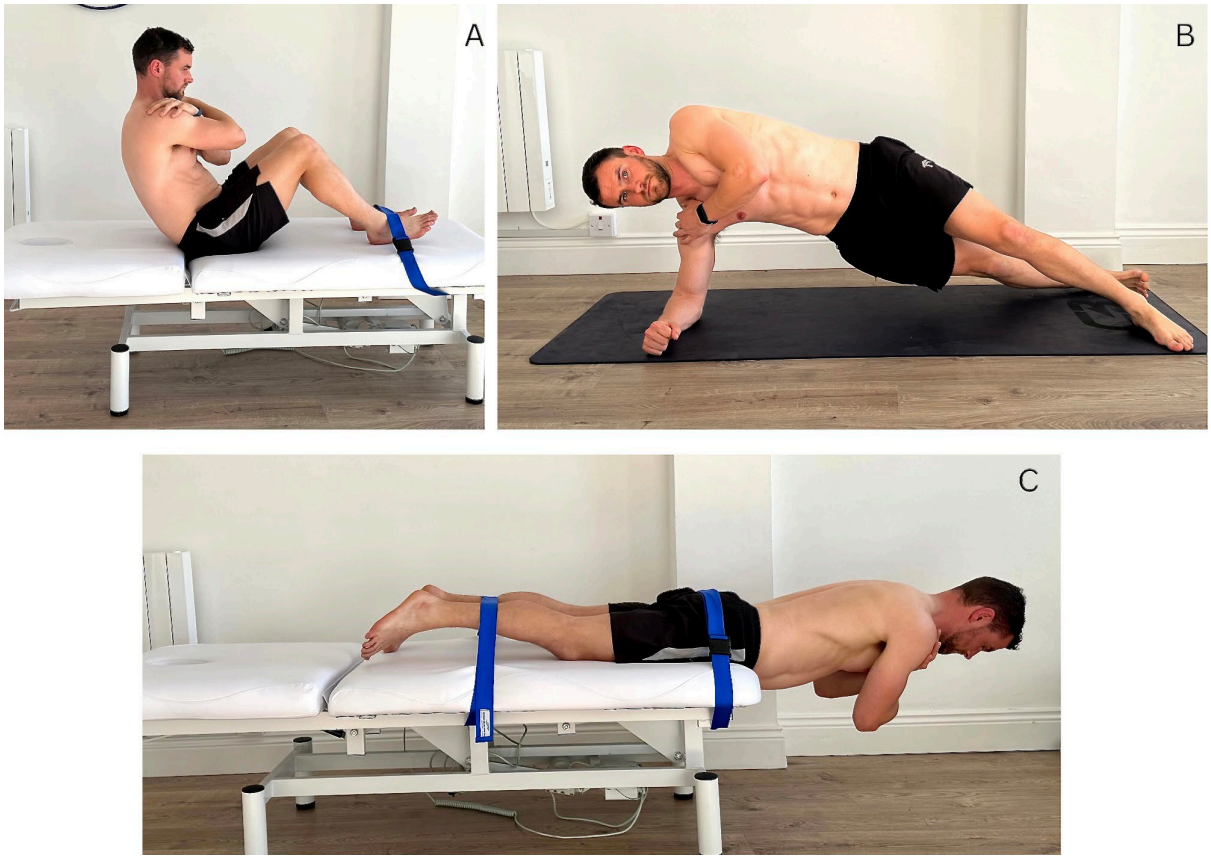
*Biering-Sørenson Test:* The participant lay in prone with the PSIS level with the end of the bed and the arms folded across the chest. Straps were placed across PSIS and 10cm superior to malleoli.

Long-lever protocol (Figure 4)

*Long-lever flexion (LL flexion):* The participant sat on the bed with knees at 0° and hips flexed to 30°. The trunk was supported by the bed prior to the test beginning. A strap was placed 10cm superior to malleoli.

*Long-lever lateral flexion (LL lateral flexion):* The participant lay in side-lying with the ASIS level with the end of the bed and the arms folded across the chest. Straps were placed across the ASIS and 10cm superior to malleoli.

**Figure 3 – The trunk endurance tests (McGill Protocol)**




3 (A) V-Sit Test, (B) Side Bridge, (C) Biering-Sørenson

**Figure 4 – The long-lever trunk endurance tests**




(A) Long-Lever Flexion (B) Long-Lever Lateral Flexion

**Statistical Analysis**

Peak isometric force measured in Newtons (N) using the HHD was determined by taking the highest value of the three maximal efforts (23). All endurance tests were measured in seconds (27). Data were analysed using IBM Statistics SPSS v 29.0.2.0. Initial screening with the Kruskall-Wallis test demonstrated normality of the data distributions and the test results were summarised using means and standard deviations. Relative reliability was determined using the Intraclass Correlation Coefficient (ICC 2,1), with 95% CI, applying a two-way random effects model, with absolute agreement for a single measurement (41). The ICC was considered to be low if it was <0.40, moderate if 0.40-0.59, good if 0.6-0.75 and excellent if >0.75 (10). Based on an expected ICC of 0.85, precision of 0.1, 6 repetitions per subject, alpha of 0.05 and power of 80%, calculations showed that the minimum sample size

for the study was 18 participants (45). The absolute reliability was measured using the standard error of measurement (SEM) and coefficient of variation (CV). The SEM was calculated from the ANOVA table, taking the square root of the Mean Squared Error of the residual (SEM = $\sqrt{\sigma^2}_{residual}$ ) (43). The minimal detectable change (MDC) was calculated as MDC= SEM × 1.96*√2 (47). The CV was calculated as $\frac{SD}{Mean}$ X 100 (3,42)

**RESULTS**

In total, 24 male athletes were eligible for the study. One participant was unable to attend the second testing day due to logistical reasons and therefore was excluded from the study. Therefore, 23 participants were completed all testing on both days. Baseline participant characteristics are shown in Table 1. All athletes played at an amateur level i.e. not at elite level in Gaelic football or hurling, or semi/full professional in soccer, with some athletes playing more than one sport (Table1). The mean days between testing was 3.0 (SD = 1.93). Mean strength and endurance values are shown in Table 2.

Intratester reliability for all tests using ICC, SEM and MDC measurements, are shown in Table 1. All isometric strength tests using the HHD were found to have good to excellent relative reliability (ICC = 0.7-0.91). All isometric endurance tests showed excellent intratester relative reliability (ICC = 0.77-0.96) except the right LL lateral flexion test which showed moderate intra-tester reliability (ICC = 0.57). For the strength tests the SEM ranged between 13-39N and the MDC from 38-109N. For the endurance tests the SEM ranged between 6-58secs and MDC from 17-161 secs.

371 **Table 1:** Baseline participant Characteristics

| | Mean (SD) | | |
|---|---|---|---|
| **Age (Years)** | 26.4 (5.6) | | |
| **Current Training & Match sessions per week (self-reported)** | 3.7 (1.0) | | |
| **Steps per day (self-reported)** | 11,073.7 (5243.3) | | |
| **Sports Played** | **Gaelic Football** | **Hurling** | **Soccer** |
| Participants | 18 | 6 | 4 |

372

373

374

375

376

**Table 2:** Intratester reliability values of trunk strength (Newtons) and endurance (seconds).

| **Isometric Strength Tests** | **T1 Mean (SD)** N | **T2 Mean (SD)** N | **Total Mean (SD)** N | **CV %** | **Ratio to Extension Strength** | **ICC** 2,1 | **95% CI for ICC** | **SEM** N | **MDC** N |
|---|---|---|---|---|---|---|---|---|---|
| **Peak Flexion** | 241.5 (62.0) | 238.2(58.6) | 240.3 (59.7) | 24.8 | 1.37 | 0.90 | 0.79 - 0.96 | 18.90 | 52.38 |
| **Peak Rotation R** | 235.8 (51.0) | 227.5 (49.5) | 231.0 (49.8) | 21.6 | 1.31 | 0.83 | 0.65 - 0.92 | 20.56 | 57.00 |
| **Peak Rotation L** | 246.3 (53.5) | 243.1 (54.1) | 245.5 (53.2) | 21.7 | 1.40 | 0.84 | 0.67 - 0.93 | 21.54 | 59.71 |
| **Peak Lateral Flexion L** | 220.8 (68.9) | 246.4 (82.5) | 233.5 (76.3) | 32.7 | 1.33 | 0.70 | 0.40 - 0.86 | 39.41 | 109.25 |
| **Peak Lateral Flexion R** | 239.2 (80.8) | 260.2 (76.7) | 247.8 (78.9) | 31.8 | 1.41 | 0.74 | 0.46 - 0.88 | 38.00 | 105.34 |
| **Peak Extension** | 170.6 (42.6) | 178.0 (50.0) | 175.9 (46.0) | 26.2 | 1.00 | 0.91 | 0.80 - 0.96 | 13.99 | 38.77 |
| **Isometric Endurance Tests** | **T1 Mean (SD)** Sec | **T2 Mean (SD)** Sec | **Total Mean (SD)** Sec | **CV %** | **Ratio to Biering-Sorenson** | **ICC** 2,1 | **95% CI for ICC** | **SEM** Sec | **MDC** Sec |
| **V-Sit** | 250.4 (161.3) | 244.5 (151.6) | 245.7 (154.8) | 63.0 | 2.11 | 0.87 | 0.71 - 0.94 | 58.12 | 161.11 |
| **Side Bridge L** | 83.5 (23.2) | 80.7 (23.4) | 81.7 (23.1) | 28.3 | 0.70 | 0.89 | 0.77 - 0.95 | 7.64 | 21.16 |
| **Side Bridge R** | 85.7 (21.7) | 84.8 (19.9) | 85.2 (20.6) | 24.2 | 0.73 | 0.80 | 0.59 - 0.91 | 9.45 | 26.19 |
| **Biering-Sorensen Test** | 117.7 (36.2) | 115.0 (32.2) | 116.2 (33.9) | 29.2 | 1.00 | 0.82 | 0.63 - 0.92 | 14.67 | 40.67 |
| **LL Flexion** | 86.7 (76.3) | 93.5 (65.3) | 89.2 (70.4) | 78.9 | 0.77 | 0.96 | 0.90 - 0.98 | 13.98 | 38.76 |
| **LL Lateral Flexion L** | 39.6 (15.3) | 46.4 (16.2) | 42.8 (16.0) | 37.4 | 0.37 | 0.77 | 0.30 - 0.91 | 6.25 | 17.32 |
| **LL Lateral Flexion R** | 44.2 (17.0) | 52.3 (16.5) | 48.0 (17.1) | 35.6 | 0.41 | 0.57 | 0.18 - 0.80 | 10.18 | 28.21 |

379 *Mean Isometric Strength values (Newtons) with standard deviations and ratios normalised to extension isometric strength.*
380 *Mean Isometric Endurance values (secs) with standard deviations and ratios normalised to Biering-Sorenson test (trunk extension endurance)*
381 *duration.*
382
383 *T1= first testing session, T2 = second testing session, SD =Standard Deviation, L = Left, R= Right, LL = Long-Lever, CV%- Coefficient of*
384 *variation, ICC 2,1 = Intra Class Correlation Coefficient with two-way random effect model; SEM = Standard Error of Measurement; MDC =*
385 *Minimum Detectable Change; N=Newtons; Sec = seconds*

## DISCUSSION

The aim of the current study was to investigate the intra-rater reliability (relative and absolute) of field-tests for multi-directional isometric trunk strength and endurance. Good to excellent relative reliability was demonstrated for all HHD strength tests. Excellent relative reliability was found for all McGill protocol endurance tests. Moderate to excellent relative reliability was found for the long-lever tests. Most tests showed relatively low SEM values, indicating good absolute reliability and MDC values that would allow confidence in the use of these tests to detect true change in clinical practice. Thus, isometric flexion, extension and rotation strength tests and the Biering-Sorenson, side-bridge and long-lever tests can be considered reliable clinical tests of trunk function.

### Strength Tests

Studies investigating intratester reliability of trunk strength using a HHD have consistently shown high relative reliability. De Blaiser et al. (6), when investigating athletes, showed ICC values of 0.9 and 0.93 for flexion and extension respectively, which are very similar to the present findings. Tarca et al., (39) assessed the intra-rater reliability of the HHD in trunk isometric flexion in a similar position (trunk at 25º flexion) with ICC results of findings of 0.86, which again are similar to the present study. In contrast, Moreland et al. (29) found intra-rater ICC values of 0.25 and 0.24 respectively for flexion and extension isometric strength using a HHD. The discrepancy in the results of this latter study may arise from measurements being taken by students who may have unfamiliar with HHD use and positional differences for extension.

The absolute reliability (SEM values) found in the present study for flexion and extension strength are similar to Althobaiti et al (1) (14.7N and 19.6N respectively) and De Blaiser et al (6) (17.7N and 14.4N respectively). In the present study, the SEM led to the calculation of an MDC of 52.4N and 38.8N for flexion and extension respectively. This allows the practitioner to know that increases over these values, for example following a program designed to enhance trunk strength, are likely to be due to real changes in force output rather than measurement error. Indeed, isometric extension strength was seen to increase by 36N in a population of older adults after a 9-week trunk strength program compared to controls (15) which is similar to the extension strength MDC in this study.

The technique to assess isometric trunk rotation strength was similar to Stevens et al (38) who found excellent reliability for all muscles tested using EMG. Oyama et al (32) investigated intersession reliability of trunk rotation strength in supine using a bar connected to a HHD. Their ICC findings of 0.80 are similar to the present study (0.83-0.84). SEM and MDC values of the rotation isometric strength in our study are higher than others (1), which may reflect differences in test position. Comparison of SEM and MDC to Oyama et al. (32) is difficult as they calculated strength normalised to the participants body weight.

Numerous studies have investigated trunk isometric lateral flexion strength using an isokinetic machine or a bespoke dynamometer rig (9,13,36). Reliability of isometric lateral flexion strength using a HHD was assessed by Newman et al (30) in a seated position with the ICC values of 0.53-0.77, being similar to the present study results (0.70-0.74). The SEM and MDC values of lateral flexion (38-39.4N; 105.4-109.3N) in our study are quite high in comparison to measures of flexion (18.9N; 52.4N), rotation (20.6-21.5N; 57-59.7N), and extension (14N; 38.8N). The above MDC values would mean that to have 95% confidence that a change that

435 occurred in lateral flexion strength is not due to chance, the difference in strength would have
436 to be greater than 105N on retesting. This may be unattainably large therefore their use in
437 clinical practice is questionable.
438
439 The results of the present study show that mean peak flexion force (235.8N) was higher than
440 that of extension (170.6N), which is at odds with other research showing that isometric (6,9)
441 and isokinetic (21) extension forces outperform that of flexion. Although the same positions
442 were used as De Blaiser et al (6) with the addition of the straps, trunk flexion values in our
443 study far exceed theirs (241.5N vs 136.8 respectively), with our extension values being less
444 than theirs (170.6N vs 195.2N). Possible explanations for this discrepancy may be strength
445 differences inherent in this cohorts sport or the testing set up. For example, HHD placement
446 for extension presented a challenge in some muscular participants, as large rhomboid and
447 trapezius muscle bulk may have prevented optimal T4 bony contact. This may account for the
448 lower extension values found and future studies with highly developed athletes may wish to
449 consider scapula positioning in extension testing to ensure good HHD contact. However, this
450 is also the first such study utilising this cohort and so it is unknown what trunk strength profiles
451 are representative of this population.
452
453 **Endurance Tests**
454 The reliability of the isometric trunk endurance tests of the McGill protocol have been
455 evaluated in multiple studies (12,25). The ICC results of the current study show excellent intra-
456 tester relative reliability for all 4 tests; Biering-Sørenson (0.82), V-Sit (0.87), side bridge left
457 (0.89) and side bridge right (0.80). These are similar to the ICC values found by others (44)
458 (0.66-0.96), (31) (0.91-0.96) and (12) (0.81-0.95) respectively. All of these studies investigated
459 the McGill protocol in non-athlete specific populations. Therefore, the results of the current

study demonstrate these tests are also reliable for athletic populations. The Biering-Sørenson test is the most studied test within the protocol. Latimer et al. (1999) investigated intertester reliability of the Biering-Sørenson test and found an ICC value of 0.83 for asymptomatic participants. Furthermore, the Biering-Sørenson test shows good absolute reliability with a SEM of 14secs in the present study. The SEM is the estimation of the variation around the true score when repeated measures are taken (47). Simmonds et al. (35) found a mean difference of 29sec in Biering-Sørenson values between those with and without LBP. Thus, an SEM of 14 secs should give practitioners confidence that they can accurately detect change in those with and without LBP.

The long-lever endurance tests showed mixed reliability with the LL Flexion showing the best ICC (0.96), followed by left LL Lateral Flexion (0.77) and right LL Lateral Flexion (0.57). The discrepancy of the reliability in the left and right LL lateral flexion is interesting as they are the same test, simply on opposite sides. One explanation may be related to the fact that the right-sided test was the last test performed in the whole testing battery. Retrospective analysis of the data has shown that when larger discrepancies were seen between the first and second LL lateral flexion right test results, there was a strong trend for the second (Day 2) score to being considerably higher. We hypothesise that this may reflect both a learning effect of the participants, combined with the knowledge that it was their last test being performed in the study and thus potentially motivating them to finish with a strong score.

The long-lever tests were developed as both V-Sit and side bridge tests involve greater hip-flexor and shoulder contributions respectively and are therefore not necessarily trunk specific (2,16). Furthermore, from our experience, the V-Sit appears to be notoriously easy for athletes to undertake as is highlighted by a high mean test score of over 4 minutes. By comparison the

LL flexion test biases the trunk with athletes anecdotally reporting the primary sensations of muscle fatigue being in the anterior abdominal muscles, as opposed to the hip flexors with the V-Sit. Further studies are needed to confirm this with electromyography. The mean score for LL flexion was 89.2 secs in this cohort compared to the V-Sit which was 245.7secs. Thus, the LL flexion test is better suited to clinical practice where time-constraints are usually present. Lastly, the absolute reliability of the LL flexion test is greater than the V-Sit with the SEM and MDC values (14 and 38.8 respectively) being much lower than the V-Sit (58.1 and 161.1sec respectively). When taken collectively we advocate the use of the LL flexion test over the V-Sit for the evaluation of trunk flexion endurance in athletic populations. As the LL lateral flexion tests demonstrate moderate to excellent reliability and biases the lateral trunk muscles in the absence of upper limb support we would also advocate its use over the side-bridge.

**Strengths and Limitations**

There are several limitations of this study. It was decided to use a single familiarisation trial and omit a warm-up due to time constraints on the participants however we acknowledge that this may have impacted test values. Data were collected during both in-season and off-season phases, and we could not standardise the duration between matches and the day of testing which may have affected testing. This constraint reflects the pragmatic constraints of testing non-elite amateur athletes whose playing season is highly subject to change and the ecological validity where muscle-testing is performed at different time points in the season and during rehabilitation programs. Furthermore, we acknowledge that the generalisability of this study would be enhanced by diversification of the cohort in terms of participant sex and athletic ability. This should be a consideration for future studies. Although these tests are field-based they still require an examination table and so this may still preclude them from some settings. A significant strength is that this is the first time that multidirectional trunk strength and

endurance testing has been assessed in a field-athletic population by a single study. This allows for direct comparison between the different tests, thus allowing practitioners to integrate these tests as an entire comprehensive protocol into their own practice.

## CONCLUSIONS

In conclusion, good to excellent relative reliability was found for all HHD strength tests (ICC = 0.70-0.91). Relative reliability for trunk endurance tests showed excellent results for the McGill protocol (ICC = 0.80-0.89) and moderate to excellent reliability for the long-lever tests (ICC = 0.57-0.96). By comparison, the V-Sit test and isometric lateral flexion strength test showed lower absolute reliability, with a higher standard error of measurement (SEM). Thus, we recommend that practitioners evaluate athlete isometric trunk function by using a HHD to assess flexion, extension and rotation trunk strength and the Biering-Sørenson, long-lever lateral flexion and flexion tests to assess trunk endurance.

# REFERENCES


1. Althobaiti S, Falla D. Reliability and criterion validity of handheld dynamometry for measuring trunk muscle strength in people with an
2. d without chronic non-specific low back pain. Musculoskelet Sci Pract. 2023 Aug 1;66.
2. Andersson EA, Nilsson J, Ma Z, Thorstensson A. Abdominal and hip flexor muscle activation during various training exercises. Eur J Appl Physiol Occup Physiol. 1997;75(2):115–23.
3. Atkinson G, Nevill AM. Statistical Methods For Assessing Measurement Error (Reliability) in Variables Relevant to Sports Medicine. Sports Medicine [Internet]. 1998;26(4):217–38. Available from: http://link.springer.com/10.2165/00007256-199826040-00002
4. Bianco A, Lupo C, Alesi M, Spina S, Raccuglia M, Thomas E, et al. The sit up test to exhaustion as a test for muscular endurance evaluation. Springerplus [Internet]. 2015 Dec 2;4(1):309. Available from: http://www.springerplus.com/content/4/1/309
5. Biering-Sørenson F. Physical Measurements as Risk Indicators for Low-Back Trouble Over a One-Year Period. Spine (Phila Pa 1976) [Internet]. 1984 Mar;9(2):106–19. Available from: http://link.springer.com/10.1007/978-1-4471-5451-8_63
6. De Blaiser C, De Ridder R, Willems T, Danneels L, Roosen P. Reliability and validity of trunk flexor and trunk extensor strength measurements using handheld dynamometry in a healthy athletic population. Physical Therapy in Sport [Internet]. 2018;34:180–6. Available from: https://doi.org/10.1016/j.ptsp.2018.10.005
7. Brooks JHM, Fuller CW, Kemp SPT, Reddin DB. Epidemiology of injuries in English professional rugby union: Part 1 match injuries. Br J Sports Med. 2005;39(10):757–66.
8. Brotons-Gil E, García-Vaquero MP, Peco-González N, Vera-Garcia FJ. Flexion-Rotation Trunk Test to Assess Abdominal Muscle Endurance. J Strength Cond Res [Internet]. 2013 Jun;27(6):1602–8. Available from: https://journals.lww.com/00124278-201306000-00019
9. Bucke J, Mattiussi A, May K, Shaw J. The reliability, variability and minimal detectable change of multiplanar isometric trunk strength testing using a fixed digital dynamometer. J Sports Sci. 2024;42(9):840–6.
10. Cicchetti D V. Guidelines, criteria, and rules of thumb for evaluating normed and standardized assessment instruments in psychology. Psychol Assess [Internet]. 1994 Dec;6(4):284–90. Available from: https://doi.apa.org/doi/10.1037/1040-3590.6.4.284
11. Dong K, Yu T, Chun B. Effects of Core Training on Sport-Specific Performance of Athletes: A Meta-Analysis of Randomized Controlled Trials. Behavioral Sciences [Internet]. 2023 Feb 9;13(2):148. Available from: https://www.mdpi.com/2076-328X/13/2/148
12. Evans K, Refshauge KM, Adams R. Trunk muscle endurance tests: Reliability, and gender differences in athletes. J Sci Med Sport. 2007 Dec;10(6):447–55.
13. Ezechieli M, Siebert CH, Ettinger M, Kieffer O, Weißkopf M, Miltner O. Muscle strength of the lumbar spine in different sports. Technology and Health Care. 2013;21(4):379–86.
14. García-Vaquero MP, Barbado D, Juan-Recio C, López-Valenciano A, Vera-Garcia FJ. Isokinetic trunk flexion–extension protocol to assess trunk muscle strength and endurance: Reliability, learning effect, and sex differences. J Sport Health Sci. 2020;9(6):692–701.

15. Granacher U, Lacroix A, Muehlbauer T, Roettger K, Gollhofer A. Effects of core instability strength training on trunk muscle strength, spinal mobility, dynamic balance and functional mobility in older adults. Gerontology. 2013 Feb;59(2):105–13.
16. Greene PF, Durall CJ, Kernozek TW. Intersession reliability and concurrent validity of isometric endurance tests for the lateral trunk muscles. J Sport Rehabil. 2012;21(2):161–6.
17. Hackett DA, Sabag A. The Influence of Muscular Strength and Local Muscular Endurance on Accuracy of Estimated Repetitions to Failure in Resistance-Trained Males. Sports. 2022 Feb 1;10(2).
18. Harding AT, Weeks BK, Horan SA, Little A, Watson SL, Beck BR. Validity and test-retest reliability of a novel simple back extensor muscle strength test. SAGE Open Med. 2017;5:1–9.
19. Horníková H, Zemková E. The importance of core strength for change of direction speed. Front Physiol [Internet]. 2024 Mar 26;15. Available from: https://www.frontiersin.org/articles/10.3389/fphys.2024.1376422/full
20. Juan-Recio C, López-Plaza D, Barbado Murillo D, García-Vaquero MP, Vera-García FJ. Reliability assessment and correlation analysis of 3 protocols to measure trunk muscle strength and endurance. J Sports Sci. 2018;36(4):357–64.
21. Juan-Recio C, López-Plaza D, Barbado Murillo D, García-Vaquero MP, Vera-García FJ. Reliability assessment and correlation analysis of 3 protocols to measure trunk muscle strength and endurance. J Sports Sci. 2018;36(4):357–64.
22. Jubany J, Busquets A, Marina M, Cos F, Angulo-Barroso R. Reliability and validity of a custom-made instrument including a hand-held dynamometer for measuring trunk muscle strength. J Back Musculoskelet Rehabil. 2015;28(2):317–26.
23. Kato S, Murakami H, Demura S, Yoshioka K, Shinmura K, Yokogawa N, et al. Abdominal trunk muscle weakness and its association with chronic low back pain and risk of falling in older women. BMC Musculoskelet Disord. 2019 Jun 3;20(1).
24. Kibler W Ben, Press J, Sciascia A. The role of core stability in athletic function. Sports Med. 2006;36(3):189–98.
25. Latimer J, Maher CG, Refshauge K, Colaco I. The Reliability and Validity of the Biering–Sorensen Test in Asymptomatic Subjects and Subjects Reporting Current or Previous Nonspecific Low Back Pain. Spine (Phila Pa 1976) [Internet]. 1999 Oct;24(20):2085. Available from: http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=emed4&NEWS=N&AN=1999364179
26. McGill S. Core training: Evidence translating to better performance and injury prevention. Strength Cond J. 2010;32(3):33–46.
27. McGill SM, Childs A, Liebenson C. Endurance times for low back stabilization exercises: Clinical targets for testing and training from a normal database. Arch Phys Med Rehabil. 1999;80(8):941–4.
28. Mokkink LB, Terwee CB, Patrick DL, Alonso J, Stratford PW, Knol DL, et al. The COSMIN checklist for assessing the methodological quality of studies on measurement properties of health status measurement instruments: An international Delphi study. Quality of Life Research. 2010 May;19(4):539–49.
29. Moreland J, Finch E, Stratford P, Balsor B, Gill C. Interrater Reliability of Six Tests of Trunk Muscle Function and Endurance. Journal of Orthopaedic & Sports Physical Therapy [Internet]. 1997 Oct;26(4):200–8. Available from: http://www.jospt.org/doi/10.2519/jospt.1997.26.4.200
30. Newman BL, Pollock CL, Hunt MA. Reliability of Measurement of Maximal Isometric Lateral Trunk-Flexion Strength in Athletes Using Handheld Dynamometry. J

Sport Rehabil [Internet]. 2012 Nov 1;21(4). Available from: https://journals.humankinetics.com/view/journals/jsr/21/4/article-jsr.2012.tr6.xml.xml

31. de Oliveira IO, Pilz B, Santos RLG, Vasconcelos RA, Mello W, Grossi DB. Reference values and reliability for lumbopelvic strength and endurance in asymptomatic subjects. Braz J Phys Ther [Internet]. 2018;22(1):33–41. Available from: http://dx.doi.org/10.1016/j.bjpt.2017.09.008
32. Oyama S, Garza E, Dugan K. Intrasession and intersession reliability of isometric trunk and hip strength measurements using the portable tension dynamometer. J Sport Rehabil. 2021 Sep 1;30(7):1111–4.
33. Park H won, Baek S, Kim HY, Park JG, Kang EK. Reliability and validity of a new method for isometric back extensor strength evaluation using a hand-held dynamometer. Ann Rehabil Med. 2017;41(5):793–800.
34. Rodríguez-Perea Á, Reyes-Ferrada W, Jerez-Mayorga D, Ríos LC, Van den Tillar R, Ríos IC, et al. Core training and performance: a systematic review with meta-analysis. Vol. 40, Biology of Sport. Institute of Sport; 2023. p. 975–92.
35. Simmonds MJ, Olson SL, Jones S, Hussein T, Lee CE, Novy D, et al. Psychometric Characteristics and Clinical Usefulness of Physical Performance Tests in Patients With Low Back Pain. Spine (Phila Pa 1976) [Internet]. 1998 Nov;23(22):2412–21. Available from: http://journals.lww.com/00007632-199811150-00011
36. Spudić D, Vodičar J, Vodičar M, Hadžić V. Isometric Trunk Strength Assessment of Athletes: Effects of Sex, Sport, and Low Back Pain History. J Sport Rehabil. 2022 Jan 1;31(1):38–46.
37. Stark T, Walker B, Phillips JK, Fejer R, Beck R. Hand-held dynamometry correlation with the gold standard isokinetic dynamometry: A systematic review. PM and R [Internet]. 2011;3(5):472–9. Available from: http://dx.doi.org/10.1016/j.pmrj.2010.10.025
38. Stevens VK, Bouche KG, Mahieu NN, Cambier DC, Vanderstraeten GG, Danneels LA. Reliability of a functional clinical test battery evaluating postural control, proprioception and trunk muscle activity. Am J Phys Med Rehabil. 2006 Sep;85(9):727–36.
39. Tarca BD, Wycherley TP, Meade A, Bennett P, Ferrar KE. Validity and reliability of hand-held dynamometry for abdominal flexion muscular assessment. J Sport Rehabil. 2021 Feb 1;30(2):343–6.
40. Thorborg K, Petersen J, Magnusson SP, Hölmich P. Clinical assessment of hip strength using a hand-held dynamometer is reliable. Scand J Med Sci Sports. 2010;20(3):493–501.
41. Trevethan R. Intraclass correlation coefficients: clearing the air, extending some cautions, and making some requests. Health Serv Outcomes Res Methodol. 2017 Jun 1;17(2):127–43.
42. Venegas-Carro M, Kramer A, Moreno-Villanueva M, Gruber M. Test–Retest Reliability and Sensitivity of Common Strength and Power Tests over a Period of 9 Weeks. Sports. 2022 Nov 1;10(11).
43. de Vet HCW, Terwee CB, Mokkink LB, Knol DL. Measurement in Medicine - A Practical Guide. New York: Cambridge University Press; 2011.
44. Waldhelm A, Li L. Endurance tests are the most reliable core stability related measurements. J Sport Health Sci. 2012;1(2):121–8.
45. Walter SD, Eliasziw M, Donner A. Sample size and optimal designs for reliability studies. Stat Med. 1998 Jan 15;17(1):101–10.

46. Wang K, Wang X, Wang Y. Factors, mechanisms and improvement methods of muscle strength loss. Vol. 12, Frontiers in Cell and Developmental Biology. Frontiers Media SA; 2024.
47. Weir JP, Vincent WJ. Statistics in Kinesiology. 5th ed. Human Kinetics; 2020. 165–177 p.
48. Willardson JM. Core Stability Training: Applications to Sports Conditioning Programs. The Journal of Strength and Conditioning Research [Internet]. 2007;21(3):979. Available from: http://nsca.allenpress.com/nscaonline/?request=get-abstract&doi=10.1519%2FR-20255.1
49. Wirth K, Hartmann H, Mickel C, Szilvas E, Keiner M, Sander A. Core Stability in Athletes: A Critical Analysis of Current Guidelines. Sports Medicine. 2017 Mar 1;47(3):401–14.
50. Youdas JW, Boor MM, Darfler AL, Koenig MK, Mills KM, Hollman JH. Surface electromyographic analysis of core trunk and hip muscles during selected rehabilitation exercises in the side-bridge to neutral spine position. Sports Health. 2014 Sep;6(5):416-21. doi: 10.1177/1941738114539266.