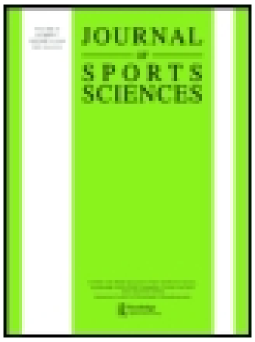

Routledge
Taylor & Francis Group

Journal of Sports Sciences

ISSN: 0264-0414 (Print) 1466-447X (Online) Journal homepage: http://www.tandfonline.com/loi/rjsp20

Reliability assessment and correlation analysis of 3 protocols to measure trunk muscle strength and endurance

Casto Juan-Recio, Diego López-Plaza, David Barbado Murillo, M. Pilar García-Vaquero & Francisco J. Vera-García

JOURNAL OF SPORTS SCIENCES, 2017
http://dx.doi.org/10.1080/02640414.2017.1307439

Reliability assessment and correlation analysis of 3 protocols to measure trunk muscle strength and endurance

Casto Juan-Recio, Diego López-Plaza, David Barbado Murillo, M. Pilar García-Vaquero and Francisco J. Vera-García

Sport Research Centre, Miguel Hernández University of Elche, Elche (Alicante), Spain

ABSTRACT

Different methods have been developed to quantify trunk muscle strength and endurance. However, some important protocol characteristics are still unclear, hindering the selection of the most suitable tests in each specific situation. The aim of this study was to examine the reliability and the relationship between 3 representative tests of the most common type of protocols used to assess trunk muscle strength and endurance. Twenty-seven healthy men performed each test twice spaced 1 month apart. Trunk strength and endurance were evaluated with an isokinetic dynamometer and 2 field tests including *Biering-Sørensen test* and *Flexion–rotation trunk test*.

All tests showed a good relative consistency (intraclass correlation coefficient [ICC]> 0.75), except for the isokinetic endurance variables which had low–moderate reliability (0.37 < ICC > 0.65). Absolute reliability seemed slightly better in the isokinetic protocol than in the field tests, which showed about 12% of test–retest score increase. No significant correlations were found between test scores.

After a familiarisation period for the field tests, the 3 protocols can be used to obtain reliable measures of trunk muscle strength and endurance. Based on the correlation analysis, these measures are not related, which highlights the importance of selecting the most suitable trunk test for each situation.

ARTICLE HISTORY
Accepted 28 February 2017

KEYWORDS
Isokinetic dynamometry; field tests; endurance; reliability; core muscles

Introduction

Trunk muscle function has attracted the interest of coaches, athletes and clinicians, as it has been related to sport performance (Barbado et al., 2016; McGill, 2006), injury prevention and rehabilitation (Biering-Sørensen, 1984; Lindsay & Horton, 2006; Luoto, Heliövaara, Hurri, & Alaranta, 1995; McGill, Childs, & Liebenson, 1999) and efficiency in everyday tasks (Borghuis, Hof, & Lemmink, 2008). Consequently, different methods have been developed to quantify trunk muscle strength (i.e., the ability to exert maximum trunk muscle force) and endurance (i.e., the ability to exert trunk muscle force repeatedly or continuously over long periods of time) in order to evaluate athletes' and patients' progress, and to examine the relationship between, for example, injury and trunk muscle endurance (Mayer, Gatchel, Betancur, & Bovasso, 1995; McGill et al., 1999). Based on protocol characteristics, such as reliability, accuracy, cost and availability, several isokinetic dynamometry protocols and field tests are used in clinical, sport, research and educational settings (Evans, Refshauge, & Adams, 2007; Juan-Recio, Lopez-Vivancos, Moya, Sarabia, & Vera-Garcia, 2015; Mayer et al., 1995; McGill et al., 1999).

Isokinetic dynamometry is considered the "gold standard" for measuring trunk muscle strength (Clayton et al., 2011; Hall, Hetzler, Perrin, & Weltman, 1992; Knudson, 2001; Knudson & Johnston, 1995; Mayer et al., 1995), mainly because it allows a controlled and accurate assessment of a large number of muscle force parameters. These parameters include the type of contraction, speed, position and duration. The use of moment of force reduces the possible variations in trunk performance due to the individual's size and other factors, such as the linear sensors' set-up. Most isokinetic protocols have evaluated strength variables (Delitto, Rose, Crandell, & Strube, 1991; Dvir & Keating, 2001; Mayer, Smith, Keeley, & Mooney, 1985; Newton & Waddell, 1993; Wessel, Ford, & van Driesum, 1992) to analyse the differences between, for example, patients with low back pain and asymptomatic individuals, to establish normative values, and to identify injury risk variables (Lindsay & Horton, 2006; Mayer et al., 1985). However, very few isokinetic protocols have focused on assessing trunk endurance variables (Barbado et al., 2016; García-Vaquero, Barbado, Juan-Recio, Lopez-Valenciano, & Vera-Garcia, in press; Lindsay & Horton, 2006; Mayer et al., 1995), even though endurance imbalances between trunk muscle groups and deficits in trunk extensor endurance have been documented as risk factors for low back disorders (Biering-Sørensen, 1984; Lindsay & Horton, 2006; Luoto et al., 1995; McGill et al., 1999), and trunk muscle endurance has been identified as an important factor for good sport performance (McGill, 2006). In addition, the high technology requirements of these isokinetic protocols and their substantial economic cost have limited their use mainly to high performance sport, clinical and research settings.

Field tests to assess trunk muscle function are used in many different contexts, for example, clinics, high performance and recreational sports, fitness and physical education, as they are characterised by the small amount of material required, low cost, short execution time and ease of use. Unlike isokinetic

CONTACT Francisco J. Vera-García fvera@umh.es Sport Research Centre, Miguel Hernández University of Elche, Avda. de la Universidad s/n, 03202, Elche (Alicante), Spain

dynamometry protocols, they have been principally used to assess trunk muscle endurance (Brotons-Gil, Garcia-Vaquero, Peco-Gonzalez, & Vera-Garcia, 2013; Juan-Recio, Barbado, López-Valenciano, & Vera-García, 2014; Knudson & Johnston, 1995; McGill et al., 1999), with the exception of a few field tests that have been used as trunk muscle strength/power measures, for example, the *front abdominal power test* and the *side abdominal power test* (Cowley & Swensen, 2008; Leetun, Ireland, Willson, Ballantyne, & Davis, 2004). There are 2 main types of trunk endurance field tests: (1) dynamic endurance tests, among which we can identify "timed" trunk flexor and flexor–rotator protocols (Brotons-Gil et al., 2013; Faulkner, Sprigings, McQuarrie, & Bell, 1989; Knudson & Johnston, 1998, 1995), "cadenced" trunk flexor (Faulkner et al., 1989) and extensor protocols (Burns, Hannon, Saint-Maurice, & Welk, 2014; Hannibal, Plowman, Looney, & Brandenburg, 2006); and (2) isometric endurance tests, which basically involve maintaining a prone, supine or lateral posture against gravity for as long as possible to measure trunk extensor, flexor and lateral-flexor endurance, respectively (Biering-Sørensen, 1984; Evans et al., 2007; Hannibal et al., 2006; McGill et al., 1999).

Reliability or consistency of measures is a fundamental characteristic of any protocol that accurately assesses trunk muscle function. Regarding the reliability of isokinetic protocols for assessing trunk muscle strength and endurance, most show high or excellent relative reliability with intraclass correlation coefficient (ICC) values around 0.80 for strength variables (Delitto et al., 1991; Dvir & Keating, 2001; García-Vaquero et al., in press; Keller, Hellesnes, & Brox, 2001; Laughlin, Lee, Loehr, & Amonette, 2009; Mayer et al., 1985; Newton & Waddell, 1993; Wessel et al., 1992), but there are fewer studies of trunk endurance consistency with moderate–low levels of relative reliability (ICC ≤0.69) (García-Vaquero et al., in press; Mayer et al., 1995). Absolute measures of reliability of isokinetic trunk protocols show less consistency, with standard error of measurement (SEM) values ranging between 3% and 29% for strength variables (Delitto et al., 1991; Dvir & Keating, 2001; García-Vaquero et al., in press; Laughlin et al., 2009; Wessel et al., 1992) and between 5.0% and 11.5% for endurance variables (García-Vaquero et al., in press). Most of the published field tests have also shown good relative reliability with ICCs higher than 0.75 (Brotons-Gil et al., 2013; Chan, 2005; Demoulin, Vanderthommen, Duysens, & Crielaard, 2006; Evans et al., 2007; Liemohn, Baumgartner, & Gagnon, 2005; McGill et al., 1999); however, the few studies that have analysed their absolute reliability using SEMs have demonstrated varying and controversial results (4% < SEM < 114%) (Brotons-Gil et al., 2013; Evans et al., 2007; Juan-Recio et al., 2014; Moreland, Finch, Stratford, Balsor, & Gill, 1997).

Based on the test characteristics presented earlier, and given the numerous performance parameters, different trunk muscle groups and capabilities evaluated, there cannot be one best protocol to measure trunk muscle function. Every test has its advantages and limitations, and the choice depends on many factors, such as the context in which the test will be applied, the participants' characteristics and needs, and the capability of the trunk muscles to be measured (including their isometric endurance and maximum dynamic strength). However, in both the scientific literature and the practical field, there are many examples of protocols that do not logically follow the principle of specificity in matching the test to the performance or injury variables of interest. For example, although the McGill standardised testing battery (McGill et al., 1999) is not specific to dynamic sports actions (Clayton et al., 2011), many researchers and coaches often use this isometric testing battery to measure core stability, strength or endurance in sports with high dynamic demands (Chan, 2005; Clayton et al., 2011; Evans et al., 2007). In addition, despite trunk extensor endurance deficits (Biering-Sørensen, 1984; Lindsay & Horton, 2006; Luoto et al., 1995) and the observation that endurance imbalances between trunk muscle groups are related to low back disorders (McGill et al., 1999), most health-related fitness test batteries only include dynamic trunk flexor measures, that is, sit-up or curl-up tests (Europe, 1988; President's Council on Fitness [PCFSN], 2010). Further research is needed to understand the relationship between the scores of these trunk strength and endurance protocols better, which will allow us to determine to what extent a single trunk measure (evaluated under specific conditions) may be generalisable or not generalisable to other measures of trunk muscle strength and/or endurance.

In order to improve the application of 3 representative tests of the most common type of protocols used to assess trunk muscle function, this study analysed some characteristics of a flexion–extension isokinetic protocol used to assess trunk muscle strength and endurance (Barbado et al., 2016; García-Vaquero et al., in press). The study also analysed 2 field tests: the *Biering-Sørensen test* (BST) (Biering-Sørensen, 1984) to measure trunk extensor isometric endurance, and the *flexion–rotation trunk test* (FRT) (Brotons-Gil et al., 2013) to evaluate trunk flexor–rotator dynamic endurance. The main purpose of this study was to analyse the relative and absolute reliability of these 3 protocols. Additionally, based on the arbitrary and non-specific use of some trunk tests in both the scientific literature and the practical field, a correlation analysis between the 3 test scores was carried out. Overall, this information will facilitate the decision-making process when selecting trunk muscle tests.

Methods

Participants

A total of 27 healthy young men (age: 24.1 ± 2.9 years; height: 177 ± 5.6 cm; mass: 76 ± 9.2 kg) voluntarily participated in this study. They were physically active, performing 1–3 h of moderate physical activity in recreational sports, 1–3 days · week^{-1}. Exclusion criteria for this study include known medical problems, episodes of back pain in the previous 6 months and/or involvement in structured trunk exercise programmes during the time of the study. Participants were asked to continue their regular physical activity practice during the study, but not to perform strenuous exercise in the 24 h prior to each assessment session. All participants were informed of the risks of this study and signed an informed consent form based on the 2013 Declaration of Helsinki and approved by the Ethics Committee of the University.

Procedures

Three tests were used to assess trunk muscle function. A trunk flexion–extension test was performed using a Biodex® isokinetic dynamometer (Model 2000, Multi-joint System 4 Pro, Biodex Corporation, Shirley, NY, USA) to assess trunk muscle strength and endurance. Two field tests were carried out to evaluate the endurance of the trunk extensor and flexor–rotator muscles: the BST (Biering-Sørensen, 1984) and the FRT (Brotons-Gil et al., 2013), respectively.

Participants performed each test twice. In order to avoid the influence of muscle fatigue on test scores and to reduce the learning effect of the tests, participants underwent 4 test sessions spaced a month apart between each one. The isokinetic trunk test was carried out in the first 2 sessions and the BST and FRT were executed in the last 2 sessions. The field tests were performed in a counterbalanced order with a 5-min rest between each test. Participants were strongly encouraged verbally to maximise their efforts to obtain the maximum score in each test. They were not given outcome feedback until the end of the study. Before each assessment session, participants performed a warm-up exercise that consisted of 2 sets of 15 curl-ups and another 2 sets of 15 back extensions in a Roman chair, with a 30-s rest between the sets and the exercises.

Isokinetic trunk flexion–extension test

Participants were placed on the *dual position back extension/flexion attachment* of the Biodex® in the position described by García-Vaquero et al. (in press), shown in Figure 1. The protocol consisted of 4 sets of 15 concentric, maximum and consecutive trunk flexion and extension repetitions at a speed of $120° \cdot s^{-1}$ (Watkins & Harris, 1983). The range of trunk motion was 50° (from 30º of trunk flexion to 20º of trunk hyperextension), beginning the movement in the flexion direction (Grabiner, Jeziorowski, & Divekar, 1990). There was 1-min rest between sets

The absolute peak torque (PT) and relative peak torque (RPT) and the absolute maximum work (MW) and relative maximum work (RMW) in load range were calculated during the isokinetic window to measure trunk muscle strength in the flexion and extension directions. In addition, based on previous studies (García-Vaquero et al., in press; Knudson & Johnston, 1995; Mayer et al., 1995), 3 variables were used for the assessment of trunk muscle endurance in both directions (expressed in percentages):

(1) The modified endurance ratio (MER) was obtained by dividing the work (*W*) performed during the last 3 repetitions of each set by 3 times the MW reached in a repetition during the set and multiplied by 100. This variable represents the ability to maintain the force output during successive efforts (throughout each set).

$$\text{MER} = \frac{\sum W\,(13, 14, 15)}{3 \times \text{MW}\,(\text{rep.})} \times 100 \qquad (1)$$

(2) The maximum work ratio (MWR) was obtained by dividing the MW reached during a repetition in the last set by the MW performed during any set and multiplied by 100. This variable represents the ability to maintain the force output during intermittent efforts (between sets).

$$\text{MWR} = \frac{\text{MW}\,(\text{rep.})\,(\text{series } 4)}{\text{MW}\,(\text{rep.})\,(\text{series})} \times 100 \qquad (2)$$

(3) The fatigue final ratio (FFR) was obtained by dividing the *W* performed during the last 3 repetitions in the last set by 3 times the MW performed in a repetition of any set and multiplied by 100 (Mayer et al., 1995). This variable represents the ability to maintain the force output during successive and intermittent efforts (throughout repetitions and sets).

$$\text{FFR} = \frac{\sum \text{W}\,(13, 14, 15)\,(\text{series } 4)}{3 \times \text{MW}\,(\text{rep.})\,(\text{series})} \times 100 \qquad (3)$$

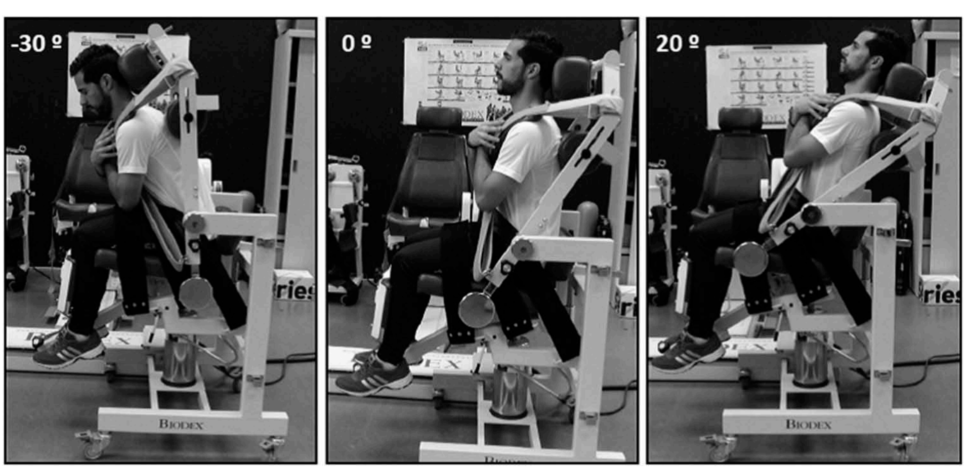

Figure 1. Participant performing a maximum effort of trunk flexion–extension in the isokinetic dynamometer with a ROM of 50° (−30° trunk flexion; 0° initial position; 20° trunk hyperextension).

The Biering-Sørensen test

To assess trunk extensor isometric endurance, participants were placed in a prone position (Figure 2), with the lower part of the body fixed to a test bench by Velcro® inextensible straps at the ankle, knee and hip level, and with the upper body extended horizontally and cantilevered over the edge of the bench; the anterior-superior iliac spines were aligned with the edge of the bench. The participant's arms were held crossed over the chest with each hand in contact with the opposite shoulder. The test consisted of maintaining the trunk in a horizontal position for as long as possible. The time in seconds was recorded by a digital stopwatch (CASIO HS-30W-N1V) (Biering-Sørensen, 1984).

The flexion–rotation trunk test

For the assessment of abdominal dynamic endurance, participants were placed in a supine position on a semi-rigid mat, with their feet placed on the floor, knees together and bent 90°, and upper body resting on the mat (Figure 3(a)). The arms were extended over the trunk and thighs, hands overlapped and both thumbs interlaced. A researcher knelt at the participant's feet, holding his lower limbs and introducing his thumbs behind the participant's knees. In this position, the participant was asked to carry out the maximum number of upper-trunk flexion–rotation movements possible in 90 s. Each repetition consisted of performing a trunk flexion with rotation until the participant touched the knuckle of the little finger of the researcher with his fingertips (Figure 3(b)), then returning to the starting position. The participant performed twists to one side and the other successively starting the protocol twisting to the right. The researcher recorded only the repetitions performed correctly. Participants received feedback of the time left at 30, 60 and 75 s into the protocol (Brotons-Gil et al., 2013).

Figure 2. Participant performing the Biering-Sørensen test.

Statistical analyses

Descriptive statistics (means and standard deviations [SDs]) were calculated for all variables. The normality of the data was examined using the Kolmogorov–Smirnov statistical test. An ANOVA of 3 (isokinetic variables, BST score, FRT score) × 2 (session 1, session 2) was carried out to examine the differences of tests scores between sessions, with a Bonferroni *post hoc* analysis. The level of significance was set at $P < .05$.

To analyse the intersession absolute reliability of each test, the typical error percentage (percentage within-participants variation) and the minimum detectable change (MDC; 1.5 times the typical error) (Hopkins, 2000) were calculated. The percentage of typical error was established using log-transformed data using the following formula: 100 (s^{-1}), where s is the typical error (SD of the difference between session 1 and session 2, divided by $\sqrt{2}$). The relative reliability of the different measures was analysed using the $ICC_{2,1}$, calculating 90% confidence limits. The ICC values were categorised as follows: excellent (0.90–1.00), high (0.70–0.89), moderate (0.50–0.69) and low (<0.50) (Fleiss, 1986).

The Pearson correlation coefficient (r) was used to analyse the relationship between variables once all outliers (scores higher or lower than the mean ± 3 SD) were eliminated. Statistical analyses were performed with the SPSS statistics software (version 18.0 for Windows 7; SPSS Inc., Chicago, IL, USA).

Results

Table 1 shows the descriptive statistics and absolute and relative reliability values for both field tests and the strength and endurance isokinetic variables, respectively. The ANOVA showed significant differences in the within-participant factor for BST ($F = 7.303$; $P = .013$) and FRT ($F = 18.867$; $P < .001$) and for MW ($F = 6.807$, $P = .015$) and RMW ($F = 6.998$; $P = .014$) in isokinetic flexion.

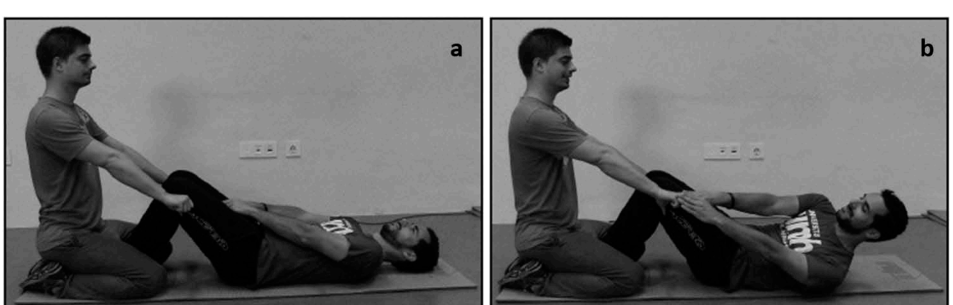

Figure 3. Lateral view of the initial position (a) and of the flexion–rotation position (b) of an FRT repetition.

The FRT showed a typical error percentage of 11.1% and an ICC of 0.86, whereas the BST obtained a typical error percentage of 15.4% and an ICC of 0.78. Regarding isokinetic strength variables, typical error percentages ranged between 9.3% for RPT and PT in extension and 7.5% for RPT and PT in flexion, while for the RMW and MW they were 15.2% in extension and 6.2% in flexion. Typical error percentages of isokinetic endurance variables ranged between 8.2% for MWR and 13.8% for FFR in extension, and between 8.9% for MER and 17.7% for FFR in flexion. In relation to the relative reliability, the ICC values obtained for strength variables were 0.57 ≤ ICC ≤ 0.77 in extension and 0.62 ≤ ICC ≤ 0.84 in flexion, while for endurance variables they were 0.37 ≤ ICC ≤ 0.55 in extension and 0.45 ≤ ICC ≤ 0.65 in flexion.

The Pearson correlation analysis showed no significant correlations between field test scores and isokinetic strength and endurance variables (Tables 2 and 3).

Discussion

In the practical field, the choice of tests to measure trunk muscle strength and endurance is an important and complex decision which does not always follow the principle of specificity (Clayton et al., 2011), but tends to be influenced instead by economic factors and/or accessibility to specific instruments and facilities. In order to obtain information to facilitate decision-making when trunk strength and endurance tests are selected, this study examined the reliability and the possible relationships between the outcomes of 2 trunk endurance field tests (BST and FRT) and an isokinetic trunk flexion–extension test.

Relative reliability was high in the 3 analysed protocols, with most ICC values above 0.75, except for the endurance variables in the isokinetic test, in which reliability was low–moderate with values ranging between 0.37 and 0.65. These results agree with those of previous studies that found ICC values greater than 0.75 for different trunk endurance field tests (Brotons-Gil et al., 2013; Chan, 2005; Demoulin et al., 2006; Evans et al., 2007; Juan-Recio et al., 2014; McGill et al., 1999) and greater than 0.80 for isokinetic strength protocols (Delitto et al., 1991; Dvir & Keating, 2001; García-Vaquero et al., in press; Keller et al., 2001; Laughlin et al., 2009; Newton & Waddell, 1993; Wessel et al., 1992). Concerning the isokinetic endurance variables, our resulting values were very similar to those obtained by García-Vaquero et al. (in press) (0.43 < ICC < 0.69) using the same protocol, and slightly higher than those obtained by Mayer et al. (1985) (0.35 < ICC < 0.42) using a similar protocol. In general, the relative consistency results obtained in the current study point out the robustness of isokinetic and field measures to assess trunk muscle strength and endurance. However, the levels of reliability showed for the isokinetic endurance variables could affect the correlations between tests negatively; results therefore should be interpreted with caution. Future studies should attempt to develop more reliable isokinetic endurance variables.

With reference to the absolute reliability, the values of the typical error percentages and the MDC for the field tests were relatively high (Table 1). According to Hopkins (2000), these MDC values indicate that changes higher than 16.6% and

Table 1. Descriptive statistics and relative and absolute reliability of flexion–rotation trunk test (FRT) and Biering-Sørensen test (BST) and strength and endurance variables of isokinetic test.

	Variables	Movement	Session 1 (mean ± SD)	Session 2 (mean ± SD)	Typical error (%) (mean – 90% CL)	MDC (%)	Change in the mean (%) (mean – 90% CL)	$ICC_{(2,1)}$ (mean – 90% CL)
FIELD TESTS	FRT (reps)	–	83.00 ± 19.99	93.74 ± 23.94	11.11 (8.99–14.68)	16.66	12.16 (6.81–17.78)*	0.86 (0.74–0.92)
	BST (s)	–	136.92 ± 41.84	148.69 ± 36.38	15.42 (12.44–20.50)	23.13	12.72 (5.46–20.48)*	0.78 (0.62–0.88)
ISOKINETIC STRENGTH VARIABLES	PT (N · m)	Extension	394.90 ± 70.74	408.96 ± 71.34	9.31 (7.50–12.44)	13.96	1.97 (−2.33–6.46)	0.77 (0.59–0.88)
		Flexion	234.43 ± 24.56	229.20 ± 27.99	7.54 (6.10–9.98)	11.31	−2.44 (−5.74–0.98)	0.62 (0.38–0.79)
	RPT ($N \cdot m \cdot kg^{-1}$)	Extension	5.19 ± 0.89	5.38 ± 0.87	9.31 (7.50–12.44)	13.96	1.97 (−2.33–6.46)	0.75 (0.56–0.87)
		Flexion	3.10 ± 0.41	3.02 ± 0.42	7.54 (6.10–9.98)	11.31	−2.44 (−5.74–0.98)	0.75 (0.57–0.86)
	MW (J)	Extension	204.06 ± 39.07	206.25 ± 43.81	15.18 (12.20–20.30)	22.77	0.59 (−5.93–7.55)	0.57 (0.31–0.76)
		Flexion	105.10 ± 13.22	99.60 ± 14.27	6.23 (5.03–8.28)	9.34	−4.49 (−7.25 – −1.66)*	0.82 (0.67–0.90)
	RMW ($J \cdot kg^{-1}$)	Extension	2.69 ± 0.49	2.73 ± 0.63	15.18 (12.20–20.30)	22.77	0.59 (−5.93–7.55)	0.62 (0.38–0.79)
		Flexion	1.39 ± 0.18	1.31 ± 0.19	6.23 (5.03–8.28)	9.34	−4.49 (−7.25 – −1.66)*	0.84 (0.70–0.92)
ISOKINETIC ENDURANCE VARIABLES	MER (%)	Extension	77.39 ± 7.53	73.34 ± 10.71	9.54 (7.68–12.75)	14.31	−4.10 (−8.24 – −0.22)	0.55 (0.26–0.75)
		Flexion	68.93 ± 7.40	68.65 ± 8.03	8.96 (7.24–11.88)	13.44	−0.55 (−4.51–3.58)	0.45 (0.15–0.68)
	FFR (%)	Extension	73.55 ± 9.71	68.49 ± 11.91	13.84 (11.14–18.48)	20.76	−7.54 (−13.05 – −1.69)	0.37 (0.05–0.62)
		Flexion	58.48 ± 12.56	60.40 ± 13.82	17.77 (14.20–24.03)	26.65	7.77 (−0.43–16.65)	0.65 (0.41–0.81)
	MWR (%)	Extension	84.42 ± 7.20	81.36 ± 9.93	8.27 (6.66–11.03)	12.40	−2.32 (−6.00–1.51)	0.54 (0.24–0.74)
		Flexion	78.82 ± 10.79	82.64 ± 08.19	14.63 (11.73–19.70)	21.74	5.24 (−1.49–12.44)	0.55 (0.26–0.74)

Reps: repetitions; PT: peak torque; RPT: relative peak torque; MW: maximum work; RMW: relative maximum work; MER: modified endurance ratio; FFR: final fatigue ratio; MWR: maximum work ratio; SD: standard deviation; CL: confidence limits; MDC: minimum detectable change; ICC: intraclass correlation coefficient. *$p \le .05$.

Table 2. Correlations between the Biering-Sørensen test (BST) and flexion–rotation trunk test (FRT) scores and the endurance variables of the isokinetic test.

	ENDURANCE							
			MER (%)		MWR (%)		FFR (%)	
Variables	BST (s)	FRT (reps)	Flexion	Extension	Flexion	Extension	Flexion	Extension
BST (s)	–	.342	.087	−.042	−.059	−.146	.325	−.251
FRT (reps)	.342	–	.151	−.161	−.025	−.069	.021	−.267

Reps: repetitions; MER: modified endurance ratio; MWR: maximum work ratio; FFR: final fatigue ratio.

Table 3. Correlations between the Biering-Sørensen test (BST) and flexion–rotation trunk test (FRT) scores and the strength variables of the isokinetic test.

	STRENGTH							
	PT (N · m)		RPT (N · m · kg^{-1})		MW (J)		RMW (J · kg^{-1})	
Variables	Flexion	Extension	Flexion	Extension	Flexion	Extension	Flexion	Extension
BST (s)	−.118	−.239	.102	−.076	.124	−.025	.303	−.153
FRT (reps)	.279	.099	.369	.240	.224	−.033	.351	.044

Reps: repetitions; PT: peak torque; RPT: relative peak torque; MW: maximum work; RMW: relative maximum work.

23.1% in the FRT and BST scores, respectively, would be necessary to guarantee that real changes had occurred after a treatment or intervention and that the changes observed were not due to measurement errors. These results question the reliability of these tests when detecting small changes in trunk muscle endurance, especially in highly trained athletes in whom small changes are significant (Kraemer & Ratamess, 2004). However, they could be acceptable in other contexts, such as in the health, fitness or physical education fields, where the participants may have large increases in trunk endurance after training due to their high potential reserve of adaptation (Brotons-Gil et al., 2013; Juan-Recio et al., 2015).

The isokinetic test showed slightly better results for typical error percentage and MDC, both in strength variables (9.3% < MDC < 22.7%) and in endurance variables (12.4% < MDC < 26.6%). Most previous studies have only analysed the SEM in isokinetic strength variables, obtaining similar results (slightly higher (Delitto et al., 1991; Dvir & Keating, 2001; Wessel et al., 1992) or slightly lower (Laughlin et al., 2009)) compared with those obtained in the present study. To the best of our knowledge, only the study by García-Vaquero et al. (in press) analysed the absolute reliability of isokinetic endurance variables, obtaining values of typical error slightly lower than ours (between 5.0% and 11.5%).

A learning effect existed in the field tests, with a significant score increase of 12.1% in the FRT and 12.7% in the BST between the first and second sessions. These results are consistent with the data of previous studies (Brotons-Gil et al., 2013; Juan-Recio et al., 2014; Liemohn et al., 2005). Although only a test–retest, or even a single measurement, is performed when evaluating trunk endurance in clinics and sport facilities, the results show that 2 test trials are not sufficient to make the learning effect negligible. Therefore, it seems necessary to perform previous familiarisation sessions so participants learn, for instance, to tolerate the fatigue feelings better during the BST or learn to maintain a proper cadence during the FRT. In this sense, Brotons-Gil et al. (2013) showed that at least 3 test trials of the FRT were needed before participants' scores plateaued. On the contrary, in the isokinetic protocol, only 2 variables analysed (MW and RMW in flexion) showed significant differences between both sessions (Table 1), indicating, in general, a lower absolute error in the measurements in comparison to field tests. Most previous isokinetic studies did not find a learning effect in PT during trunk flexion/extension movements (Cowley, Fitzgerald, Sottung, & Swensen, 2009; Dervisevica, Hadzic, & Burger, 2007; Dvir & Keating, 2001; García-Vaquero et al., in press; Laughlin et al., 2009; Müller et al., 2014; Wessel et al., 1992), whereas only a few found a learning effect (Delitto et al., 1991; Keller et al., 2001; Newton & Waddell, 1993). Therefore, it seems that participants do not need to carry out a long familiarisation period before performing the isokinetic trunk protocol.

The correlational analysis showed no significant correlations between field test scores and isokinetic variables. Most previous studies (Knudson, 2001; Knudson & Johnston, 1995; Mayer et al., 1995) found no significant relationship between field tests that assessed trunk endurance and isokinetic strength variables, except Hall et al. (1992), who found a weak significant negative correlation (r = −0.41; P < .01). Moreover, Mayer et al. (1995) showed a moderate negative correlation (−0.54 < r < −0.60; P < .05) when comparing the BST with different isokinetic endurance measurements. These results obtained by Mayer et al. (1995) should be interpreted with caution because of the low reliability shown by both the BST (ICC = 0.20) and the isokinetic endurance variables (0.35 < ICC < 0.42). Concerning the FRT, although no previous correlational studies have been found in the literature, weak correlations (r = 0.50, P < .05; r = 0.38, P = .07) were found when the relationship was analysed between another "timed curl-up test" with similar characteristics to the FRT (the *bench trunk curl-up test*) and an isokinetic test (Knudson, 2001; Knudson & Johnston, 1995).

Although the results of this study should be analysed with caution, given the moderate–low relative reliability of the isokinetic endurance variables (which could affect the correlations between the tests), the absence of significant correlations between the field tests and the isokinetic endurance variables in the present study could be explained by the differences between protocols. The BST is an isometric timed protocol performed until exhaustion, in which the trunk is positioned horizontally and the resistance to overcome (upper body weight) is lower than 50% of maximal voluntary contraction in men (Mayer et al., 1995). In contrast, the isokinetic protocol consists of dynamic maximal efforts with the trunk in a vertical position, involving 4 sets of repeated fast movements in the sagittal plane. In this protocol, the individual's endurance is evaluated as his ability to maintain the force output across repetitions and sets. In addition, although the FRT and the isokinetic protocol consist of both dynamic trunk muscle contractions, there are also important differences between the 2 protocols: test duration, speed, recovery time, trunk position, and resistance to overcome. It should be noted that a greater endurance in the isokinetic measures means that there is a lower drop in the work output across repetitions and sets, which differs from the FRT where a greater endurance is associated with a higher number of repetitions.

The results of this study should be carefully analysed, given the relatively small sample size. However, according to Springate (2012), a sample of 25–30 participants could be enough for studies of measurement reliability. Another limitation could be the long time between sessions (a month). Although this time was established to reduce the learning effect and to facilitate and optimise the use of the laboratory and the isokinetic dynamometer in a recording schedule, it could affect an individual's trunk muscle function due to training or detraining over time. In order to avoid this, participants were instructed to continue their regular physical activity throughout the study.

Practical applications

Field tests have the advantage of not requiring expensive equipment and sophisticated analysis, and most of them can be applied to a large number of participants at the same time; therefore, their use could be recommended in the health, fitness or physical education fields. The isokinetic protocols allow a large number of variables to be assessed at the same time in a controlled way (e.g., type of contraction, speed, position and duration), so their use could be more appropriate in clinical, high performance sport and research fields. The results of this study show that all the protocols analysed have a good relative reliability (except for the isokinetic endurance variables), and therefore they are able to accurately discriminate differences in trunk muscle strength and endurance between adult males with similar characteristics (Hopkins, 2000). Concerning the absolute reliability, the isokinetic protocol seems slightly better than the field tests in detecting real changes that occur after an intervention. Finally, based on these and previous results (García-Vaquero et al., in press), a single 10-min trial may be sufficient when the isokinetic protocol is used; but this does not apply to the field tests, in which at least 2 previous familiarisation sessions would be needed to obtain results close to the participants' real levels.

Although the 3 analysed protocols certainly have face validity as trunk strength or endurance measures (Brotons-Gil et al., 2013; Mayer et al., 1995), the absence of significant correlations between them suggests that they measure trunk muscle function through protocols with different biomechanical demands, such as different muscle action, duration, speed, recovery time, position and resistance. Coaches, physical trainers and clinicians should choose the test that best suits the biomechanical characteristics required for success in a given sport (specificity criteria), while taking other important criteria into account, such as reliability, cost and availability. In this sense, the FRT could be applied in sports that require repeated flexion–rotation movements, for example, throwing and striking sports. The BST could be used in sports with great isometric back endurance demands, for example, hockey, gymnastics and ski descent, as well as in health and clinical settings, since previous studies have shown a relationship between low BST scores and low back disorders (Biering-Sørensen, 1984; Luoto et al., 1995). Finally, isokinetic protocols could be more appropriate in dynamic sports requiring a high level of trunk muscle strength during explosive movements, for example, judo (Barbado et al., 2016), fight sports, American football, etc.

Acknowledgements

This research was made possible by the financial support of Ministerio de Ciencia e Innovación (DEP2010-16493) and Generalitat Valenciana (ACOMP/2011/130), Spain. Casto Juan-Recio was supported by a predoctoral grant (Val i+d) given by Generalitat Valencia. The authors wish to thank the participation of the University students who offered their time to take part in this research.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This research was made possible by the financial support of the Ministerio de Ciencia e Innovación [DEP2010-16493] and Generalitat Valenciana [ACOMP/2011/130].

References

Barbado, D., Lopez-Valenciano, A., Juan-Recio, C., Montero-Carretero, C., van Dieen, J. H., & Vera-Garcia, F. J. (2016). Trunk stability, trunk strength and sport performance level in Judo. *PLoS One*, *11*(5), e0156267. doi:10.1371/journal.pone.0156267

Biering-Sørensen, F. (1984). Physical measurements as risk indicators for low-back trouble over a one-year period. *Spine*, *9*, 106–119. doi:10.1097/00007632-198403000-00002

Borghuis, J., Hof, A. L., & Lemmink, K. A. (2008). The importance of sensory-motor control in providing core stability: Implications for measurement and training. *Sports Medicine*, *38*(11), 893–916. doi:10.2165/00007256-200838110-00002

Brotons-Gil, E., Garcia-Vaquero, M. P., Peco-Gonzalez, N., & Vera-Garcia, F. J. (2013). Flexion-rotation trunk test to assess abdominal muscle endurance: Reliability, learning effect, and sex differences. *Journal of Strength and Conditioning Research*, *27*(6), 1602–1608. doi:10.1519/JSC.0b013e31827124d9

Burns, R. D, Hannon, J. C, Saint-Maurice, P. F, & Welk, G. J. (2014). Concurrent and criterion-referenced validity of trunk muscular fitness tests in school-aged children. *Advances In Physical Education*, *4*, 41-50.

Chan, R. H. (2005). Endurance times of trunk muscles in male intercollegiate rowers in Hong Kong. *Archives of Physical Medicine and Rehabilitation*, *86*(10), 2009–2012. doi:10.1016/j.apmr.2005.04.007

Clayton, M. A., Trudo, C. E., Laubach, L. L., Linderman, J. K., De Marco, G. M., & Barr, S. (2011). Relationships between isokinetic core strength and field based athletic performance tests in male collegiate baseball players. *Journal of Exercise Physiology Online*, *14*(5), 20–30.

Cowley, P. M., Fitzgerald, S., Sottung, K., & Swensen, T. (2009). Age, weight, and the front abdominal power test as predictors of isokinetic trunk strength and work in young men and women. *Journal of Strength and Conditioning Research*, *23*(3), 915–925. doi:10.1519/JSC.0b013e3181a06f59

Cowley, P. M., & Swensen, T. C. (2008). Development and reliability of two core stability field tests. *Journal of Strength and Conditioning Research*, *22*(2), 619–624. doi:10.1519/JSC.0b013e3181634cb4

Delitto, A., Rose, S. J., Crandell, C. E., & Strube, M. J. (1991). Reliability of isokinetic measurements of trunk muscle performance. *Spine*, *16*(7), 800–803. doi:10.1097/00007632-199107000-00019

Demoulin, C., Vanderthommen, M., Duysens, C., & Crielaard, J. M. (2006). Spinal muscle evaluation using the Sorensen test: A critical appraisal of the literature. *Joint Bone Spine*, *73*(1), 43–50. doi:10.1016/j.jbspin.2004.08.002

Dervisevica, E., Hadzic, V., & Burger, H. (2007). Reproducibility of trunk isokinetic strength findings in healthy individuals. *Isokinetics and Exercise Science*, *15*(2), 99–109.

Dvir, Z., & Keating, J. (2001). Reproducibility and validity of a new test protocol for measuring isokinetic trunk extension strength. *Clinical Biomechanics*, *16*(7), 627–630. doi:10.1016/S0268-0033(01)00038-9

Europe, C. O. (1988). *Eurofit: Handbook for the Eurofit tests of physical fitness*. Rome, Italy: Council of Europe, Committee for the Development of Sport.

Evans, K., Refshauge, K. M., & Adams, R. (2007). Trunk muscle endurance tests: Reliability, and gender differences in athletes. *Journal of Science and Medicine in Sport*, *10*(6), 447–455. doi:10.1016/j.jsams.2006.09.003

Faulkner, R. A., Sprigings, E. J., McQuarrie, A., & Bell, R. D. (1989). A practical curl-up protocol for adults based on an analysis of two procedures. *Canadian Journal of Sport Science*, *14*, 135–141.

Fleiss, J. L. (1986). Analysis of data from multiclinic trials. *Controlled Clinical Trials*, *7*(4), 267–275. doi:10.1016/0197-2456(86)90034-6

García-Vaquero, M., Barbado, D., Juan-Recio, C., Lopez-Valenciano, A., & Vera-Garcia, F. (in press). Isokinetic trunk flexion–extension test to assess trunk muscle strength and endurance: Reliability, learning effect and sex differences. *Journal of Sport and Health Science*. doi:10.1016/j.jshs.2016.08.011

Grabiner, M. D., Jeziorowski, J. J., & Divekar, A. D. (1990). Isokinetic measurements of trunk extension and flexion performance collected with the biodex clinical data station. *Journal Orthopedics and Sports Physical Theraphy*, *11*(12), 590–598. doi:10.2519/jospt.1990.11.12.590

Hall, G. L., Hetzler, R. K., Perrin, D., & Weltman, A. (1992). Relationship of timed sit-up tests to isokinetic abdominal strength. *Research Quarterly for Exercise and Sport*, *63*(1), 80–84. doi:10.1080/02701367.1992.10607560

Hannibal, N., Plowman, S. A., Looney, M. A., & Brandenburg, J. (2006). Reliability and validity of low back strength/muscular endurance field tests in adolescents. *Journal of Physical Activity and Health*, *3*, S78. doi:10.1123/jpah.3.s2.s78

Hopkins, W. G. (2000). Measures of reliability in sports medicine and science. *Sports Medicine*, *30*(1), 1–15. doi:10.2165/00007256-200030010-00001

Juan-Recio, C, Barbado, D, López-Valenciano, A, & Vera-García, F. J. (2014). Test de campo para valorar la resistencia de los músculos del tronco. *Apunts. Educación Física y Deportes*, *117*, 59-68.

Juan-Recio, C., Lopez-Vivancos, A., Moya, M., Sarabia, J., & Vera-Garcia, F. (2015). Short-term effect of crunch exercise frequency on abdominal muscle endurance. *The Journal of Sports Medicine and Physical Fitness*, *55*(4), 280–289.

Keller, A., Hellesnes, J., & Brox, J. I. (2001). Reliability of the isokinetic trunk extensor test, Biering-Sørensen test, and Åstrand bicycle test: Assessment of intraclass correlation coefficient and critical difference in patients with chronic low back pain and healthy individuals. *Spine*, *26*(7), 771–777. doi:10.1097/00007632-200104010-00017

Knudson, D. (2001). The validity of recent curl-up tests in young adults. *Journal of Strength and Conditioning Research*, *15*(1), 81–85.

Knudson, D., & Johnston, D. (1995). Validity and reliability of a bench trunk-curl test of abdominal endurance. *Journal Strength and Conditioning Research*, *9*(3), 165–169.

Knudson, D., & Johnston, D. (1998). Analysis of three test durations of the bench trunk curl. *Journal of Strength and Conditioning Research*, *12*(3), 150–151.

Kraemer, W. J., & Ratamess, N. A. (2004). Fundamentals of resistance training: Progression and exercise prescription. *Medicine & Science in Sports & Exercise*, *36*(4), 674–688. doi:10.1249/01.MSS.0000121945.36635.61

Laughlin, M. S., Lee, S. M., Loehr, J. A., & Amonette, W. E. (2009). Isokinetic strength and endurance tests used pre-and post-spaceflight: Test-retest reliability. *NASA Technical Memorandom*.

Leetun, D. T., Ireland, M. L., Willson, J. D., Ballantyne, B. T., & Davis, I. M. (2004). Core stability measures as risk factors for lower extremity injury in athletes. *Medicine & Science in Sports & Exercise*, *36*(6), 926–934. doi:10.1249/01.MSS.0000128145.75199.C3

Liemohn, W. P., Baumgartner, T. A., & Gagnon, L. H. (2005). Measuring core stability. *Journal of Strength and Conditioning Research*, *19*(3), 583–586. doi:10.1519/1533-4287(2005)19[583:MCS]2.0.CO;2

Lindsay, D. M., & Horton, J. F. (2006). Trunk rotation strength and endurance in healthy normals and elite male golfers with and without low back pain. *National American Journal Sports Physical Therapy*, *1*(2), 80–89.

Luoto, S., Heliövaara, M., Hurri, H., & Alaranta, H. (1995). Static back endurance and the risk of low-back pain. *Clinical Biomechanics*, *10*(6), 323–324. doi:10.1016/0268-0033(95)00002-3

Mayer, T., Gatchel, R., Betancur, J., & Bovasso, E. (1995). Trunk muscle endurance measurement. Isometric contrasted to isokinetic testing in normal subjects. *Spine*, *20*(8), 920–927. doi:10.1097/00007632-199504150-00007

Mayer, T. G., Smith, S. S., Keeley, J., & Mooney, V. (1985). Quantification of lumbar function. Part 2: Sagittal plane trunk strength in chronic low-back pain patients. *Spine*, *10*(8), 765–772. doi:10.1097/00007632-198510000-00012

McGill, S. (2006). *Ultimate back fitness and performance* (3rd ed.). Waterloo: Barckfitpro.

McGill, S. M., Childs, A., & Liebenson, C. (1999). Endurance times for low back stabilization exercises: Clinical targets for testing and training from a normal database. *Archives Physical Medicine Rehabilitation*, *80*(8), 941–944. doi:10.1016/S0003-9993(99)90087-4

Moreland, J., Finch, E., Stratford, P., Balsor, B., & Gill, C. (1997). Interrater reliability of six tests of trunk muscle function and endurance. *Journal of Orthopaedic & Sports Physical Therapy*, *26*(4), 200–208. doi:10.2519/jospt.1997.26.4.200

Müller, J., Müller, S., Stoll, J., Fröhlich, K., Baur, H., & Mayer, F. (2014). Reproducibility of maximum isokinetic trunk strength testing in healthy adolescent athletes. *Sports Orthopedics Traumatology*, *30*(3), 229–237. doi:10.1016/j.orthtr.2014.02.007

Newton, M., & Waddell, G. (1993). Trunk strength testing with iso-machines: Part 1: Review of a decade of scientific evidence. *Spine*, *18*(7), 801–811. doi:10.1097/00007632-199306000-00001

President's Council on Fitness, S., and Nutrition. (2010). *The president's challenge: Physical activity & fitness awards program 2010-2011*. Retrieved from https://www.presidentschallenge.org/tools-resources/docs/PresChal_booklet_10-11.pdf

Springate, S. D. (2012). The effect of sample size and bias on the reliability of estimates of error: A comparative study of Dahlberg's formula. *The European Journal of Orthodontics*, *34*(2), 158–163. doi:10.1093/ejo/cjr010

Watkins, M., & Harris, B. (1983). Evaluation of isokinetic muscle performance. *Clinics in Sports Medicine*, *2*(1), 37–53.

Wessel, J., Ford, D., & van Driesum, D. (1992). Measurement of torque of trunk flexors at different velocities. *Scandinavian Journal Rehabilitation Medicine*, *24*(4), 175–180.