New protocols to assess trunk muscle strength and endurance

Doctoral thesis

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NEW PROTOCOLS TO ASSESS TRUNK MUSCLE STRENGTH AND ENDURANCE

Doctoral thesis

A dissertation presented by
María del Pilar García Vaquero

Graduate in Physical Activity and Sports Science

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NEW PROTOCOLS TO ASSESS TRUNK MUSCLE STRENGTH AND ENDURANCE

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ABSTRACT

Due to the important contribution of the trunk musculature to many sports and daily life activities, diverse field and laboratory protocols have been developed to assess trunk muscle strength and endurance in sport, fitness, clinical and research settings. Nevertheless, the isokinetic dynamometry protocols have rarely been used to evaluate trunk muscle endurance. In addition, field tests that measure rotation trunk muscle endurance in the horizontal plane are lacking. The main purposes of this doctoral thesis were: a) to develop new protocols to assess trunk muscle performance in healthy and physically active populations; and b) to analyze the most important characteristics of these protocols in order to facilitate their adequate use. The 3 studies included in this doctoral thesis provide 2 new reliable protocols to assess trunk muscle performance: 1) an isokinetic trunk flexion–extension protocol to simultaneously assess trunk muscle strength and endurance; and 2) a timed field test to measure trunk flexion-rotation endurance (*flexion-rotation trunk test* [FRT test]). Based on the good reliability results obtained for all isokinetic strength variables in the first study, any of them could be used to assess trunk muscle strength. However, regarding the isokinetic endurance variables, endurance ratio and modified endurance ratio showed the best reliability results, mainly in the extension direction, and overall in males. As no learning effect was found in the isokinetic protocol, only 1 session seems enough to assess trunk muscle strength and endurance in males and females. In the second study, the FRT test showed high reliability values in males and females, which improved with test practice. Significant increases in FRT test scores across testing sessions indicated the need for performing at least 3 trials of practice to make learning effect negligible. In this study, males showed higher FRT test scores than females, as well as a higher learning effect, especially in the first 2 testing sessions. In the third study, an electromyographic and kinematic analysis of the FRT test was performed. The results of this study showed the main role of the abdominal muscles (mainly rectus abdominis) in the execution of the FRT test and the effect of test execution on abdominal muscle fatigue. On the other hand, although each trunk flexion-rotation repetition involved an average 8–14º hip flexion, the rectus femoris activation was low and it showed no muscle fatigue after test execution. Based on these results, the FRT test is a valid field protocol to assess abdominal muscle endurance in trunk flexion-rotation exertions.

Key words: *Dynamometry; muscle fatigue; performance; testing; trunk muscles; trunk twisting.*

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RESUMEN

Debido a la importante contribución de la musculatura del tronco en muchos deportes y actividades de la vida diaria, diversos protocolos de campo y laboratorio han sido desarrollados para evaluar la fuerza y la resistencia de la musculatura del tronco en ámbitos del deporte, el *fitness*, la rehabilitación y la investigación. Sin embargo, rara vez se han utilizado protocolos de dinamometría isocinética para evaluar la resistencia muscular del tronco. Además, no tenemos constancia de la existencia de pruebas de campo que midan la resistencia muscular del tronco en el plano horizontal. Los principales objetivos de esta tesis doctoral fueron: a) desarrollar nuevos protocolos para evaluar el rendimiento muscular del tronco en poblaciones sanas y físicamente activas; y b) analizar las características más importantes de estos protocolos para facilitar un uso adecuado de los mismos. Los 3 estudios incluidos en esta tesis doctoral proporcionan 2 nuevos protocolos fiables para evaluar el rendimiento de los músculos del tronco: 1) un protocolo isocinético de flexo-extensión del tronco para valorar simultáneamente la fuerza y la resistencia muscular del tronco; y 2) una prueba de campo cronometrada para medir la resistencia flexo-rotadora del tronco (*flexion-rotation trunk test* [FRT test]). Teniendo en cuenta los buenos resultados de fiabilidad obtenidos en el primer estudio por todas las variables de fuerza isocinética, cualquiera de ellas podría ser usada para evaluar la fuerza muscular del tronco. Sin embargo, en cuanto a las variables de resistencia isocinética, la ratio de resistencia y la ratio de resistencia modificada mostraron los mejores resultados de fiabilidad, principalmente en la dirección de la extensión, y en general en los hombres. Como no se encontró efecto de aprendizaje en el protocolo isocinético, sólo 1 sesión de registro parece suficiente para evaluar la fuerza y la resistencia muscular del tronco en hombres y mujeres. En el segundo estudio, el FRT test mostró valores de fiabilidad altos en hombres y mujeres, los cuales mejoraron con la práctica del test. Se registraron

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incrementos significativos en los resultados del FRT test a lo largo de las sesiones de registro, indicando la necesidad de realizar al menos 3 ensayos de práctica para controlar el efecto de aprendizaje. En este estudio, los hombres mostraron mejores resultados que las mujeres en el FRT test, así como un mayor efecto de aprendizaje, especialmente en las 2 primeras sesiones de registro. En el tercer estudio, se realizó un análisis electromiográfico y cinemático del FRT test. Los resultados de este estudio mostraron el papel fundamental de los músculos abdominales (principalmente del recto del abdomen) en la ejecución del FRT test, así como el efecto de la ejecución del test en la fatiga de los músculos del abdomen. Por otro lado, aunque en cada repetición de flexo-rotación del tronco se produjo una flexión media de la cadera de 8 a 14º, la activación del recto femoral fue baja y este músculo no mostró fatiga muscular al finalizar la ejecución del test. En función de estos resultados, el FRT test es un protocolo de campo válido para evaluar la resistencia de los músculos del abdomen en esfuerzos de flexo-rotación del tronco.

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Palabras clave: *Dinamometría; fatiga muscular; rendimiento; valoración; músculos del tronco; rotación del tronco.*

ABBREVIATIONS

ANOVA: Analysis of variance with repeated measures.

ChM: Change in the mean.

CL: Confidence limits.

EMG: Electromyography.

ER: Endurance ratio.

FFR: Final fatigue ratio.

FFT: Fast Fourier Transform.

FRT test: Flexion-rotation trunk test.

ICC: Intra-class correlation coefficient.

IO: Internal oblique.

L: Left.

maxTW: Maximum total work.

MDC: Minimum detectable change.

MER: Modified endurance ratio.

MPF: Mean power frequency.

MRR: Modified recovery ratio.

MVC: Maximal voluntary isometric contraction.

MW: Maximum work.

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o.u.: original units.

PT: Peak torque.

R: Right.

RA: Rectus abdominis.

RF: Rectus Femoris.

RMANOVA: Analysis of variance with repeated measures.

ROM: Range of motion.

RPT: Relative peak torque.

RR: Recovery ratio.

RTW: Relative total work.

SD: Standard deviation.

T: Trail.

TE: Typical error.

TW: Total work.

W: Work.

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CHAPTER 1

GENERAL INTRODUCTION

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CHAPTER 1

GENERAL INTRODUCTION

1.1. Trunk Muscle Groups

The muscles located at the central region of the human body play an essential role in human movement and posture, generating moments of force which actively participate in the three movement planes (155). The muscles located at the front of the trunk (rectus abdominis, external oblique and internal oblique), as well as those located at the back of the trunk (e.g. erector spinae, multifidus and latissimus dorsi), are involved in trunk sagittal flexion and extension actions, respectively. The muscles located at the side of the trunk (e.g. external oblique, internal oblique, transversus abdominis, quadratus lumborum, multifidus and latissimus dorsi) are responsible for trunk lateral flexion exertions (coronal plane). Finally, the muscles with fibers that have an oblique orientation respect to the length of the trunk (e.g. external oblique, internal oblique, multifidus and latissimus dorsi) perform trunk rotation actions (horizontal plane).

Considering that trunk flexor, extensor, lateral-flexor and rotator muscles are responsible for a large number of everyday and sport activities (such as carrying groceries, moving furniture, kicking a ball or throwing a javelin) (2, 44, 61, 94), the development of trunk muscle function is a common objective of athletic, recreational and health programs.

1.2. Trunk Muscle Strength and Endurance

Trunk muscle strength (i.e. the ability to exert maximum trunk muscle force) and trunk muscle endurance (i.e. the ability to exert trunk muscle force repeatedly or continuously over long periods of time) have been suggested as two of the most important trunk muscle capabilities in both the athletic and the general population (7, 52, 127).

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Trunk muscle strength has been recognized to be an important element for sport performance (7, 21, 124, 130). In this sense, it has been theorized that strong trunk muscles allow an efficient and powerful transfer of forces from the lower body to the upper body and vice versa, which may have an influence on proper technique execution (20, 32, 66, 108, 115). For example, Barbado et al. (7) found higher trunk extensor strength in international level judokas than in national level judokas, showing the relevance of trunk muscle strength in this sport. Additionally, diverse studies have suggested that poor trunk muscle strength could lead to the difficulty to transfer energy optimally throughout the trunk, causing less efficient movements, reducing sport performance and increasing injury risk (48, 59, 108, 114). In relation to the role of trunk muscle strength in the clinical field, trunk muscle strength testing has been an important element of injury rehabilitation and prevention programs. For decades, low levels of trunk muscle strength have been associated to patients with low back injuries and pain (8, 68, 88, 136, 156), so the increase of trunk muscle strength in these patients has been one of the main objectives to restore normal trunk musculoskeletal function (17, 19, 120).

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Regarding trunk muscle endurance, prospective and cross-sectional studies (10, 64, 92, 113) found that patients with low back disorders had worse performance in endurance tests than healthy or asymptomatic individuals. In the same way, the results of several experimental studies suggest that trunk endurance exercises/programs may be effective for the treatment of low back injuries (5, 26, 56, 76). Additionally, a minimum level of trunk muscle endurance seems to be needed to perform many daily activities properly (60, 90, 98). In this sense, poor trunk muscle endurance may lead to muscle fatigue and loss of control and precision (116), affecting functional capacity, mainly in athletic performance.

Considering trunk muscle performance seems to play an important role in low back injury prevention and treatment, functional capacity and sport performance, several methods have been developed to quantify trunk muscle strength and endurance in sport, clinical, educational and research settings.

1.3. Methods to Assess Trunk Muscle Strength and Endurance

1.3.1 Dynamometry to assess trunk muscle strength

Although different medicine ball toss tests (in forward, backward and rotational directions) have been employed in field settings to measure dynamic trunk muscle strength/power (24, 129), in research and clinical settings most trunk muscle strength protocols are based on the use of the dynamometry. For example, hand-held dynamometers (37, 104, 138), strain gauges (27, 84, 150) and lumbar-extension dynamometers (54, 123) have been used to measure isometric trunk muscle strength. On the other hand, isoinertial dynamometers (i.e. using of a constant load throughout the range of motion) (6, 50, 65, 116) and isokinetic dynamometers (i.e. using of a constant speed throughout the range of motion) (29, 75, 77, 109) have been commonly employed to assess dynamic trunk muscle strength, although the isometric mode also can be used in both types of dynamometers (8, 55, 101, 141).

The isokinetic dynamometry has been one of the most widely employed techniques to evaluate trunk muscle performance for more than three decades (58, 77, 105, 109, 139). For example, isokinetic trunk protocols have been used to evaluate trunk muscle strength in patients with low back pain, either comparing their results with those obtained by healthy/asymptomatic individuals (8, 84, 88, 131, 156) or determining the effect of several rehabilitation programs (8, 15, 46, 121). In addition, these protocols have also been employed to establish normative strength values in healthy athletic (41, 69, 154) and non-athletic populations (70, 84, 109). The popularity of the isokinetic dynamometry is mainly due to three reasons: 1) the isokinetic dynamometers are considered valid instruments to

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measure muscle strength (35); 2) they allow the measurement of different angular speeds and types of contraction (isometric, concentric and eccentric) (131) in a safe way, i.e. controlling the angular velocity, range of motion and body position (31, 49, 148); and 3) the reliability studies on trunk isokinetic strength protocols have shown high levels of consistency for their variables (23, 29, 75, 77, 87, 96, 105). Nevertheless, the high economic and time cost of the isokinetic dynamometry has limited its use mainly to clinical and research settings.

1.3.2. Protocols to assess trunk muscle endurance.

The assessment of trunk muscle endurance has habitually been carried out by static and dynamic field tests. The static endurance tests basically consist in maintaining a prone (10, 25, 42, 67, 99, 104), supine (25, 42, 67, 99, 104) or lateral (25, 42, 99) position against gravity for as long as possible, to measure trunk extensor, flexor and lateral-flexor endurance, respectively. On the other hand, most dynamic endurance tests consist in performing the maximum number of trunk flexion or extension motions in 60-120 s (timed tests) (79, 122) or at a cadence of 20-30 repetitions/min (cadence tests) (18, 45, 104). Overall, these protocols measure trunk muscle endurance during flexion, extension or lateral bending exertions; however, we have no knowledge of trunk endurance field tests involving rotation. Considering that trunk rotator muscles play an important role in many everyday life and sport activities (61, 147), further research is needed to develop new protocols to measure trunk rotation endurance.

In relation to the isokinetic dynamometry, although it has been extensively used to evaluate trunk muscle strength, very few isokinetic protocols have been developed to assess trunk muscle endurance (91, 96), and these have showed inconsistent reliability data. Despite technical and economic limitations of using isokinetic dynamometers, future studies should develop new isokinetic protocols to measure trunk muscle endurance in

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clinical and research settings. Based on the isokinetic dynamometry characteristics, these new protocols may allow to assess both the maximum isokinetic force (isokinetic strength) and the ability to maintain the isokinetic force production over time (isokinetic endurance), and all while properly controlling the execution.

The development of new trunk field and laboratory protocols would allow to evaluate the function of the different trunk muscle groups in very diverse conditions, facilitating the selection of those tests that best fit the needs of each individual. As any measurement tool, the new protocols should satisfy important criteria, such as validity, reliability, sensitivity, time efficiency, applicability, etc.

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CHAPTER 2

RESEARCH OBJECTIVES AND HYPOTHESES

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CHAPTER 2

RESEARCH OBJECTIVES AND HYPOTHESES

2.1. General objective

Based on the limitations of the literature, the general objectives of this doctoral thesis were *to develop new protocols to evaluate trunk muscle strength and endurance and to analyze the main characteristics of these protocols in order to facilitate their adequate use.*

To carry out the referred objectives, three studies were performed:

- Study 1: Isokinetic trunk flexion–extension protocol to assess trunk muscle strength and endurance: reliability, learning effect and sex differences.
- Study 2: Flexion-rotation trunk test to assess abdominal muscle endurance: reliability, learning effect and sex differences.
- Study 3: Electromyographic and kinematic analysis of the flexion-rotation trunk test.

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2.2. Specific objectives

The specific objectives have been structured depending on the three studies of this doctoral thesis:

Study 1:

1. To assess the absolute and relative reliability and the learning effect of a new isokinetic trunk flexion–extension protocol designed to simultaneously assess trunk muscle strength and endurance.
2. To examine the effect of the participants’ sex on the data reliability.

Study 2:

3. To evaluate the absolute and relative reliability and the learning effect of a new field test, i.e. the flexion-rotation trunk test (FRT test), which was developed to assess the abdominal muscle endurance through movements which combine trunk flexion and rotation in lying supine.
4. To analyze the effect of the participants' sex on FRT test performance.

Study 3:

5. To describe the trunk and hip muscle activation and fatigue and the range of hip flexion of the FRT test.
6. To analyze the relationships between the FRT test scores and the electromyographic and kinematic variables.

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2.3. Research hypotheses

The following hypotheses were established in the three studies of this doctoral thesis:

Study 1:

1. Based on previous studies on trunk isokinetic dynamometry, the strength variables of the isokinetic trunk flexion–extension protocol will show high relative reliability (see for example: 23, 87, 96, 105) and moderate to good absolute consistency (see for example: 23, 34, 87, 105). Regarding the learning effect of the protocol, 1 or 2 testing sessions will be enough to perform a reliable trunk muscle strength evaluation (see for example: 23, 87, 105, 109).
2. Although Mayer et al. (96) found low reliability values for isokinetic trunk endurance variables, our protocol will obtain better reliability results for these variables. This increase in measurement consistency will be due to the differences

between protocols, especially the higher number of sets and repetitions of our protocol which will facilitate the evaluation of the trunk muscle force reduction during the exertion.

3. Despite the lack of agreement between the results of previous isokinetic trunk studies about sex effect on data reliability (29, 38, 75), males and females in our study will obtain similar reliability values in most variables. This will be due to several methodological criteria (e.g. appropriate strapping, controlling body position across sets, etc.) applied to reduce the effect of anthropometric differences between males and females on measurement reliability.

Study 2:

4. Based on previous studies on curl-up field protocols (79, 104, 133), high reliability values will be obtained in the FRT test, which will improve with test practice.
5. Considering previous studies on curl-up protocols analyzing participants' sex effect on test scores (45, 132), males will show better results than females.

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Study 3:

6. Taking into account the results of several electromyographic cross curl-up studies (4, 74, 81, 103), the abdominal muscles will show significantly higher activation levels and fatigue in the FRT test than the hip flexor muscles, which will show very low or no activation and consequently no fatigue.
7. Hip flexion during the FRT test will be very low, as curl-ups are basically trunk motions with minimal hip participation (40). Nevertheless, considering the FRT test is a timed protocol (which may involve sudden accelerations) and that execution speed has an important effect on curl-up performance (40), some participants may have problems to control lower-body position throughout the test, which may increase hip motion.

8. Higher abdominal muscle fatigue after the FRT test and lower hip movement during the protocol will be associated with higher FRT test scores. In this sense, participants who are able to minimize hip participation, will be more efficient (and will obtain better results) than those who have to flex trunk and hip to perform each repetition.

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CHAPTER 3

STUDY 1

In press in Journal of Sport and Health Science.

Isokinetic trunk flexion–extension protocol to assess trunk muscle strength and endurance: reliability, learning effect and sex differences.

Maria P. García-Vaquero, David Barbado, Casto Juan-Recio, Alejandro López-Valenciano, Francisco J. Vera-Garcia.

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CHAPTER 3

STUDY 1

Isokinetic trunk flexion–extension protocol to assess trunk muscle strength and endurance: reliability, learning effect and sex differences.

by

Maria P. García-Vaquero, David Barbado, Casto Juan-Recio, Alejandro López-Valenciano, Francisco J. Vera-Garcia.

Abstract

The purpose of this study was to examine the reliability and the learning effect of an isokinetic trunk flexion–extension protocol designed to simultaneously assess trunk muscle strength and endurance. In addition, the effect of the participants' sex on the reliability data was also examined. Fifty-seven healthy and physically active young men (*n* = 28) and women (*n* = 29) performed the isokinetic protocol 5 times, separated by a week between each of the first 4 sessions and by a month between the last 2 sessions. The protocol consisted in performing 4 trials of 15 maximum flexion–extension concentric exertions at 120°/s (range of trunk motion = 50°). The absolute and relative peak torque and total work were calculated to assess trunk flexion and extension strength. In addition, endurance ratio, modified endurance ratio, fatigue final ratio, recovery ratio and modified recovery ratio variables were used for the assessment of trunk muscle endurance in both directions. Regarding the absolute reliability, no relevant changes were found between paired-comparison sessions for most strength and endurance variables, except for total work and relative total work variables in the flexion movement in both sexes. In addition,

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the typical error of the isokinetic variables was lower than 10% in both males and females and minimum detectable changes ranged from 7% to 20%, with a tendency to be higher in females and in endurance variables. The strength variables showed high intraclass correlation coefficients (ICC; > 0.74); however, for the endurance variables only the endurance ratio and the modified endurance ratio obtained moderate–high ICC values (0.57 < ICC < 0.82). In addition, the analysis of the variance reported no significant differences between consecutive pairs of sessions for most variables in both sexes. Overall, these findings provide clinicians, trainers, and researchers with a 10 min single-session protocol to perform a reliable muscle strength and endurance evaluation of trunk flexor and extensor muscles, all within the same protocol.

Key words: *core muscles; fitness; spine; isokinetic dynamometry; performance; testing.*

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1. Introduction

The contribution of the trunk musculature to many sports (e.g. taekwondo, judo, tennis, golf, baseball, handball, rowing, etc.) (7, 22, 25, 43, 157) and daily life activities, has aroused considerable interest in trainers, clinicians, and researchers (9, 60). In the field of sports, it is thought that trunk muscle strength, as well trunk muscle endurance, can improve athletic performance (7, 21, 118) and help prevent and treat back disorders in individuals with trunk muscle weakness (36, 43). For these reasons, many field and laboratory protocols have been developed to assess trunk muscle strength and endurance in sport, fitness, clinical and research settings.

For decades, isokinetic dynamometry has been widely used to measure trunk muscle strength in sport performance (7, 69, 154), as well as to identify injury risks (88, 156) and to assess the progress of rehabilitation programs (8, 46) in clinical settings. The main reasons for its popularity are the validity and reliability shown by the isokinetic instrumental (35), the relative and absolute reliability of the isokinetic strength protocols (23, 34, 87, 105), and its ability to measure different muscle groups while controlling the contraction type, angular velocity, range of motion, body position, number of repetitions and sets, etc. (49). In addition, as previous studies have not found learning effect for these protocols (23, 29, 34, 38, 77, 87, 105, 153), participants do not have to carry out a long period of practice before testing.

In contrast, trunk muscle endurance has been normally evaluated using field tests (10, 16, 79, 99), as they are easy to perform, do not need large and expensive equipment, and allow numerous people to be evaluated all at once in a short period of time. However, several researchers have questioned their use, especially in the field of sports, for several reasons: a) the lack of specificity of some protocols according to sport trunk demands (21, 60, 108); b) the influence of individual anthropometry (72) and test practice/experience (16) on scores; and c) the large absolute reliability of most field protocols (42, 72, 104), which brings into question their ability to detect real improvement in the athletic population (83). Based on the isokinetic dynamometry characteristics presented above (i.e. instrumental reliability, performance control, non-learning effect, etc.), isokinetic trunk endurance protocols could be an alternative to field tests; however, to the best of our knowledge there are few studies on isokinetic trunk endurance (7, 91, 96), and only the study by Mayer et al. (96) has assessed protocol reliability. In this study, two different trunk muscle strength and endurance protocols were analyzed and only the strength variables showed high reliability, while the reliability of the endurance variables was considerably lower.

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Taking into account the lack of isokinetic trunk endurance protocols and the time constraints in sport and clinical settings, which make performing several protocols difficult, an isokinetic trunk flexion–extension protocol was developed to simultaneously evaluate both trunk muscle strength and endurance. The protocol was based on those developed by Mayer et al. (96) and has a short execution time (approximately 10 min) which facilitates its use in professional and scientific fields. Although this protocol has recently been used to show the contribution of the trunk muscle function to high-level performance in judo (7), its reliability has not been analyzed. Therefore, the main purpose of this study was to assess the absolute and relative reliability and the learning effect of this new isokinetic trunk flexion–extension protocol. In addition, we also examined the effect of the participants' sex on the reliability data, as there are only a few studies on isokinetic trunk dynamometry which do not show consistent results that have evaluated protocol reliability depending on the participants' sex (29, 38, 77).

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2. Methods

2.1. Participants

Fifty-seven healthy young volunteers, 28 males (age: 24.1 ± 3.3 years; height: 176 ± 5.2 cm; mass: 75.4 ± 8.6 kg) and 29 females (age: 22.2 ± 3.8 years; height: 164.1 ± 4.8 cm; mass: 59.0 ± 7.1 kg), took part in this study. They were physically active, performing 1–3 h of moderate physical activity 1–3 days per week. Participants, who were recruited from the university population, took part in a variety of recreational physical activities such as: team sports, aerobic exercises and strength workout routines, but none of them was involved in trunk strength and/or endurance training programs. They completed a questionnaire about their medical and sports history to assess their health status and regular physical activity. None of the participants reported a recent history of back injury, abdominal surgery, or inguinal hernia, and all participants were free of neurological, cardiorespiratory, or musculoskeletal disorders. All subjects were informed of the risks of this study and signed an informed consent based on the 2013 Declaration of Helsinki, which was approved by the Ethics Committee of the Miguel Hernandez University of Elche (Spain).

2.2. Testing protocol description

The isokinetic trunk protocol was performed in a Biodex® isokinetic dynamometer (Model 2000, Multijoint System 4 Pro, Biodex Corporation, Shirley, NY, USA). Participants were placed on the dual position back extension/flexion attachment of the dynamometer with the trunk upright, the hips and knees flexed at 90°, the thighs parallel to the floor, and the dynamometer axis of rotation aligned with the imaginary line joining the anterior superior iliac spines (51). This was considered the anatomical reference position (Figure 1). In order to hold the participant to the dynamometer attachment, adjustable pads were placed behind the head, the sacrum, and the upper-trunk and on the anterior surface of the tibia; in addition, Velcro® straps were placed on the upper-trunk, the thighs, and the pelvis. The trunk range of movement was limited at 50°, with 30° (−30°) of trunk flexion and 20° (+20°) of trunk extension, relative to the anatomical reference position (0°) described above (Figure 1). According to Grabiner and Jeziorowski (51), ranges of trunk motion no larger than 50° isolate lumbar motion, reducing hip flexion–extension. Moreover, the location of the dynamometer axis of rotation at the anterior superior iliac spine level, and the use of the pad behind the sacrum and the strap on the pelvis, minimized hip motion during the protocol.

The protocol consisted in 4 sets of 15 consecutive maximum concentric trunk flexion and extension efforts with 1 min rest between sets (7). It started from the flexion position and was performed with an angular velocity of 120°/s. This angular velocity was chosen because it is considered to be safe and reliable for measuring mechanical work

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(151). Participants were indicated to keep their hands and arms crossed over the chest during the protocol. In addition, they were instructed to perform the maximum effort from the beginning of the first set and to maintain it until the end of the test. Moreover, they were verbally encouraged with the same indications and intensity across repetitions to exert maximum physical effort throughout the protocol (75, 87).

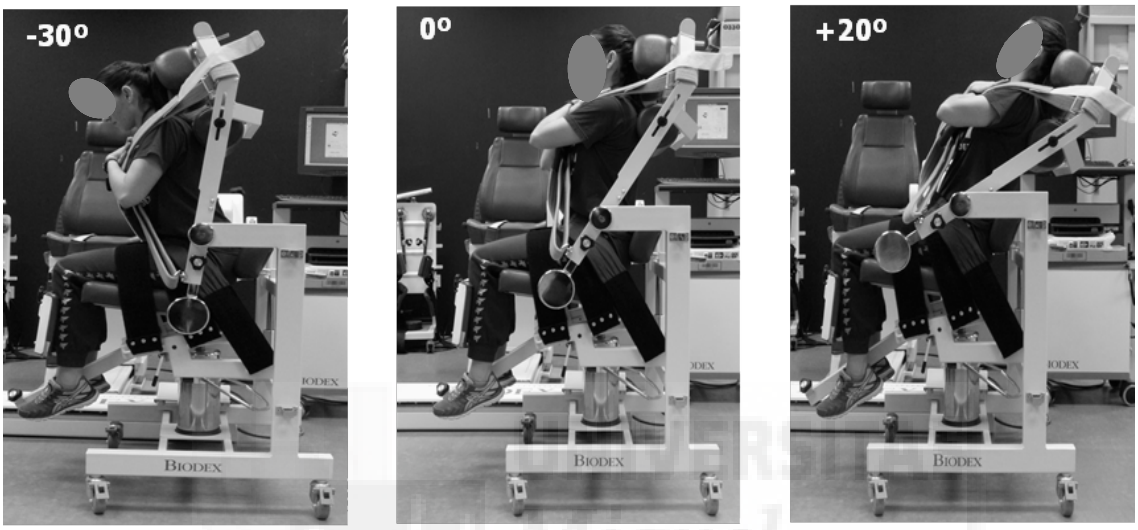

Figure 1. Participant performing a maximum effort of trunk flexion-extension in the isokinetic dynamometer with a range of motion of 50º (-30º trunk flexion; 0º initial position; 20º trunk extension).

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Before testing, participants carried out a warm-up that consisted in performing 1 set of 10 sub-maximum trunk flexion–extension exertions at testing angular velocity (120º/s). This warm-up period helped participants familiarize with the equipment and test execution. The overall testing duration was approximately 10 min.

Taking into account that at least 3 administrations of a protocol are needed to estimate its reliability accurately (63), each participant executed 5 testing sessions of the isokinetic trunk flexion–extension protocol. All the trials were performed at the same time of the day and managed by the same researcher. For each participant, the position on the dynamometer was recorded in a log sheet during the first testing session and controlled across sets (adjusting pads and straps) and testing sessions to ensure protocol reliability

(34, 75, 87, 105). There was a week rest period between the first, second, third, and fourth testing session. However, as a weekly 10 minute trunk training session has shown to be effective to improve trunk flexor endurance in adolescents with no experience in trunk exercise programs (73), a month rest was given between the fourth and fifth testing session in order to examine the possible influence of a training effect on the reliability analysis.

2.3. Data reduction

Figure 2 shows an example of the force time-history for the isokinetic trunk protocol. The first 3 repetitions of each set were discarded to avoid non-real maximum executions related to the beginning of the isokinetic performance, as most participants reached their maximum strength values after the fourth repetition (82.9% and 72.9% for the extension and flexion movement, respectively). Therefore 12 repetitions per set (i.e. the fourth to fifteenth) were considered for further analyses.

The absolute (raw scores) and relative (scores divided by body mass) peak torque (PT [N· m] and RPT [N· m/kg], respectively) and absolute and relative total work obtained from the entire set (TW [J] and RTW [J/kg], respectively) were calculated for each set. Considering that most participants did not achieve the maximum strength values during the first set, especially for the extension movement (75% of the participants), the strength values obtained in the 2 best sets were averaged for each variable and direction to assess trunk flexion and extension strength.

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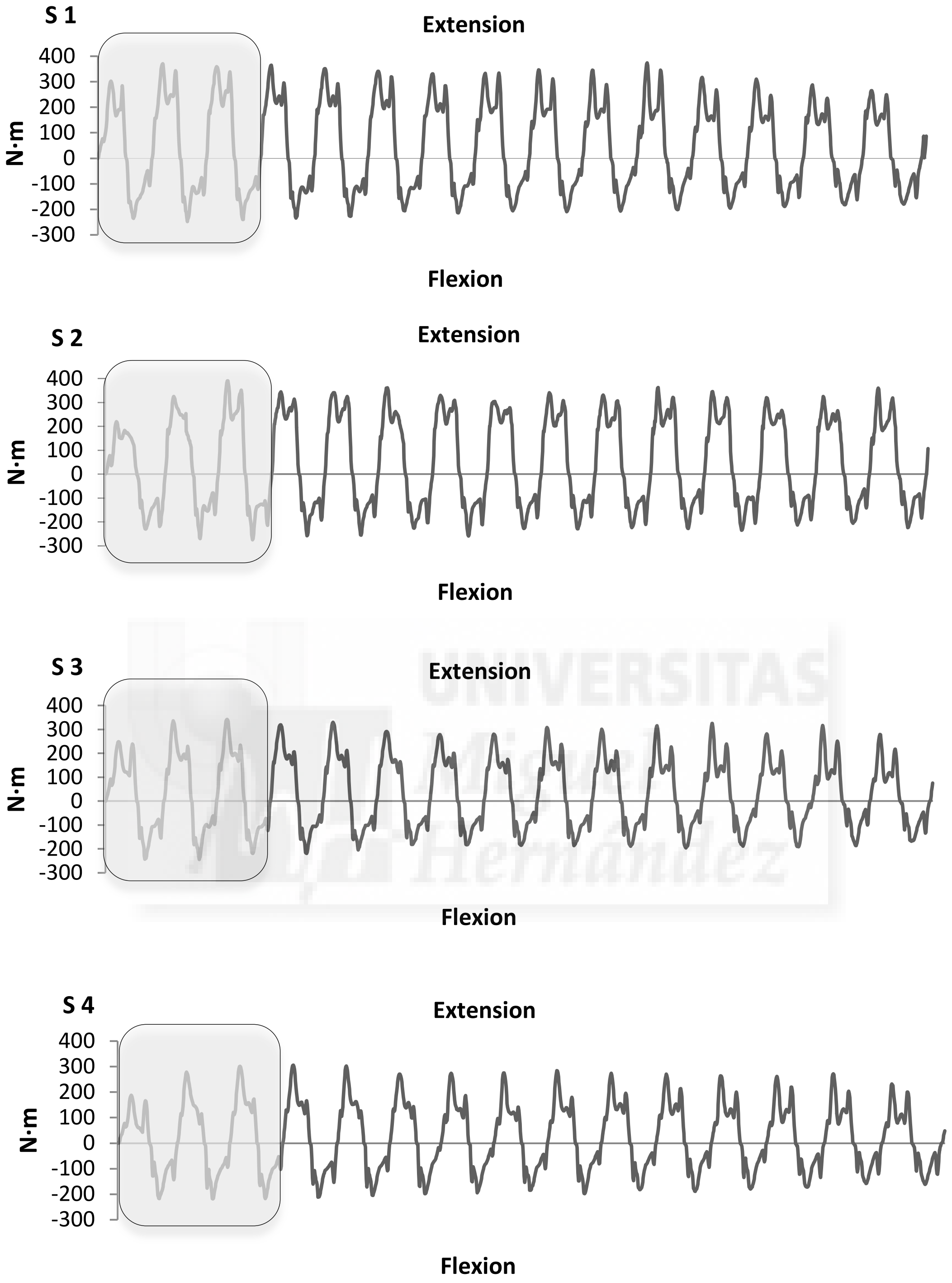

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Figure 2. Force time-history of a participant for the isokinetic protocol (4 sets × 15 repetitions). The first 3 repetitions (shaded) were not used for the data analysis.

In addition, five variables were used for the assessment of trunk muscle endurance in both directions (expressed in %):

(a) Endurance ratio (ER), obtained after dividing the work (W) performed during the last 3 repetitions of each set by the W performed during the fourth, fifth and sixth repetition of each set and multiplied by 100 (96).

$$ER = \frac{\sum \mathrm{W}\,(13{,}14{,}15)}{\sum \mathrm{W}\,(4{,}5{,}6)} \times 100$$

(a)

(b) Modified endurance ratio (MER), obtained after dividing the W performed during the last 3 repetitions of each set by 3 times the maximum W (MW) reached in any repetition during the set and multiplied by 100.

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

(b)

(c) Fatigue final ratio (FFR), obtained after dividing the W performed during the last 3 repetitions in the last set by 3 times the MW performed in any repetition of any set and multiplied by 100 (7, 96).

$$FFR = \frac{\sum \mathrm{W}\,(13, 14, 15)(\mathrm{set}\ 4)}{3 \times \mathrm{MW}\,(\mathrm{rep.})(\mathrm{sets})} \times 100$$

(c)

(d) Recovery ratio (RR), obtained after dividing the TW performed during the last set by the TW performed during the first set and multiplied by 100 (96).

$$RR = \frac{\mathrm{TW}\ (\mathrm{set}\ 4)}{\mathrm{TW}\ (\mathrm{set}\ 1)} \times 100$$

(d)

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(e) Modified recovery ratio (MRR), obtained after dividing the TW performed during the last set by the maximum TW (maxTW) performed in any set and multiplied by 100.

$$MRR = \frac{\text{TW (set 4)}}{\text{maxTW (sets)}} \times 100 \tag{e}$$

Notice that ER and MER represent the ability to maintain the force output throughout each set, while FFR, RR and MRR represent the ability to maintain the force output between sets. Therefore, a lower value in these variables represents a higher drop in trunk muscle force through the repetitions and/or sets, i.e. a lower endurance score. For ER and MER, as many participants did not show a force decrement during the first set (mainly in extension direction), the 3 sets with the lowest scores were averaged for further analyses.

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2.4. Statistical analyses

The distribution of raw data sets was checked using the Kolmogorov–Smirnov test, which demonstrated that all data had a normal distribution ($p > 0.05$). Descriptive statistics including means and standard deviations were calculated separately for each variable for both males and females. Briefly, a nine (four strength variables and five endurance variables) × five (testing sessions) × two (males and females) analysis of variance with repeated measures in the last factor (RMANOVA) were used to identify score differences between sessions (i.e. learning effect). When significant differences were obtained, post hoc t-test analyses with Bonferroni adjustments were performed for multiple comparisons. Mauchly’s test was used to check the assumption of sphericity of the data.

The detection of a possible heteroscedasticity of the random error distribution between paired sessions was done with calculation of Pearson's correlation coefficient (*r*) between absolute individual test–retest differences and individual means of each consecutive pairs of sessions. No significant correlations showed the absence of heteroscedasticity, so raw data were used for the statistical analyses (3, 12).

To analyze the inter-session absolute reliability of each variable, the typical error (TE; within-subject variation) and the change in the mean (ChM; between consecutive pairs of sessions) with their respective 90% confidence limits (CL) and the minimum detectable change (MDC; 1.5 times the typical error) were calculated using the method previously described by Hopkins et al. and Hopkins (62, 63). The absolute reliability was calculated to average the reliability for the consecutive pairs of trials (2–1, 3–2, 4–3, 5–4). The TE was established using the following formula: SDdiff/√2, where SDdiff is the standard deviation of the difference between consecutive pairs of sessions. The ChM was calculated as the mean difference between consecutive pairs of sessions. For the change in the mean, the probability that the true value of the effect was positive, trivial, or negative was inferred as follows: most unlikely, < 0.5%; very unlikely, 1–5%; unlikely, 5–25%; possibly, 25–75%; likely, 75–95%; very likely, 95–99%; most likely, > 99% (62). The current study considered a "relevant or substantial" change when a change between paired-comparison sessions was statistically significant ($p < 0.05$) and the probability of the worthwhile differences was "likely" or higher (> 75%; positive or negative).

The relative reliability of the different measures was analyzed using the intraclass correlation coefficient ($ICC_{2,1}$), calculating 90% CL. According to Hopkins et al. and Hopkins (62, 63), the ICC was calculated from the analysis of variance $(F - 1)/(F + k - 1)$, in which F is the F-ratio for the subject term and K (= 2) is the number of trials. The ICC values were categorized as follows: excellent (0.90 to 1.00), high (0.70 to 0.89), moderate

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(0.50 to 0.69), and low (< 0.50) (106). Statistical analysis was performed with the SPSS statistics software (version 18.0 for Windows 7; SPSS Inc., Chicago, IL, USA), establishing significance as $p < 0.05$.

3. Results

Descriptive statistics and the ChM between consecutive testing sessions for the isokinetic strength and endurance variables are displayed in Tables 1 and 2, respectively. For the strength variables in males and females, the ChM were generally above "likely trivial", except for specific cases shown in Table 1. Furthermore, the analysis of variance with repeated measures indicated no significant interaction effect among sessions for the extension movement in any variable and sex. In contrast, in the flexion movement a few slightly significant differences were found (Table 1). These differences were mainly detected when we compared session 1 with the rest of the sessions, as it showed higher strength values (Figure 3).

For the endurance variables (Table 2), the ChM were mainly "possibly trivial" for both males and females in flexion and extension movements, except for a few cases shown in Table 2. In addition, the analysis of variance with repeated measures reported no significant differences between consecutive pairs of sessions.

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Table 1

Descriptive values (mean ± standard deviation) for testing session 1, the change in the mean between consecutive testing sessions (mean change ± 90% confidence limits) and their probabilistic inference about the true magnitude of change are reported for the isokinetic strength variables in males and females.

Variable	Session 1	Session 2 - Session 1		Session 3 - Session 2		Session 4 - Session 3		Session 5 - Session 4	
		ChM ± CL	Inference	ChM ± CL	Inference	ChM ± CL	Inference	ChM ± CL	Inference
Males									
PT (N· m)									
Extension	373.02 ± 60.10	1.94 ± 12.20	Likely trivial	10.02 ± 9.77	Likely trivial	-11.78 ± 11.49	Possibly trivial	1.70 ± 9.16	Most likely trivial
Flexion	227.12 ± 25.25	-5.83 ± 5.08	Possibly negative	2.76 ± 5.73	Likely trivial	0.85 ± 6.69	Likely trivial	-4.23 ± 6.14	Possibly trivial
RPT (N· m/kg)									
Extension	4.98 ± 0.77	0.01 ± 0.16	Likely trivial	0.14 ± 0.13	Possibly trivial	-0.11 ± 0.13	Possibly trivial	0.03 ± 0.12	Very likely trivial
Flexion	3.05 ± 0.44	-0.09 ±0.07	Possibly trivial	0.04 ± 0.08	Likely trivial	0.01 0.09	Likely trivial	-0.05 ± 0.08	Likely trivial
TW (J)									
Extension	2139.32 ± 501.25	11.06 ± 112.44	Likely trivial	115.02 ± 77.83	Possibly positive	-159.81 ± 71.96	Likely negative	0.27 ± 81.11	Very likely trivial
Flexion	1147.34 ± 209.54	-78.04 ± 43.10	Likely negative*	28.14 ± 49.52	Possibly trivial	-19.00 ± 29.34	Likely trivial	-22.69 ± 33.17	Likely trivial
RTW (J/kg)									
Extension	28.48 ± 6.25	0.04 ± 1.50	Likely trivial	1.52 ± 1.06	Possibly positive	-2.16 ± 0.97	Likely negative	0.07 ± 1.12	Likely trivial
Flexion	15.32 ± 2.78	-1.05 ± 0.54	Likely negative*	0.37 ± 0.65	Possibly trivial	-0.37 ± 0.43	Possibly trivial	-0.29 ± 0.46	Likely trivial
Females									
PT (N· m)									
Extension	249.44 ± 41.97	6.56 ± 8.76	Possibly trivial	-3.08 ± 9.81	Likely trivial	-4.97 ± 7.03	Likely trivial	8.42 ± 8.32	Possibly trivial
Flexion	173.03 ± 22.30	-9.15 ± 5.99	Likely negative	2.31 ± 5.72	Likely trivial	-5.16 ± 6.13	Possibly negative	-2.17 ± 5.47	Likely trivial
RPT (N· m/kg)									
Extension	4.24 ± 0.64	0.10 ± 0.15	Possibly trivial	-0.05 ± 0.17	Likely trivial	-0.08 ± 0.12	Likely trivial	0.13 ± 0.14	Possibly trivial
Flexion	2.96 ± 0.42	-0.16 ± 0.11	Likely negative	0.05 ± 0.10	Likely trivial	-0.08 ± 0.11	Possibly trivial	-0.03 ± 0.09	Likely trivial
TW (J)									
Extension	1435.26 ± 323.58	69.73 ± 69.59	Possibly positive	-32.39 ± 55.31	Likely trivial	-46.82 ± 49.74	Likely trivial	31.87 ± 63.41	Possibly trivial
Flexion	701.09 ± 125.96	-50.91 ± 14.43	Most likely negative*	13.40 ± 20.70	Likely trivial	5.01 ± 19.55	Likely trivial	-8.66 ± 21.67	Likely trivial
RTW (J/kg)									
Extension	24.28 ± 4.68	1.20 ± 14.43	Possibly positive	-0.53 ± 20.70	Possibly trivial	-0.79 ± 19.55	Possibly trivial	0.38 ± 21.67	Possibly trivial
Flexion	11.90 ± 1.81	-0.87 ± 0.25	Most likely negative*	0.25 ± 0.37	Possibly trivial	0.09 ± 0.32	Likely trivial	-0.14 ± 0.34	Likely trivial

Terms for chances: possibly, 25–75%; likely, 75–95%; very likely, 95–99%; most likely, > 99%.
* Signification: $p < 0.05$
ChM= change in the mean; CL= confidence limits; PT= peak torque; RPT= relative peak torque; TW= total work; RTW= relative total work**.**

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Table 2

Descriptive values (mean ± standard deviation) for testing session 1, the change in the mean between consecutive testing sessions (mean change ± 90% confidence limits) and their probabilistic inference about the true magnitude of change are reported for the isokinetic endurance variables in males and females.

Variable	Session 1	Session 2 - Session 1		Session 3 - Session 2		Session 4 - Session 3		Session 5 - Session 4	
		ChM ± CL	**Inference**	**ChM ± CL**	**Inference**	**ChM ± CL**	**Inference**	**ChM ± CL**	**Inference**
Males									
ER (%)									
Extension	89.98 ± 12.51	-1.22 ± 2.22	Likely trivial	-0.08 ± 2.17	Likely trivial	0.89 ± 2.10	Possibly trivial	-0.30 ± 2.71	Likely trivial
Flexion	82.63 ± 6.33	0.29 ± 1.98	Possibly trivial	-0.23 ± 2.43	Possibly trivial	-2.34 ± 1.89	Possibly negative	-0.90 ± 1.92	Possibly trivial
MER (%)									
Extension	81.02 ± 7.41	-0.37 ± 1.84	Likely trivial	0.82 ± 1.74	Possibly trivial	0.34 ± 1.96	Likely trivial	0.34 ± 1.90	Likely trivial
Flexion	77.99 ± 5.95	-0.28 ± 1.63	Possibly trivial	-0.42 ± 1.93	Possibly trivial	-1.49 ± 1.54	Possibly negative	0.18 ± 1.95	Possibly trivial
FFR (%)									
Extension	71.30 ± 14.31	-0.34 ± 3.67	Likely trivial	-0.39 ± 2.97	Likely trivial	3.38 ± 3.25	Possibly positive	-1.22 ± 2.44	Likely trivial
Flexion	62.38 ± 10.10	3.83 ± 4.14	Likely positive	0.51 ± 3.36	Possibly trivial	-2.18 ± 2.58	Possibly negative	-1.19 ± 3.23	Possibly trivial
RR (%)									
Extension	95.96 ± 18.53	-6.06 ± 6.06	Possibly negative	-0.84 ± 4.57	Possibly trivial	4.65 ± 4.55	Likely positive	-2.52 ± 3.23	Possibly negative
Flexion	81.31 ± 13.16	6.28 ± 5.07	Likely positive	-1.42 ± 3.80	Possibly trivial	1.69 ± 4.52	Possibly positive	-3.87 ± 4.58	Possibly negative
MRR (%)									
Extension	87.79 ± 11.25	-0.70 ± 4.02	Possibly trivial	-2.11 ± 3.18	Possibly negative	2.94 ± 3.24	Possibly positive	-0.71 ± 2.28	Possibly trivial
Flexion	79.99 ± 10.72	4.31 ± 3.06	Likely positive	-1.18 ± 2.73	Possibly negative	1.35 ± 2.89	Possibly trivial	-3.28 ± 3.16	Likely positive
Females									
ER (%)									
Extension	71.30 ± 14.31	-3.39 ± 2.41	Likely negative	1.13 ± 2.18	Possibly trivial	0.02 2.07	Likely trivial	-0.62 ± 1.87	Likely trivial
Flexion	62.38 ± 10.10	-2.45 ± 3.11	Possibly negative	0.31 ± 2.66	Possibly trivial	2.34 ± 2.61	Possibly positive	-2.26 ± 2.87	Possibly negative
MER (%)									
Extension	82.82 ± 6.42	-1.59 ± 1.46	Possibly negative	0.18 ± 2.14	Likely trivial	-0.26 ± 1.87	Possibly trivial	-0.73 ± 1.99	Most likely trivial
Flexion	74.91 ± 6.95	-2.70 ± 3.31	Possibly negative	0.19 ± 2.60	Possibly trivial	1.04 ± 2.66	Possibly trivial	-2.17 ± 2.87	Possibly negative
FFR (%)									
Extension	76.67 ± 11.77	-2.59 ± 2.18	Possibly negative	0.84 ±3.16	Possibly trivial	-1.10 ±2.82	Possibly trivial	-0.14 ±2.83	Possibly trivial
Flexion	63.04 ± 11.63	-3.87 ± 3.82	Possibly negative	-0.15 ±3.78	Likely trivial	2.16 ±2.67	Possibly positive	-2.91 ±4.02	Possibly negative
RR (%)									
Extension	101.70 ± 18.70	-7.15 ± 4.94	Likely negative	1.07 ±4.59	Possibly trivial	-0.43 ±3.31	Possibly trivial	-1.32 ±4.39	Possibly trivial
Flexion	80.14 ± 12.05	-0.12 ± 4.76	Possibly trivial	1.90 ±3.66	Possibly trivial	0.59 ±4.40	Possibly trivial	-0.10 ±6.78	Possibly trivial
MRR (%)									
Extension	91.77 ± 8.62	-2.42 ± 1.91	Possibly negative	1.14 ±3.08	Possibly trivial	0.15 ±2.42	Possibly trivial	-0.76 ±2.48	Possibly negative
Flexion	78.60 ± 9.95	-1.82 ± 3.47	Possibly trivial	2.39 ±3.10	Possibly trivial	1.78 ±3.67	Possibly trivial	-1.12 ±5.33	Most likely trivial

Terms for chances: possibly, 25–75%; likely, 75–95%; very likely, 95–99%; most likely, > 99%.
ChM= change in the mean; CL= confidence limits; ER= endurance ratio; MER= modified endurance ratio; FFR= final fatigue ratio; RR= recovery ratio; MRR= modified recovery ratio.

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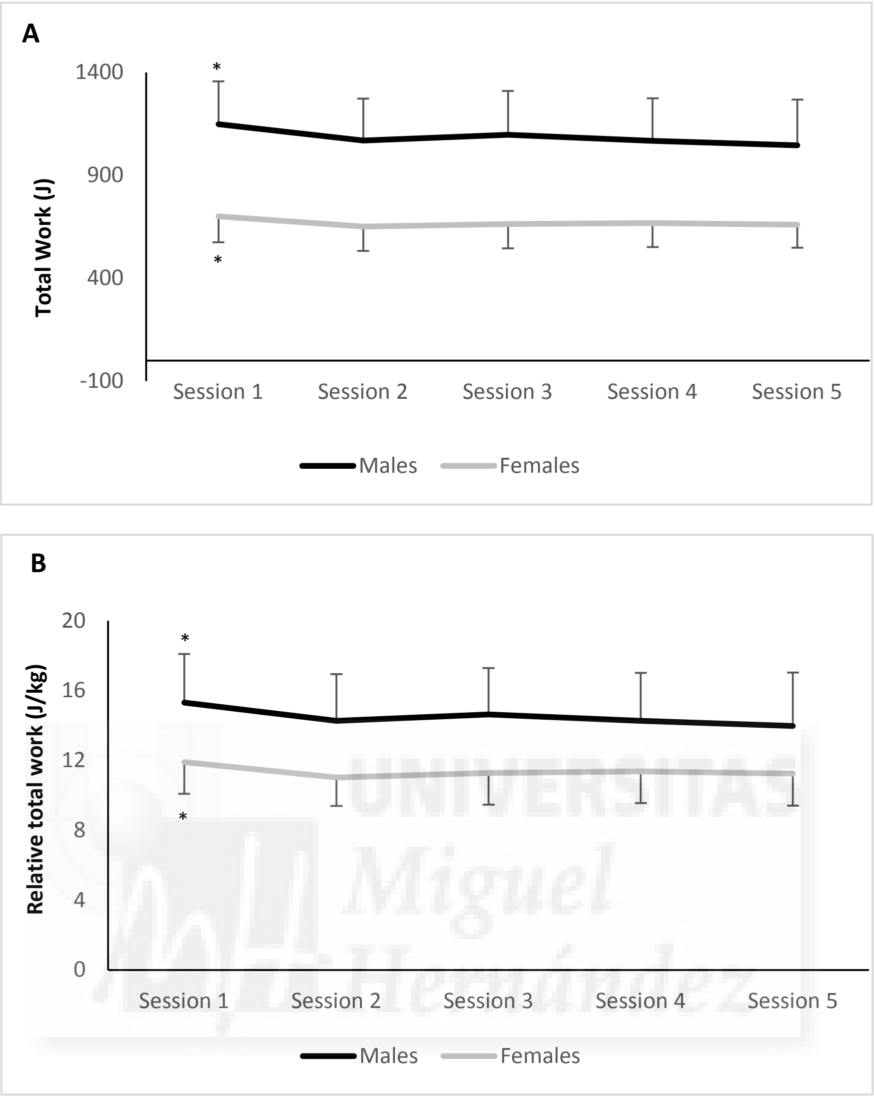

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Figure 3. Evolution of absolute (A) and relative (B) total work throughout the 5 sessions of the study for flexion direction. *significant differences between session 1 and 2.

Test–retest reliability statistics for the isokinetic strength and endurance variables (between consecutive pairs of testing sessions [2–1, 3–2, 4–3, 5–4]) are presented in Tables 3 and 4, respectively. In order to facilitate the result comprehension, data have been presented as the mean of the 4 paired testing sessions.

The strength variables (Table 3) showed mean ICC values above 0.74 (0.74 < ICC < 0.91) and mean TE values below 10% (5% < TE < 10%), while MDC was lower than

14% (8% < MDC < 14%). Comparing males and females, similar relative and absolute reliability values were obtained.

The endurance variables (Table 4) showed lower relative reliability values compared with strength variables, especially in females and in trunk flexion movement. However, ER and MER for trunk flexion and extension movements and FFR for trunk extension movement in males, and ER and MER for trunk extension movement in females presented moderate to high mean ICC scores (0.57 < ICC < 0.82).

Regarding absolute reliability, most variables showed mean values of TE below 10% (4% < TE < 10%), but FFR and RR in males and females and MRR in females presented mean values which ranged from 11% to 14% (Table 4). MDC ranged from 7% to 20%, tending to be higher in females than in males.

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Table 3

Mean of test-retest reliability statistics between consecutive testing sessions for the *isokinetic strength variables* for males and females expressed in the original units of measurement (o.u.). Probabilistic inferences are presented for intraclass correlation coefficients.

Variable	TE (o.u.) (mean – 90%CL)	TE (%)	MDC (o.u.)	MDC (%)	ICC (o.u.) (mean – 90%CL)	Inference[a] ICC
Males						
PT_{EXT}	23.56 (20.96-27.06)	6.26	35.34	9.39	0.91 (0.86-0.95)	very high
PT_{FLE}	13.04 (9.16-14.44)	5.83	19.56	8.75	0.79 (0.69-0.87)	high
RPT_{EXT}	0.30 (0.27-0.34)	5.95	0.45	8.93	0.90 (0.85-0.94)	high
RPT_{FLE}	0.18 (0.16-0.20)	5.89	0.27	8.84	0.83 (0.75-0.90)	high
TW_{EXT}	191.68 (170.56-220.13)	8.90	287.52	13.35	0.88 (0.82-0.93)	high
TW_{FLE}	86.94 (77.41-100.06)	8.01	130.41	12.02	0.84 (0.76-0.90)	high
RTW_{EXT}	2.59 (2.31-2.98)	9.07	3.89	13.61	0.85 (0.77-0.91)	high
RTW_{FLE}	1.16 (1.03-1.33)	8.02	1.74	12.03	0.84 (0.75-0.90)	high
Females						
PT_{EXT}	19.08 (17.03-21.92)	7.52	28.62	11.28	0.86 (0.79-0.91)	high
PT_{FLE}	12.99 (11.60-14.92)	8.00	19.49	12.00	0.74 (0.63-0.84)	high
RPT_{EXT}	0.32 (0.29-0.37)	7.52	0.48	11.28	0.79 (0.69-0.87)	high
RPT_{FLE}	0.23 (0.20-0.26)	8.23	0.35	12.35	0.81 (0.71-0.88)	high
TW_{EXT}	133.55 (119.21-153.39)	9.12	200.33	13.68	0.87 (0.80-0.92)	high
TW_{FLE}	43.19 (38.53-49.50)	6.46	64.79	9.69	0.87 (0.81-0.92)	high
RTW_{EXT}	2.33 (2.08-2.67)	9.38	3.50	14.07	0.80 (0.70-0.88)	high
RTW_{FLE}	0.73 (0.65-0.83)	6.39	1.10	9.59	0.84 (0.77-0.91)	high

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[a] Terms for ICC magnitudes: low, 0.20-0.50; moderate, 0.50-0.75; high, 0.75-0.90; very high, 0.90-0.99. TE= typical error; CL= confidence limits; MDC= minimal detectable change; ICC= intraclass correlation coefficient; EXT= extension; FLE= flexion; PT= peak torque; RPT= relative peak torque; TW= total work; RTW= relative total work.

Table 4

Mean of test-retest reliability statistics between consecutive testing sessions for the isokinetic endurance variables for males and females expressed in the original units of measurement (o.u.). Probabilistic inferences are presented for the intraclass correlation coefficients.

Variable	TE (o.u.) (mean – 90%CL)	TE (%)	MDC (o.u.)	MDC (%)	ICC (o.u.) (mean–90%CL)	Inference[a] ICC (o.u.)
Males						
$\mathrm{ER}_{\mathrm{EXT}}$	5.06 (4.51-5.83)	5.65	7.59	8.48	0.82 (0.73-0.89)	High
$\mathrm{ER}_{\mathrm{FLE}}$	4.38 (3.90-5.05)	5.30	6.57	7.95	0.58 (0.43-0.72)	Moderate
$\mathrm{MER}_{\mathrm{EXT}}$	4.10 (3.64-4.70)	5.03	6.15	7.55	0.69 (0.57-0.81)	Moderate
$\mathrm{MER}_{\mathrm{FLE}}$	3.85 (3.43-4.45)	4.97	5.78	7.46	0.57 (0.42-0.72)	Moderate
$\mathrm{FFR}_{\mathrm{EXT}}$	6.85 (6.09-7.86)	9.52	10.28	14.28	0.68 (0.55-0.80)	Moderate
$\mathrm{FFR}_{\mathrm{FLE}}$	7.41 (6.59-8.51)	11.46	11.12	17.19	0.51 (0.35-0.67)	Moderate
$\mathrm{RR}_{\mathrm{EXT}}$	10.08 (8.96-11.62)	11.02	15.12	16.53	0.48 (0.33-0.65)	Low
$\mathrm{RR}_{\mathrm{FLE}}$	8.46 (7.51-9.77)	10.02	12.69	15.03	0.40 (0.24-0.58)	Low
$\mathrm{MRR}_{\mathrm{EXT}}$	7.11 (6.33-8.17)	8.18	10.67	12.27	0.43 (0.27-0.60)	Low
$\mathrm{MRR}_{\mathrm{FLE}}$	6.45 (5.75-7.44)	7.80	9.68	11.70	0.52 (0.37-0.68)	Moderate
Females						
$\mathrm{ER}_{\mathrm{EXT}}$	4.69 (4.18-5.40)	5.35	7.04	8.03	0.75 (0.64-0.84)	High
$\mathrm{ER}_{\mathrm{FLE}}$	6.31 (5.63-7.23)	7.93	9.47	11.90	0.32 (0.17-0.50)	Low
$\mathrm{MER}_{\mathrm{EXT}}$	3.97 (3.54-4.55)	4.88	5.96	7.32	0.63 (0.50-0.76)	Moderate
$\mathrm{MER}_{\mathrm{FLE}}$	6.43 (5.74-7.37)	8.83	9.65	13.25	0.21 (0.07-0.39)	Low
$\mathrm{FFR}_{\mathrm{EXT}}$	6.20 (5.53-7.11)	8.31	9.30	12.47	0.58 (0.44-0.72)	Moderate
$\mathrm{FFR}_{\mathrm{FLE}}$	8.03 (7.14-9.21)	13.29	12.05	19.94	0.55 (0.40-0.70)	Moderate
$\mathrm{RR}_{\mathrm{EXT}}$	9.55 (8.48-10.96)	10.01	14.33	15.02	0.55 (0.40-0.70)	Moderate
$\mathrm{RR}_{\mathrm{FLE}}$	11.09 (9.87-12.71)	13.75	16.64	20.63	0.31 (0.16-0.49)	Low
$\mathrm{MRR}_{\mathrm{EXT}}$	5.58 (4.98-6.41)	6.19	8.37	9.29	0.51 (0.36-0.67)	Moderate
$\mathrm{MRR}_{\mathrm{FLE}}$	8.79 (7.82-10.07)	11.11	13.19	16.67	0.44 (0.28-0.60)	Low

[a] Terms for ICC magnitudes: low, 0.20-0.50; moderate, 0.50-0.75; high, 0.75-0.90; very high, 0.90-0.99. TE= typical error; CL= confidence limits; MDC= minimal detectable change; ICC= intraclass correlation coefficient; EXT= extension; FLE= flexion; ER= endurance ratio; MER= modified endurance ratio; FFR= final fatigue ratio; RR= recovery ratio; MRR= modified recovery ratio.

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4. Discussion

Although isokinetic dynamometry protocols are commonly used to assess trunk muscle strength in clinical and sports fields, they have seldom been used to evaluate trunk muscle endurance (7, 91, 96). The purpose of this study was to examine the reliability and the learning effect of an isokinetic protocol designed to simultaneously assess trunk muscle strength and endurance in physically active males and females. The main findings of the current study were the high and moderate relative reliability for the strength and endurance variables, respectively. Thus, both variables seem adequate to rank individuals according to their strength or endurance level (33, 63). In addition, strength and endurance variables showed low absolute reliability values, indicating they may be useful to detect real changes when an intervention (treatment or training) is applied (33, 63). Finally, significant improvements in strength and endurance variables were not found across sessions, suggesting that a single testing session could be enough to assess trunk muscle strength and endurance.

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Regarding the relative reliability, isokinetic strength variables in flexion and extension efforts showed high ICC values in both males and females ($0.74 < ICC < 0.91$) (Table 3). These findings agree with previous studies in which the strength was measured in different isokinetic conditions (velocity, range of motion, isokinetic devices, subject placement, etc.) (23, 75, 77, 87, 96, 105, 109). Overall, the results of all these studies indicate the robustness of isokinetic measures to assess trunk muscle strength.

Concerning endurance variables, we found moderate–high ICC values for those variables which assessed the drop of the performance within sets (ER and MER ($0.57 < ICC < 0.82$), mainly for flexion–extension movements in males and for extension movements in females (Table 4). However, those endurance variables which evaluated the drop of the performance between sets (FFR, RR and MRR) obtained low relative reliability values (Table 4). It is possible that the rest time between sets was enough to allow some participants to partially recover from the effort performed, reducing or avoiding the drop of the strength between sets in these participants. In the same way, some participants may have adopted conservative strategies during the protocol, not performing a maximum effort from the beginning of the protocol, which can be seen in some participants by the lack of a drop-off in work performance (75, 96). In general, the ICC values obtained in this study were higher than those found by Mayer et al. (96) using similar variables ($0.35 < ICC < 0.42$), maybe because in our protocol participants performed 4 sets and in Mayer et al.'s protocol participants performed 2 sets.

Regarding the absolute reliability, overall, strength and endurance variables showed typical percentage error close to or below 10% in both males and females (Tables 3 and 4). Although there are no clear guidelines to decide the adequate cut-off that ensures the precision of the measurement, some authors have suggested that a variability of a measure lower than 10% could be considered appropriate for clinical and research purposes (3, 149). Therefore, most strength and endurance variables analyzed in this study seem to have good test–retest absolute consistency. To the best of our knowledge, no previous studies have examined the absolute reliability of isokinetic trunk endurance protocols. In relation to the isokinetic strength protocols, we found similar (23, 34, 87, 105) or better (29, 38, 153) absolute reliability than previous studies did, which could be due to the fact that the angular velocities (29) and ranges of motion (23, 105) used in some of the previous studies were higher than those used in our protocol (120°/s and 50°). In this sense, angular velocities higher than 120°/s could increase the error between sessions (29) and large ranges of motion could result in a misalignment between the biological axis of the trunk and the mechanical axis of the dynamometer (34, 38).

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With the intention of improving the interpretation of the absolute reliability, the MDC was assessed, which in terms of practical applications can be used to indicate the limit for the smallest change that indicates a real improvement on the measurement after an intervention (152). The results show that changes over 14% in strength variables and over 20% in endurance variables (Tables 3 and 4) would be needed to ensure that the observed changes are real changes rather than measurement errors or participants' variability. In addition, the general trivial changes observed between consecutive testing sessions for strength and endurance variables may support the idea that no systematic error associated with learning effects occurred.

Interestingly, the reliability obtained in trunk extension exertions was slightly higher than the reliability observed in trunk flexion exertions, mainly in endurance variables. In the present study, the differences between extension and flexion directions could be due to the structure of the dynamometer used. The Biodex® isokinetic dynamometer has a rigid support both in the back and in the front of the legs (Figure 1), helping participants to consistently transmit the forces from the lower extremities to the trunk during extension exertions. However, the dynamometer does not have these rigid structures on the chest or behind the legs, which could make the performance of maximum flexion exertions more difficult and, therefore, less consistent. In this sense, with the goal of enhancing flexion exertion reliability, it would be interesting to modify the dynamometer structure by implementing a rigid support on the chest and behind the legs to allow a better force transmission in both phases of the movement.

Regarding reliability differences between males and females, both samples presented similar relative and absolute reliability values. These results support those previously obtained by Delitto et al. (29), but differ from those by Dvir et al. and Keller et al. (38, 77), who found higher reliability values for females and males, respectively. In

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addition, most isokinetic studies on other muscle groups have shown worse reliability results in males than in females, probably due to a higher difficulty of controlling the males' body position during the protocol. In this sense, the higher anthropometric dimensions and the higher experience in maximum efforts of some males in these studies may have allowed them to exert higher forces (77), so inappropriate strapping could have changed the initial position, affecting the pelvic axis alignment (34, 38, 75). On the contrary, the lack of reliability differences between sexes in the current study could be caused by: (a) an adequate position standardization in the attachment of the dynamometer via the different adjustable pads and straps used; (b) the control of body position across the sets; and/or (c) similar male and female experience performing maximum efforts, which could decrease the differences between them. Although males and females obtained similar reliability values, both samples showed large differences in trunk muscle performance (Tables 1 and 2). Males showed higher trunk flexion and extension strength and higher trunk flexion endurance than females, but no sex differences were observed for trunk extension endurance.

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For a compressive analysis of the isokinetic protocol reliability, the learning effect was assessed through 5 testing sessions. Although a few significant differences were found for total work and relative total work, generally the strength and endurance variables showed no significant differences between sessions in both sexes (Tables 1 and 2), demonstrating the consistency of the measurements. In addition, when small differences were found for the strength variables, a reduction between the first and the rest of the sessions was observed (Figure 3), which cannot be interpreted as a learning effect of the protocol. The reason for this decrease may be the lack of motivation of the participants because of the extensive and intensive demands of the protocol (i.e. 4 × 15 maximum flexion–extension exertions) and the long study duration (i.e. 5 testing sessions in 8 weeks). Therefore, only one session would be enough to obtain reliable strength and endurance values in this protocol. These results are supported by previous studies also analyzing strength variables which found no significant differences between sessions (23, 29, 34, 38, 77, 87, 105, 153).

Application of the data of this study is limited to healthy and physically active young males and females. Future investigations should include individuals with different spinal conditions, ages, physical activity levels, and so on. In this sense, due to the high physical demands of this protocol, some modifications may be needed in order to use it with untrained or low back injured individuals (e.g. increasing warm-up duration, reducing angular velocity and number of sets, etc.). In addition, as it has been explained before, our results are influenced by the characteristics of the dynamometer used in this study (e.g. adjustable pads and straps, rigid supports, etc.). Thus, if this protocol is carried out using other dynamometers, it would be advisable to perform new reliability analyses. Another limitation of this study is that the participants' body mass was only measured in the first testing session. Although researchers did not appreciate significant weight variations in the participants and the reliability of the relative peak torque and relative total work (variables which depend on participant's body mass) was high, anthropometry changes throughout the study could affect our results.

5. Conclusions

The findings of this study provide trainers and researchers with a 10 min single-session protocol to perform a reliable muscle strength and endurance evaluation of trunk flexor and extensor muscles, all within the same protocol. Based on the good reliability results obtained for all strength variables, any of them could be used to assess trunk muscle strength in physically active young males and females. However, regarding the endurance

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variables, ER and MER showed the best reliability results, mainly in the extension direction and in males.

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CHAPTER 4

STUDY 2

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Flexion-rotation trunk test to assess abdominal muscle endurance: reliability, learning effect and sex differences.

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CHAPTER 4

STUDY 2

Flexion-rotation trunk test to assess abdominal muscle endurance: reliability, learning effect and sex differences.

by

Evaristo Brotons-Gil, Maria P. García-Vaquero, Noelia Peco-González, Francisco J. Vera-Garcia.

Abstract

Trunk endurance tests are generally performed in sagittal or frontal plane. However, trunk field tests which measure the endurance of the rotator muscles are lacking. In view of this situation, we developed a flexion-rotation trunk test (FRT test) to assess the oblique abdominal muscle endurance. This new field test consists mainly in performing the maximum number of upper trunk flexion and rotation movements (repetitions) possible in 90 s. The objectives of this study were to analyze the FRT test reliability, and to examine the effect of both the repetition and sex on test results. Fifty-one recreationally trained men (n = 35) and women (n = 16) completed 4 trails of the FRT test (T1, T2, T3 and T4), separated by 7 days each. The scores increased significantly between T1 and T3 (p < 0.001), showing a clear learning effect, but the increase between T3 and T4 was only 4.25% (p = 0.108). The intraclass correlation coefficient (ICC) between trials was ≥ 0.83 and the typical error (TE) ≤ 7.54 reps. The ICC values between trials increased and TE decreased with test repetition, reaching an ICC of 0.94 and a TE of 6.46 repetitions between T3 and T4. The comparison between sexes showed higher abdominal endurance

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in men when compared with that in women (p = 0.003), and also a higher learning effect in men, especially at the beginning of the study. These findings suggest that, the FRT test is a reliable field protocol which differentiates between the abdominal endurance of men and women. However, it is necessary to perform an extensive familiarization period prior to testing (at least 3 trials of practice) to make learning effect negligible.

Key words: *assessment; muscular fitness; spine; health.*

1. Introduction

The functional importance of the trunk musculature in performing thorax and pelvis movements (flexion, extension, bending and twisting) and controlling the stability of the spine against internal and external forces (99, 143, 144), and the interest of many coaches and practitioners in training core/trunk stability to prevent low-back and lower-extremity injuries in athletes (78), have given rise to the development of a variety of tests to assess the functions of these muscles in different settings inside and outside the laboratory.

The assessment of trunk stability in field setting is very complex as it requires the combination of different measures, for example, trunk muscle strength and endurance tests (25, 42, 100, 135), lumbopelvic posture control assays (89, 135, 140), etc. The use of trunk endurance field tests has become very popular, since trunk endurance has been identified as an important muscle capability for low-back health (10, 91, 92, 99) and the protocols are simple and relatively inexpensive. Most of the trunk endurance tests evaluate the endurance of the flexor, extensor or lateral bending muscles (25, 42, 99). However, we have no knowledge of field tests which measure the endurance of the trunk rotator muscles (e.g. oblique muscles).

In throwing and striking sports (tennis, handball, hockey, golf, etc.), the trunk rotator muscle endurance is important both for performance and for the spine safety, as muscular fatigue can hinder coordination, postural control and spine stability (53, 95, 134, 142). In addition, a mechanical study which analyzed the response of the trunk to loading in different directions (143), found that participants had more problems maintaining trunk stability under twisting torque when compared to sagittal torque. Therefore, it is necessary to develop new and reliable protocols to measure the function of the trunk rotator muscles in sport, fitness, physical education, etc. Interestingly, although trunk rotation exercises are common in core training programs (e.g. cross curl-up or cross crunch, consisting in twisting and flexing the upper trunk simultaneously while lying in supine) (74, 81, 146), the protocols used to measure the endurance of the oblique abdominal muscles are generally based on trunk flexion motions without rotation, for example, timed (60-120 s) or cadence (20-30 repetitions/min) curl-up tests performed in supine: Partial Curl-Up Test (45, 71, 104, 128, 132), Bench Trunk Curl Test (79, 80, 146), etc.

In view of this situation, we developed a FRT test to measure the abdominal muscle endurance through movements which combine trunk rotation and flexion in lying supine (Figure 4). The main purpose of this study was to examine the FRT test reliability in field settings (schools, fitness centers, clinics, etc.). As the repetition of the protocol may cause variations in the technique and/or cadence of the execution, which may improve the test results, the learning or training effect (63) was also analyzed throughout 4 testing sessions. In addition, the sensitivity of the FRT test to compare the abdominal endurance between males and females was also assessed, given the fact that in previous studies males have obtained better results than females in dynamic abdominal endurance tests (45, 132).

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2. Methods

2.1. Experimental approach to the problem

As commented before, trunk muscle endurance measurements are usually part of the evaluation of the trunk stability (14, 135) and their results could be used to establish risk factors related to low-back health (10, 91, 92, 99). Although there are different flexor, extensor and lateral bending endurance tests (25, 42, 99), the FRT field test allows us to evaluate the endurance of the rotator muscles using a simple and fast protocol which does not need expensive equipment, and which is easy to use in sport, fitness sessions and physical education classes. As rotation in standing or sitting position with no external resistance generates low-moderate trunk activation levels (146), we developed a timed protocol in lying supine based on performing the maximum number of flexion-rotation movements (i.e. cross curl-ups) possible in 90 s (Figure 4). The subject's score was the number of repetitions accomplished by the subject in the 90-second test administration. This duration was established based on the study carried out by Knudson and Jhonston (80), comparing 3 different Bench Trunk Curl Test durations (60, 90 and 120 s) to evaluate abdominal muscle endurance. In this study, it was concluded that unlike the 60-second test, which according to the authors measures muscle power, the 90-second test showed a higher correlation with the 120-second test ($r = 0.88$; $p = 0.01$). Based on this data, in timed curl-up tests, 90- or 120-second durations seem more adequate to measure abdominal endurance than 60-second duration; therefore, looking for a higher time economy, we decided to use 90 s as the duration for the FRT test.

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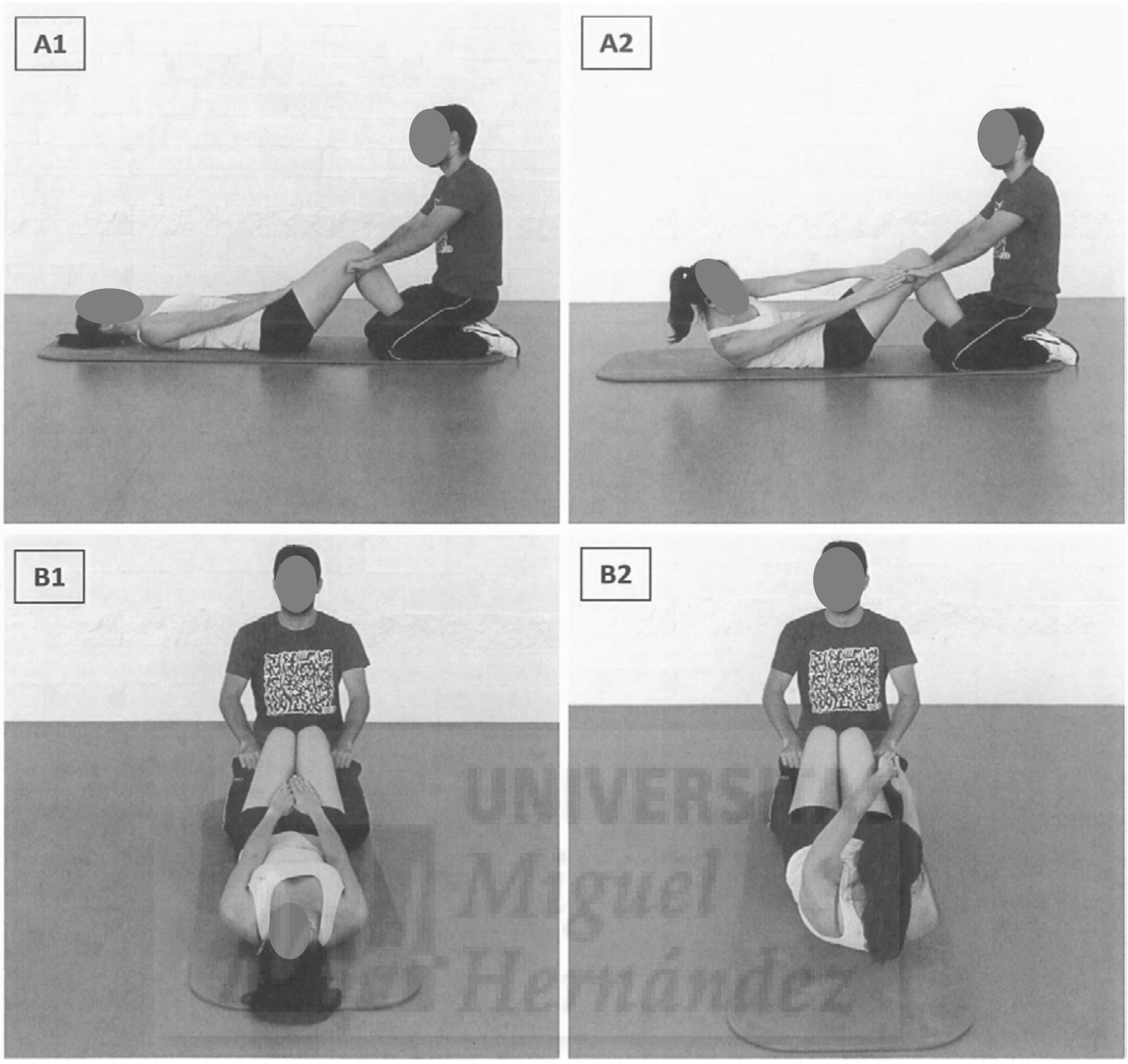

Figure 4. Flexion-rotation trunk test consists in performing the maximum number of upper trunk flexion-rotation movements possible in 90 s A lateral view (A) and a posterior view (B) of the initial position (1) and of the flexion-rotation position (2) of a test repetition are shown in these images.

Our main purposes in this investigation were to assess the relative and absolute reliability (152) of the FRT test, and to know the number of trials needed to make learning effect negligible (63) before using the test in field settings. As Hopkins stated in a review of measures of reliability in sports medicine and science (63), reasonable precision for estimates of reliability requires studies with approximately 50 participants and at least 3 administrations of the test. In this study, we used a longitudinal design in which 51 volunteers performed the FRT test 4 times, separated by 7 days each. This allowed us to analyze both the consistency of the FRT test scores and the learning effect.

2.2. Participants

Seventy volunteers initially took part in the study, of which 51 (35 males and 16 females) completed the 4 recording sessions (Table 5). Subjects were informed of the experimental risks and signed an informed consent form before the investigation. Approval for the investigation was provided by the Ethic Committee of the University. People with known medical problems, histories of spinal, shoulder or hip surgery or episodes of back pain requiring treatment 12 months before this study were excluded. All subjects were recreational physically active, participating in aerobic, strength and/or sport training with a work-out frequency of 2–5 days per week.

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Table 5
Descriptive values (mean ± standard deviation) of participant's age, mass and height.

	n	**Age (years)**	**Mass (kg)**	**Height (cm)**
All participants	51	23.20 ± 4.07	71.46 ± 11.57	174.57 ± 7.59
Males	35	23.97 ± 4.45	77.75 ± 7.57	178.46 ± 4.66
Females	16	21.56 ± 2.53	58.50 ± 6.36	166.31 ± 5.80

2.3. Procedure

After a measurement schedule, each participant executed the FRT test in 4 different sessions (T1, T2, T3 and T4), separated by 1 week each and conducted at the same time of the day for each participant (between noon and 2:00 p.m.). The trials were performed in an acclimatized fitness room (18-22º C) at the University during the first 3 months of the year. The participants were encouraged to not change their regular activity level at that moment throughout the study (mainly in relation to the trunk muscles), to not perform a work-out session at least 15 h before each recording session, and to maintain a good sleep routine and to not eat-drink excessively prior to testing.

Seven days before the first trial, there was a familiarization session in which subjects were informed of the test execution rules and the recording schedule. In this session, participants did not perform the test, but they only carried out 10 repetitions to familiarize with the basic technique of the test.

2.4. Test description

As mentioned above, the FRT protocol is a timed cross curl-up test which consists in performing the maximum number of trunk flexion and rotation movements possible in 90 s. To carry out the test, the subject was placed in a supine position on a semirigid mat, resting the sole of the feet on the floor, with legs together and a knee flexion of 90º (Figure 4). A manual goniometer (Comed, Strasbourg, France) was used to standardize the knee position in each subject and trial. The back and head were resting on the floor and the arms were stretched out over the trunk, with the hands resting on the thighs, overlapping, with both thumbs interlocked. An experimenter held subject’s knees in the aforementioned position (Figure 4) and helped to avoid the modification of the lower limb position during the execution of the test. For this, the experimenter was kneeling at the feet of the subject, pressing with the fists on the outer side of subject’s knees (Figure 5).

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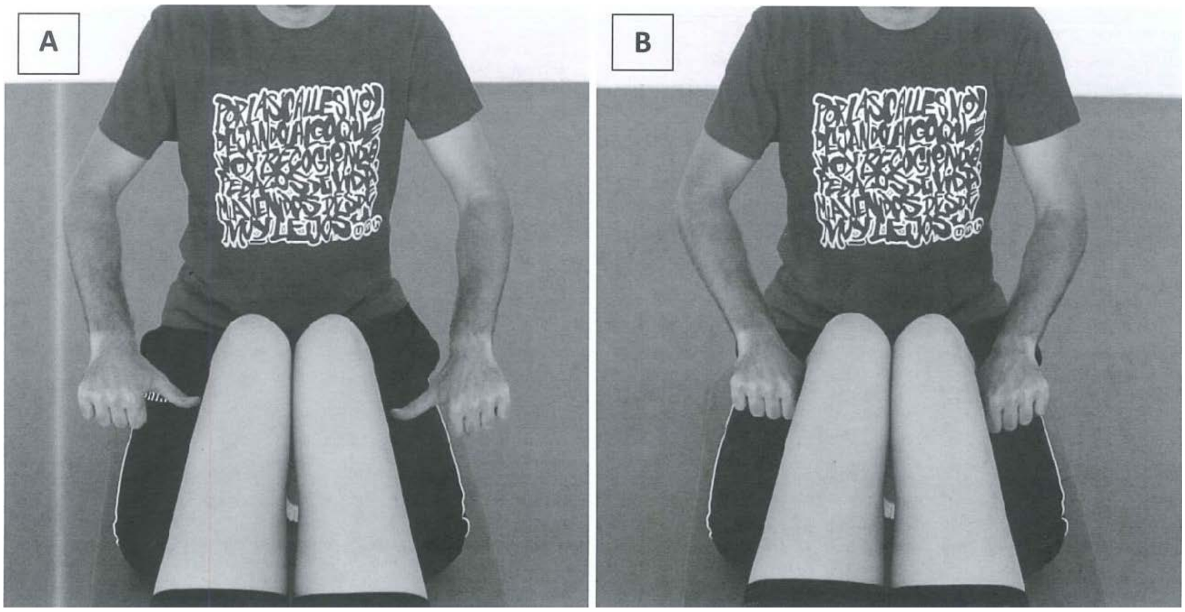

Figure 5. To standardize the location of the experimenter's fists during the FRT test, the experimenter introduced the thumbs behind the subject's knees. These images show the placing of the experimenter's hands before (A) and after (B) introducing the thumbs behind the participant's knees.

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2.5. Statistical analyses

All analyses were performed with SPSS version 20.0 (SPSS Inc., Chicago, IL, USA). Standard statistical methods were used to calculate the mean and the standard deviation of the FRT test scores (abdominal endurance) for each trial and sex. The relative intra-rater reliability of the measure was determined using an ICC (2-way random effects model). In addition, the absolute intra-rater reliability was analyzed by calculating the TE. The TE was expressed both as number of repetitions (TE = SD of the difference scores between 2 trials/√2) and as percentage of the mean value of the measurements (TE = mean of the difference scores between 2 trials × 100/mean of the first trial). To analyze the changes in the reliability measures over time, separate calculation of ICC and TE were performed on consecutive pairs of trials: T1-T2, T2-T3 and T3-T4. A comprehensive review on the quantification and use of ICC and TE to assess relative and absolute reliability has been previously presented by Hopkins (63) and Weir (152). Finally, an

RMANOVA was calculated to assess the learning effect throughout the trails (T1, T2, T3 and T4) and to explore the differences between sexes. Where applicable, post hoc analyses were performed using the Bonferroni test. An alpha level of 0.05 was considered significant for all analyses.

3. Results

Table 6 shows the absolute and relative reliability analysis results, along with the changes in the mean scores (Bonferroni post hoc) of the FRT test across the trials. The ICC values obtained between trials increased with the repetition of the test, both in the total sample and in the men and women groups. In the same way, TE tended to reduce throughout the study, reaching values of 7.27 repetitions for men and 4.24 repetitions for women between T3 and T4.

The ANOVA found significant differences for the FRT test mean scores between trials ($p < 0.001$; ἠ2 = 0.48): T1 = 70.8 ± 15.4 repetitions; T2 = 79.9 ± 20.1 repetitions; T3 = 88.1 ± 24.0 repetitions; T4 = 91.8 ± 26.1 repetitions (Figure 6). The number of repetitions obtained in the FRT test increased 12.87% from T1 to T2 ($p < 0.001$) and 10.21% from T2 to T3 ($p < 0.001$). On the contrary, the increase between T3 and T4 was low (4.25%) and not significant ($p = 0.108$).

In Figure 7, we can see the mean and SD of the results obtained in the test for both sexes. The ANOVA showed higher abdominal endurance in men than in women (p = 0.003; ἠ2 = 0.17). Results in men increased between all the trials, although the increase in the number of repetitions from T3 to T4 was only 4.60% (p = 0.044). On the other hand, the increase in women was significant from T2 to T3 (p = 0.012), but not between T1 and T2 or between T3 and T4 (Table 6).

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Table 6

Intraclass correlation coefficients (ICC) with 95% confidence interval, typical error (TE) and pairwise comparisons between mean scores (Bonferroni post hoc) throughout the recording sessions (T1, T2, T3 and T4).

	All participants				**Male**				**Female**			
	n	**T1–T2**	**T2–T3**	**T3–T4**	**n**	**T1–T2**	**T2–T3**	**T3–T4**	**n**	**T1–T2**	**T2–T3**	**T3–T4**
ICC (95% CI)	51	0.83$_{(0.72-0.90)}$	0.91$_{(0.85-0.95)}$	0.94$_{(0.89-0.96)}$	35	0.87$_{(0.76-0.93)}$	0.89$_{(0.80-0.95)}$	0.93$_{(0.86-0.96)}$	16	0.63$_{(0.20-0.85)}$	0.88$_{(0.69-0.96)}$	0.93$_{(0.81-0.98)}$
TE (repetitions)	51	7.54	6.79	6.46	35	6.70	7.65	7.27	16	7.44	4.60	4.24
TE (%)	51	12.87	10.21	4.25	35	16.28	9.59	4.60	16	4.22	11.95	3.28
***p*-Value**	51	< 0.000	< 0.000	0.108	35	< 0.000	< 0.000	0.044	16	1.00	0.012	1.00

* Signification: $p < 0.05$

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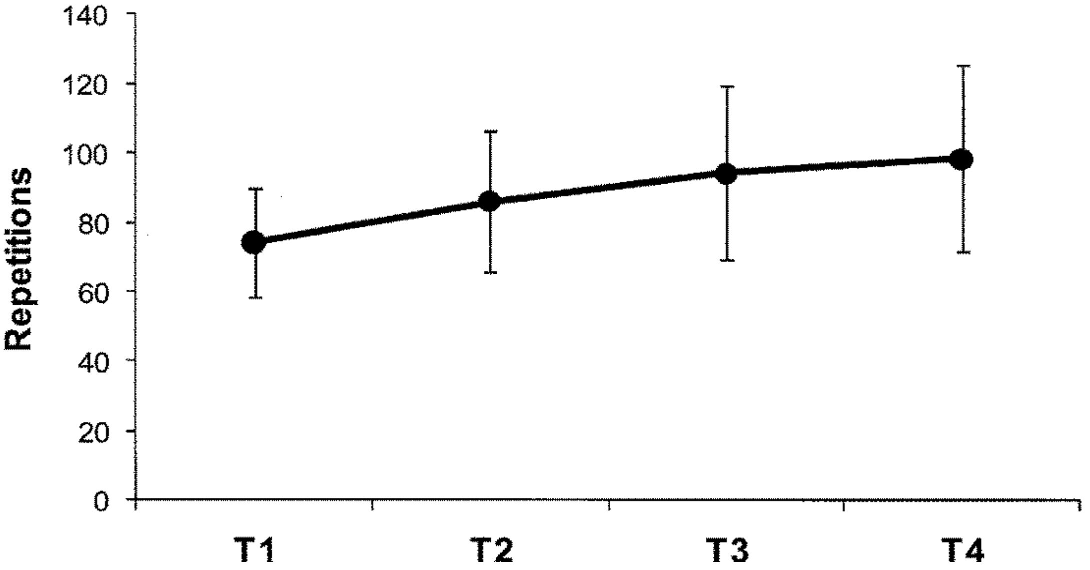

Figure 6. Mean and standard deviation of the participant's flexion-rotation trunk test scores (*n* = 51) in 4 trials (T1, T2, T3 and T4), separated by 7 days each.

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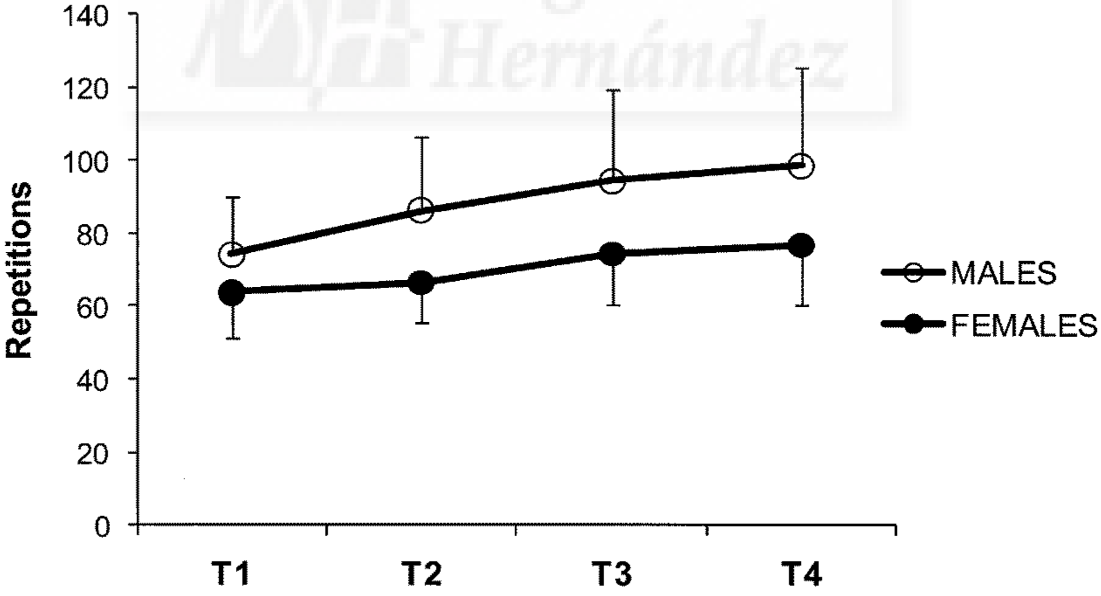

Figure 7. Mean and standard deviation of male's (*n* = 35) and female's (*n* = 16) flexion-rotation trunk test scores in 4 trials (T1, T2, T3 and T4), separated by 7 days each.

4. Discussion

Although trunk muscle function should be assessed and trained in all planes of motion for multi-directional competence (78), field tests which measure the trunk rotator endurance in the horizontal plane are lacking. The objective of this study was to analyze the reliability of a new field test, the FRT test, based on the repetition of trunk flexion-rotation movements in lying supine, and also to examine the effect of repetition and sex on test results. The data obtained in this study indicate that the reliability of the test is good, but this reliability depends on the number of times the test is repeated, as throughout the recording sessions, absolute and relative consistency of measurements increased and learning effect of the test (i.e. difference in mean scores between trials) reduced considerably. In addition, the comparison between sexes showed higher abdominal endurance in males when compared with that in females and also a higher learning effect in males, especially at the beginning of the study.

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In relation to the reliability analyses (Table 6), the high ICC (0.83-0.94) and the low TE (12.87-4.25%) values obtained between the different recording sessions, show the high relative and absolute consistency of the measurements. The TE values of the FRT test were similar (45) or even lower (45, 104) to those found in previous abdominal endurance tests. In addition, the ICC was similar to those obtained in other studies during trunk endurance field tests reliability analysis. Most field tests in literature show ICC values > 0.75: (a) dynamic trunk flexion tests, for example the Bench Trunk Curl Test with an ICC > 0.79 (79) and the Partial Curl-Up Test with an ICC > 0.88 (71, 104, 128); (b) isometric trunk flexion tests, such as the Flexor Endurance Test with an ICC > 0.93 (25, 42, 99); (c) isometric trunk extension tests, such as the Biering-Sorensen Test with an ICC > 0.75 (25, 30, 42, 99, 141); and (d) isometric lateral flexion tests, such as the Side Bridge Test with an ICC > 0.76 (25, 99). However, it is difficult to establish direct comparisons between studies as the ICC is sensitive to the between-subjects variability (63, 152).

The FRT test allows a reliable assessment of the flexor-rotator muscle endurance via a simple protocol which can be easily applied outside the laboratory. Nevertheless, as presented in Figure 6, the test scores increased throughout the study, showing a clear learning effect which must be taken into account before using it in field settings. Improvements of the FRT test scores across the longitudinal study may have occurred due to changes in the technique and/or the cadence of test execution during the first recording sessions. It is also probable that these improvements were related with motivation (63), as although we did not inform the individual of the test score, he or she was able to count the number of repetitions performed, in an attempt to improve his or her performance or beat his or her peers in future recordings. Interestingly, there seems to be an asymptotic function between trials and scores in the FRT test (Figures 6 and 7), since the increase in the test scores along the 4 trials reduced progressively until the differences between T3 and T4 were very small (males: 4.60%, $p = 0.044$; females: 3.28%, $p = 1.00$). According to this data, it would be necessary to perform the FRT test at least 3 times for the results to be consistent and in this way control the learning effect of the test. We cannot establish direct comparisons between our results and those of previous studies, as most researches that have analyzed the reliability of field tests measuring trunk muscle endurance only carried out 2 trials (test-retest), with the exception of studies like those of Moreland et al. (104) or Cowley et al. (23), in which subjects performed 3 trials.

When comparing the FRT test results between sexes (Figure 7), we found higher trunk flexor-rotator endurance in males than in females ($p = 0.003$). Previous studies which used dynamic trunk flexion tests to measure the abdominal endurance also found these differences in favor of the males (45, 132). But when isometric trunk flexion tests were

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used, no differences between sexes were found (42, 99). Other studies that analyzed the effect of sex on performance in the Side Bridge Test (trunk lateral flexion isometric endurance test), also found differences favoring the males (42, 99). On the other hand, the studies carried out with the Biering-Sorensen Test (trunk extensor isometric endurance test) found differences favoring females in studies of non-athletes (99) and similar results between males and females in studies with athletes (42). According to those studies, there seems to be an interaction between sex and training level that may modulate performance in this type of field tests. Future studies should analyze the results obtained by males and females in different sports and with different training levels in the FRT test, especially in sports in which the endurance of the trunk flexor-rotator muscles is important (e.g. tennis, judo, etc.).

The differences between sexes were not only reduced to the test scores, but also to the increase in the results throughout the 4 trials. Especially, it is worth pointing out the differences between males and females when comparing T1 and T2, in which we can see that males improved their scores in the second trial significantly (16.28%, $p < 0.001$), while females showed a lower and non-significant increase (4.22%, $p = 1.00$). We do not have enough information to establish the origin of these results; nevertheless, even though psychological variables were not analyzed in our study, the differences between sexes could be related with differences in goal orientation between males and females. It is known that males and females differ in their goal orientations (107, 117), that is, males are more motivated to compete with their peers while females are more concerned with the correct execution of the training. Therefore, it is possible that during the first 2 trials females paid their attention mainly to performing the test correctly (test score being less important), whilst males may have centered their attention on increasing the number of

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repetitions performed previously and on obtaining better results than their peers. Nevertheless, this hypothesis must be confirmed in future studies.

5. Practical Applications

Taking into account that trunk rotation endurance seems an important factor for high performance in both, throwing-striking sports (e.g. tennis, golf, baseball, etc.) and combat sports (judo, karate, etc.), and that its deficit in golfers has been related to low back pain (91), coaches and physical trainers would do well to evaluate the trunk rotation endurance of their athletes. In this sense, isokinetic dynamometry protocols have been developed in research and clinical settings to assess the endurance and strength of the trunk rotator muscles (91); however, these evaluations are expensive and not easily accessible to coaches, fitness instructors or physical educators. On the contrary, the FRT test is a reliable field protocol which requires minimal and inexpensive equipment and is simple to employ in groups of subjects. For example, a sport team or a physical education class can be divided into pairs to administer the FRT test in 2 phases: (a) one member of each pair would perform the test first (*performing partner*), with the help of the other member of the pair (*testing partner*), who would hold the legs of his or her partner and count the repetitions performed correctly; (b) then, the roles would be inverted. Since the FRT test duration is very short (90 s), a whole group/team could be measured in a few minutes. Nevertheless, due to the learning effect observed in this study, mainly in the group of men, it is advisable to perform an extensive familiarization period prior to testing (at least 3 trials of practice) to make learning effect negligible.

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CHAPTER 5

STUDY 3

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Electromyographic and kinematic analysis of the flexion-rotation trunk test.

Maria P. García-Vaquero, Ignacio Ruiz-Pérez, David Barbado, Francisco J. Vera-Garcia.

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CHAPTER 5

STUDY 3

Electromyographic and kinematic analysis of the flexion-rotation trunk test.

by

Maria P. García-Vaquero, Ignacio Ruiz-Pérez, David Barbado, Francisco J. Vera-Garcia.

Abstract

While most trunk endurance field protocols are performed in the sagittal or frontal planes, the flexion-rotation trunk (FRT) test combines trunk flexion with rotation, which may be relevant to rotation-related sports. The aim of this study was to describe the trunk and hip muscle activation and fatigue and the range of hip flexion of this test. Twenty-seven physically active male and female performed the FRT test after a period of practice. Electromyographic (EMG) signals were bilaterally collected from the rectus abdominis (RA), internal oblique (IO), and rectus femoris (RF), and hip flexion amplitude was measured using a biaxial electrogoniometer. Since the fast Fourier transform algorithm requires stationary EMG signals, participants performed a 6-s isometric trunk flexion-rotation repetition just before and just after the test execution (pre- and post-execution repetitions, respectively). RA showed the highest mean activation levels (about 30% maximal voluntary isometric contractions [MVC]) in the pre-execution repetition, followed by IO (about 20% MVC). Also, the mean power frequency (MPF) significantly decreased from the pre- to the post-execution repetition for RA and IO, which shows abdominal muscle fatigue. Although each trunk flexion-rotation repetition involved an average 8–14°

hip flexion, the RF activation was lower than 10% MVC, and no significant MPF reduction (i.e. no muscle fatigue) was observed for this muscle. Additionally, significant negative correlations were found between the FRT test scores and the normalized EMG amplitudes of RF. Based on these results, the FRT test seems a valid field protocol to assess abdominal muscle endurance in trunk flexion-rotation exertions.

Key words: *trunk muscles; testing, trunk twisting; muscle fatigue; hip flexion.*

1. Introduction

The lack of trunk muscle endurance has been identified as an important factor in the prediction and detection of low-back injuries in both athlete (43, 137) and non-athlete populations (10, 102, 122). As a consequence, improvement of trunk muscle endurance has been widely advocated as a treatment (26, 36) and preventive measure (57, 86, 97, 122) for back injuries. In addition, proper trunk muscle endurance has been suggested as necessary for daily activities (100) and for some sport-specific actions (42) involving the ability to produce work over time.

A number of tests have been developed to assess trunk muscle endurance during flexion (45, 67, 79, 104), extension (10, 67, 104), and lateral bending exertions (25, 42, 99). However, although abdominal oblique muscles are essential to perform many twisting activities in everyday life (e.g. carrying, moving, or handling objects at work or at home; pitching, throwing, or striking in rotation-related sports; etc.) (61, 147) and to stabilize the trunk against torsional loads (47, 143), to the best of our knowledge, the FRT test is the only trunk endurance protocol that involves trunk twisting (16).

The FRT test is a timed cross curl-up protocol while lying supine that consists in performing the maximum number of trunk flexion-rotation movements in 90 s. After a

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familiarization period (at least 3 trials), this test has proved to be a reliable field protocol to asses abdominal muscle endurance (ICC ≥ 0.94; SEM ≥ 6.46 repetitions) (16). It shows similar relative reliability (79, 104, 133) and similar (45) or better (45, 104) absolute consistency than other dynamic trunk flexion tests. Furthermore, the FRT test is an inexpensive and quick protocol that can be used easily with large groups.

Nevertheless, further research is needed to better understand the potential and limitations of this test. For example, although this is a cross curl-up protocol and, consequently, the rectus abdominis (RA) and external and internal oblique (IO) should be primarily responsible for generating the trunk flexion-rotation motions (4, 74, 81, 103), EMG studies on trunk muscle activation and fatigue are lacking. In addition, considering that hip motion can be observed in some individuals during the test, especially at the end of the 90-second execution, further studies should describe the trunk and hip kinematics throughout the protocol, as well as the impact of hip motion on muscle recruitment, spinal loading, and test performance.

Therefore, the aim of this study was to describe the trunk and hip muscle activation and fatigue and the range of hip flexion of the FRT test. The relationships between the test scores and the EMG and kinematic variables were also analyzed to enable a discussion of the validity of this protocol.

2. Methods

2.1. Experimental approach to the problem

Several studies have applied surface EMG as a non-invasive tool to assess trunk muscle activity (39, 97, 110) and fatigue (93, 102, 112, 125, 126). The muscle fatigue process can be observed through a decrease of the frequency content of the EMG signal, usually evidenced as a decline of the mean power frequency (MPF) or the median frequency of the EMG power spectrum (28, 93, 112, 125). The analysis of the EMG signal in the frequency domain is usually performed through mathematical algorithms such as the fast Fourier transform (FFT) to describe the temporal changes in the EMG power spectrum (28, 111).

A limitation of FFT is that it requires stationary EMG signals, since factors such as variation of the muscle tension, length, and contraction velocity during dynamic actions may modify the frequency content of the signal (11, 13). Considering that the FRT test is a dynamic task, participants performed a 6-s isometric trunk flexion-rotation repetition (Figure 8B1 and B2) both just before and just after the test execution (pre- and post-execution repetitions, respectively). In this way, we compared the frequency content of the EMG signals between the isometric pre- and post-execution repetitions to analyze the effect of FRT test performance on trunk and hip muscle fatigue. The EMG signals were also analyzed in the time domain to better understand the function of the trunk and hip muscles in the FRT test. In addition, the EMG analyses were complemented by the quantification of the hip flexion amplitude in the pre- and post-execution repetitions.

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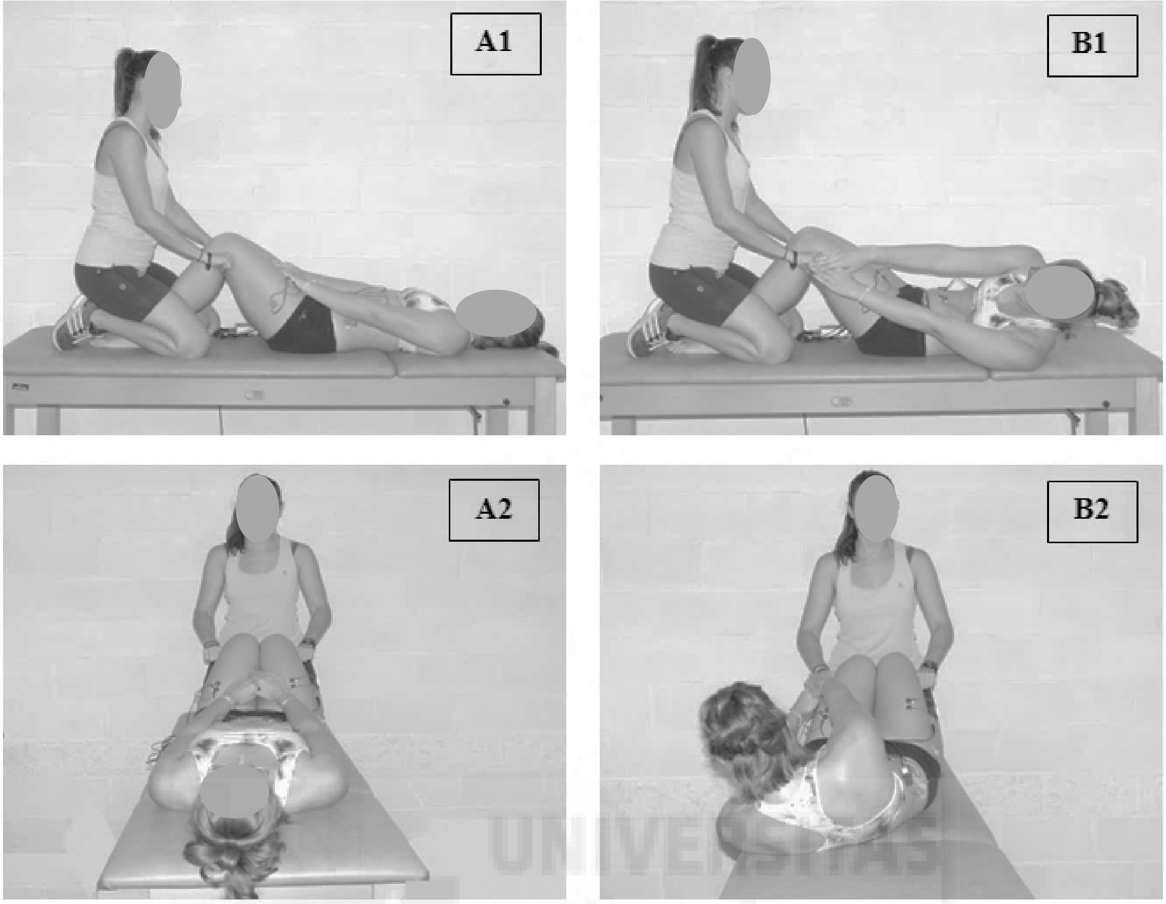

Figure 8. Example of a given participant performing a repetition of the flexion-rotation trunk test: A) participant at the initial position; B) participant at the end of the trunk flexion rotation. It should be noted that the B1 and B2 images also represent the 6-s isometric trunk flexion-rotation repetition (pre- and post-execution repetitions) performed to obtain stationary electromyographic signals.

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2.2. Participants

Twenty-seven volunteers — 16 males (age = 24.67 ± 6.11 years; mass = 76.8 ± 9.11 kg; height = 1.78 ± 0.61 m) and 11 females (age = 21.25 ± 2.8 years; mass = 58.89 ± 6.69 kg; height = 1.66 ± 0.48 m) — participated in this study. They were physically active individuals who participate in several recreational physical activities (jogging, aerobic, resistance exercises, cycling, team sports, etc.) with a 2–4 day workout frequency per week. People with medical problems, such as histories of spinal or hip surgery or episodes of back pain requiring treatment 12 months prior to this study, were excluded. Before testing, the participants were informed of the experimental procedures and potential risks of this study, and they signed an informed consent form based on the Declaration of Helsinki and approved by the University Office for Research Ethics.

2.3. Procedure

As explained before, in the testing session the participants performed the isometric pre-execution repetition (6 s) followed by the FRT test (90 s), and immediately after the end of this test, they performed the isometric post-execution repetition (6 s). Pre- and post-execution repetitions were performed by twisting the upper trunk to the left.

The FRT test has been previously described by Brotons-Gil et al. (16). Briefly, the test consisted in executing the maximum number of trunk flexion-rotation movements possible in 90 s. Prior to testing, each participant was placed in a supine position on a semirigid mat, with legs together, feet placed on the floor, and 90º of knee flexion (Figure 8A1 and A2). The arms were stretched out over the trunk, with the hands resting on the thighs, overlapping, with both thumbs interlocked. A researcher was kneeling at the feet of the participant and held the participant's knees, introducing his thumbs behind them and pressing with his fists on the outer side of the participant's knees. During the test execution, the participant performed trunk flexions with rotation to one side and the other consecutively, starting the protocol to the left side. Only the repetitions performed correctly were counted by the researchers. A correct repetition was considered when the participant touched the knuckle of the little finger of the researcher with his or her fingertips (Figure 8B1 and B2), then returning to the starting position.

Due to the recommendation to perform an extensive familiarization period of the FRT test prior to testing to reduce or avoid learning effect (16), each participant executed the FRT test four times (in four different sessions, separated by one week each) before the testing session.

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Surface EMG signals were collected (at 1000 Hz) from each subject during the pre- and post-execution repetitions using the Muscle Tester ME6000 (Mega Electronics Ltd., Kuopio, Finland). This portable microcomputer has an eight-channel A/D conversion (14 bit resolution), a common-mode rejection ratio of 110 dB, and a band-pass filter of 8–500 Hz. During the recording, the EMG signals were transferred via an optical cable to a compatible computer where they were monitored by Megawin 2.5 program (Mega Electronics Ltd., Kuopio, Finland).

The EMG signals were recorded bilaterally (R = right, L = left) in the following muscles and locations: RA, approximately 3 cm lateral to the umbilicus; IO, the geometric center of the triangle formed by the inguinal ligament, the outer edge of the rectus sheath, and the imaginary line joining the anterior superior iliac spine and the umbilicus; and the rectus femoris (RF), at 50% on the line from the anterior superior iliac spine to the superior part of the patella.

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Pairs of pre-gelled disposable bipolar Ag–AgCl surface electrodes (Arbo Infant Electrodes, Tyco Healthcare, Germany) were positioned parallel to the muscle fibers with an interelectrode distance of 3 cm. Care was taken to guarantee precise electrode placement to assure consistency of the measure. The subject was asked to contract his/her muscles to check the detection of a suitable signal.

Prior to the pre-execution repetition, 3–4 s of maximal voluntary isometric contractions (MVC) were carried out against manual resistance to obtain reference values to normalize the EMG signals. As explained elsewhere (97, 145), for the RA and IO the participant produced 2 sets of maximal isometric trials in trunk flexion, right lateral bend, left lateral bend, right twist, and left twist. For the RF, 2 sets of maximal isometric knee extensions were performed while sitting on a bench with the hip and knee flexed at 90º. A

5-min rest period was allowed between each MVC series and before the pre-execution repetition to avoid muscular fatigue.

The amplitude of the right hip flexion was measured during the pre- and post-execution repetitions using a biaxial electrogoniometer SG-110 (Biometrics Ltd., Gwent, UK) connected to the Muscle Tester ME6000 with a pre-amplifier cable (Mega Electronics Ltd., Kuopio, Finland). Following the technical specifications of the manufacturer, the proximal endblock of the electrogoniometer was attached to the side of the trunk, aligned with the midline of the pelvis, and the distal endblock was attached to the thigh so that axes of the thigh and endblock coincided. Double-sided adhesive tape was employed between the endblocks and the skin, and single-sided adhesive tape was placed over the top of the endblocks.

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2.4. Data processing

The raw EMG signals were visually inspected to eliminate possible artefacts. Then the center 3-s window of the EMG signals recorded in the pre- and post-execution repetitions was selected for further analyses.

Processing of the EMG signals in the time domain

To analyze the function of the RA, IO, and RF during the trunk flexion rotation, the raw EMG signals were full-wave rectified, averaged every 0.01 s, and normalized to maximum EMG values obtained during the MVC (47).

Processing of the EMG signals in the frequency domain

The FFT algorithm (software MegaWin 2.5) was used on the raw EMG data to compare the MPF between the pre- and post-execution repetitions. Muscle fatigue was calculated as the percentage of MPF decrease from the pre- to the post-execution repetition.

Hip flexion amplitude

The right hip flexion amplitude was calculated as the difference of the electrogoniometer signal (in degrees) between the initial position (Figure 8A1 and A2) and the trunk flexion-rotation position (Figure 8B1 and B2). The right hip flexion amplitude was estimated for the pre- and post-execution repetitions, and then the difference in hip flexion between both repetitions was assessed to describe the variations of hip position due to the test execution.

2.5. Statistical analyses

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Descriptive statistics (mean and standard deviation) were calculated for the normalized EMG amplitude (% MVC) of the pre-execution repetition, the MPF decrease (%) from the pre- to the post-execution repetition, the hip flexion amplitude in the pre- and post-execution repetitions, and the difference in hip flexion amplitude between both repetitions. Data normality was examined using the Kolmogorov–Smirnov statistic with a Lilliefors correction.

One-way RMANOVA, with ‘muscle’ (RRA, LRA, RIO, LIO, RFR, and LFR) as a within-subjects factor, was performed to compare the normalized EMG amplitude between muscles in the pre-execution repetition. In addition, two-way RMANOVA, with ‘muscle’ (RRA, LRA, RIO, LIO, RFR, and LFR) and ‘position’ (pre- and post-execution repetitions) as within-subjects factors, was carried out to compare both the MPF between the pre- and post-execution repetitions for each muscle and the percentage of MPF decrease between muscles. Where applicable, post hoc analyses were performed using the

Bonferroni test. Moreover, a paired-samples t-test was used to compare hip flexion amplitude between the pre- and post-execution repetitions.

In order to explore the relationships between the FRT test performance and the EMG and kinematic variables, Pearson correlation coefficients (*r*) were calculated between the FRT test scores and the normalized EMG amplitudes, the MPF decreases from the pre- to the post-execution repetition, the hip flexion amplitudes in the pre- and post-execution repetitions, and the difference in hip flexion amplitude between both repetitions.

The effect sizes (*d*) were also calculated to establish the magnitude of differences between muscles for the amplitude and MPF decrease analyses and for the hip flexion amplitude differences using a standardized mean difference corrected as Hedges' g_s (85). They were categorized following Rhea's (119) contributions, interpreting the values obtained for a recreationally trained sample as $d < 0.35$ (trivial), 0.35–0.80 (small), 0.80–1.50 (moderate), and > 1.5 (large).

The current study considered significant statistical differences when the paired comparisons obtained both an alpha level below 0.05 and the confidence interval of the effect sizes did not cross the zero value (85). All analyses were performed using the SPSS package (version 20, SPSS Inc., Chicago, IL, USA).

3. Results

In the pre-execution repetition, the mean levels of normalized EMG amplitude (Figure 9) of RRA (31.58 ± 12.73% MVC) and LRA (27.78 ± 16.67% MVC) were significantly higher than those of RIO (18.89 ± 11.14% MVC) ($0.01 < p < 0.05$; $0.52 < d < 0.97$), RRF (9.94 ± 7.25% MVC) ($p < 0.001$; $1.04 < d < 1.65$), and LRF (4.28 ± 4.04% MVC) ($p < 0.001$; $1.37 < d < 2.08$). Activation differences between RA (R and L) and LIO (20.69 ± 11.34% MVC) were not found. In addition, the mean levels of RIO and LIO

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activation were significantly higher than those of RRF (*p* < 0.001; 0.78 < *d* < 0.92) and LRF (*p* < 0.001; 1.27 < *d* < 1.40)

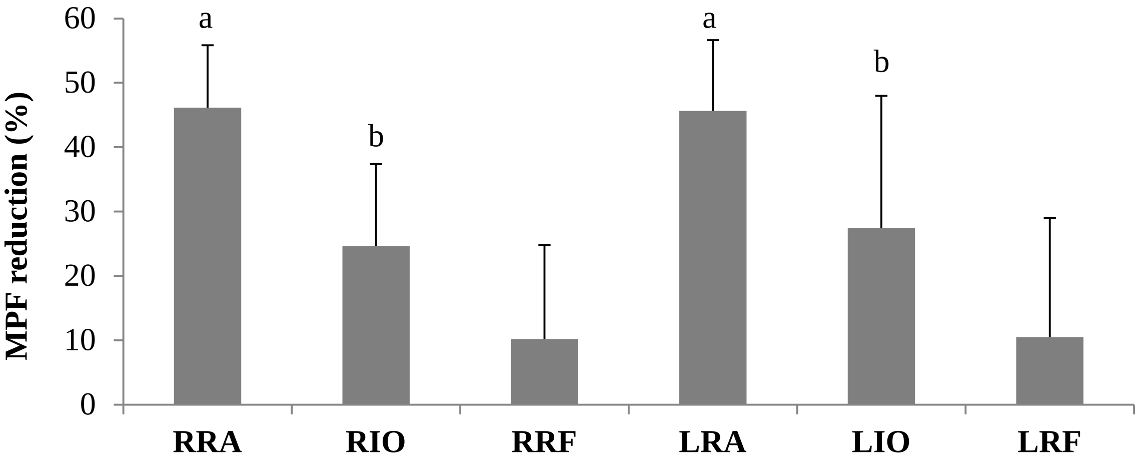

Figure 9. Average and standard deviation of the normalized electromyographic amplitudes of the rectus abdominis (RRA and LRA), internal oblique (RIO and LIO), and rectus femoris (RRF and LRF) during the pre-execution repetition. Post hoc analysis with Bonferroni adjustment and the minimal effect size value obtained were presented for multiple comparisons: ^{a}significant differences compared to RIO, RRF, and LRF (p < 0.05; d > 0.52); ^{b}significant differences compared to RRF and LRF (p < 0.001; d > 0.78).

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Regarding the frequency analysis, a significant reduction of the MPF from the pre- to the post-execution repetition was observed for the abdominal muscles (*p* < 0.001). However, the MPF reductions of RRF and LRF were not significant. The percentage of MPF reduction (Figure 10) was higher for RRA (46.15 ± 9.71%) and LRA (45.7 ± 10.97%) than for RIO (24.66 ± 12.70%) (*p* < 0.001; 1.86 < *d* < 2.15), LIO (27.42 ± 20.57%) (*p* < 0.01; 1.61 < *d* < 1.87), RRF (10.21 ± 14.55%) (*p* < 0.001; 3.14 < *d* < 3.59), and LRF (10.49 ± 18.55%) (*p* < 0.001; 3.11 < *d* < 3.57). In addition, the MPF reduction was higher for RIO and LIO than for RRF (*p* < 0.05; 0.81 < *d* < 1.10) and LRF (0.01 < *p* < 0.05; 0.80 < *d* < 1.08).

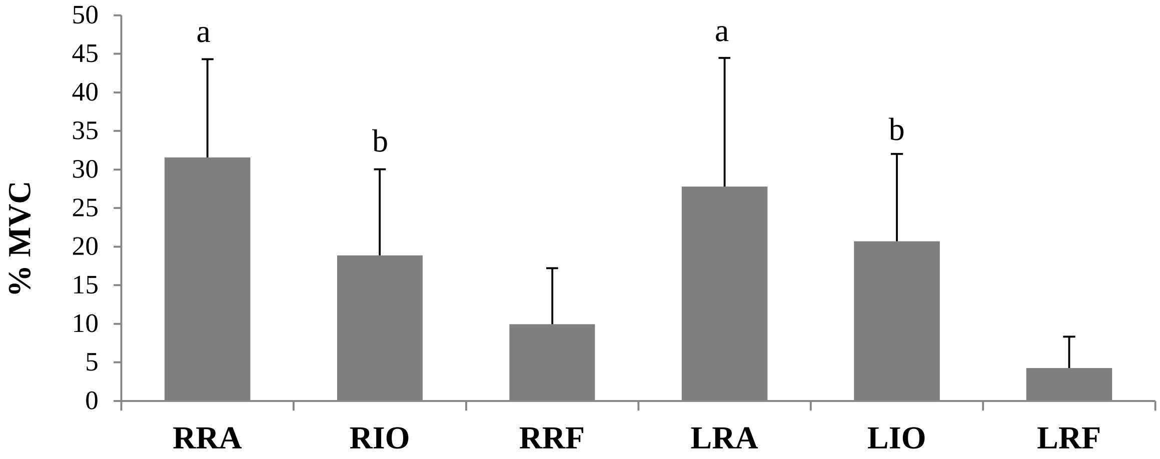

Figure 10. Average and standard deviation of the percentage of mean power frequency reduction from the pre- to the post-execution repetition for the rectus abdominis (RRA and LRA), internal oblique (RIO and LIO), and rectus femoris (RRF and LRF). Post hoc analysis with Bonferroni adjustment and the minimal effect size value obtained were presented for multiple comparisons: [a]significant differences compared to RIO, LIO, RRF, and LRF ($p < 0.01$; $d > 1.61$); [b]significant differences compared to RRF and LRF ($p < 0.05$; $d > 0.80$).

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As Figure 11 shows, the mean levels of hip flexion amplitude in the pre-execution repetition were 7.86 ± 10.73°, which significantly increased up to 14.29 ± 10.55° in the post-execution repetition ($p < 0.001$; $d = 0.58$).

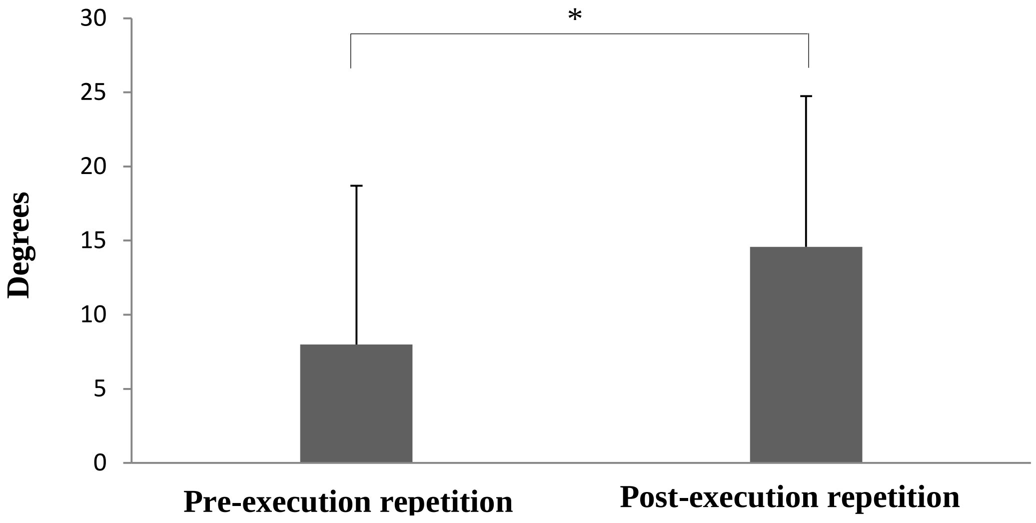

Figure 11. Average and standard deviation of the hip flexion amplitude in the pre- and post-execution repetitions. *Significant differences ($p < 0.001$; $d = 0.58$).

Regarding the correlation analysis (Table 7), significant negative correlations were found between the FRT test scores and the normalized EMG amplitude of RRF and LRF ($p < 0.05$) and between the FRT test scores and the MPF decrease of RRA ($p < 0.05$). On the contrary, a significant positive correlation was found between the FRT test scores and the MPF decrease of LIO ($p < 0.05$).

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Table 7

Correlations between the flexion-rotation trunk test scores and the normalized electromyographic amplitudes, the mean power frequency decreases from the pre- to the post-execution repetition and the hip flexion amplitudes.

	Normalized EMG amplitudes						**MPF decreases**						**Hip flexion amplitudes**		
	RRA	**RIO**	**RRF**	**LRA**	**LIO**	**LRF**	**RRA**	**RIO**	**RRF**	**LRA**	**LIO**	**LRF**	**Pre-**	**Post-**	**Diff**
Test scores	-.227	-.163	-.459*	-.001	-.351	-.383*	-.429*	.245	.144	-.333	.409*	.189	.271	.371	-.311

EMG= electromyographic; MPF= mean power frequency; RRA= right rectus abdominis; RIO= right internal oblique; RRF= right rectus femoris; LRA= left rectus abdominis; LIO= left internal oblique; LRF= left rectus femoris; Diff= difference in hip flexion amplitude between the pre- and the post-execution repetition.

*signification = $p < 0.05$.

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4. Discussion

Although trunk muscles are involved in a great number of twisting activities, to the best of our knowledge, the FRT test is the only trunk endurance protocol that involves trunk twisting. Since the information about this test is limited, this study analyzed the trunk and hip muscle activation and fatigue and the hip flexion amplitude of the FRT test.

The FRT test is a timed protocol based on the repetition of cross curl-up movements while lying supine. As it has been previously shown in the literature (4, 74, 81, 103), the abdominal muscles are the agonists of these trunk flexion-rotation actions, especially the RA. In this way, our data showed higher levels of normalized EMG amplitude for the abdominal muscles (mainly for the RA) than for the RF (Figure 9). In addition, the significant reduction of the MPF from the pre- to the post-execution repetition indicated the fatigue of the abdominal muscles after the test execution. Thus, the percentage of MPF reduction was higher for the RA (about 45–46%), followed by the IO (about 24–27%) and the RF (about 10%) (Figure 10). Interestingly, the correlational analysis found significant associations between higher FRT test scores and both lower MPF reduction of RRA (i.e. lower fatigue) and higher MPF reduction of LIO (i.e. higher fatigue) (Table 7). Although the RA is the main agonist of the trunk flexion-rotation motions (i.e. reached the highest activation levels and the highest MPF reductions), those participants who increased the participation of the oblique muscles during the protocol could produce a more efficient activation pattern, which delayed RA fatigue and increased the test score. In this sense, previous studies have demonstrated that varying the contribution of the agonist muscles can delay the progression of muscle fatigue (1, 82).

Although each trunk flexion-rotation repetition involved an average 8–14º hip flexion (Figure 11), the RF activation was lower than 10% MVC in the pre-execution repetition, and no significant MPF reduction was found from the pre- to the post-execution

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repetition (Figures 9 and 10). Nevertheless, hip flexion and RF EMG variables presented high variability between participants (Figures 9, 10, and 11), indicating that while most participants did not flex the hip noticeably during the trunk flexion-rotation repetitions, some of them needed to perform a significant hip flexion to touch the researcher’s fist during each repetition (mainly at the end of the test execution). These differences between participants could be due to differences in spine and/or shoulder flexibility, arm length, etc., and they could have an impact on test performance. In this way, the correlational analysis found that those participants who presented higher RF activation obtained lower FRT test scores (Table 7), as more hip flexor activation leads to a more fatiguing exertion (73). Trunk field tests do not need expensive or sophisticated equipment, but they are affected by participants’ body characteristics (e.g. body weight and height) (72). Future studies should analyze the effect of body anthropometry and trunk and shoulder flexibility on FRT test performance.

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5. Practical Applications

Based on the main role of the RA and IO in the execution of the FRT test and the effect of test execution on abdominal muscle fatigue, this trunk flexion-rotation protocol seems valid to assess abdominal muscle endurance. While most curl-up protocols are performed in the sagittal plane (45, 79), the FRT test combines trunk flexion with rotation, which may be relevant to rotation-related sports. In addition, it does not require expensive equipment or sophisticated data processing and is easy to employ in groups of people. However, some considerations must be taken into account for its proper use. For example, as Brotons-Gil et al. (16) showed, an extensive familiarization period of the FRT test is necessary for participants to learn the protocol appropriately (technique, cadence, etc.). In this sense, participants should be instructed to avoid sudden accelerations/decelerations and to control the lower limb and pelvis position during the test execution to minimize hip flexion while performing each flexion-rotation repetition. In addition, performing the FRT test on a non-slip surface may facilitate the control of the pelvis position and avoid the hip flexion increase throughout the test.

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CHAPTER 6

EPILOGUE

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CHAPTER 6

EPILOGUE

6.1. Conclusions

The studies included in this doctoral thesis provide two new protocols to assess trunk muscle performance in healthy and physically active populations: 1) an isokinetic trunk flexion–extension protocol to simultaneously assess trunk muscle strength and endurance; and 2) a timed field test to measure trunk flexion-rotation endurance (FRT test).

The first and second studies analyzed the reliability and the learning effect of both protocols, as well as the effect of the participants' sex on the test scores and reliability. On the other hand, the third study described the RA, IO and RF activation and fatigue and the range of hip flexion of the FRT test. Overall, the three studies provide information about some of the most important characteristics of the aforementioned protocols, which could facilitate the use and interpretation of their results.

The following summarizes the major contributions of this thesis:

Study 1:

1. The isokinetic trunk flexion–extension protocol is a 10 min test which allows to perform a reliable muscle strength and endurance evaluation of trunk flexor and extensor muscles, all within the same protocol.
2. Based on the good relative and absolute reliability results obtained for all isokinetic strength variables, any of them could be used to assess trunk muscle strength in physically active young males and females.
3. Regarding the isokinetic endurance variables, ER and MER showed the best reliability results, mainly in the extension direction, and overall in males.

4. Significant improvements in strength and endurance variables were not found across testing sessions, suggesting that only one session is enough to assess trunk muscle strength and endurance in males and females.

Study 2:

5. The FRT test showed a high relative and absolute reliability in physically active young males and females. The reliability increased with test practice.
6. Significant increases in FRT test scores across testing sessions showed the learning effect of this protocol. Based on the between-session comparison, at least three trials of practice are needed to make learning effect negligible.
7. Males showed higher FRT test scores than females, as well as a higher learning effect, especially in the first two testing sessions.

Study 3:

8. RA showed the highest mean activation levels (about 30% MVC) in the pre-execution repetition, followed by IO (about 20% MVC). In addition, the mean power frequency of the EMG spectrum significantly decreased from the pre- to the post-execution repetition for RA and IO, which showed the abdominal muscle fatigue after test execution.
9. Although each trunk flexion-rotation repetition involved an average 8–14º hip flexion, the RF activation was lower than 10% MVC, and no significant RF mean power frequency reduction (i.e. no muscle fatigue) was observed. Additionally, significant negative correlations were found between the FRT test scores and the RF activation.
10. Based on the results of this study, the FRT test is a valid field protocol to assess abdominal muscle endurance in trunk flexion-rotation exertions.

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6.2. Conclusiones

Los estudios incluidos en esta tesis doctoral proporcionan dos nuevos protocolos para valorar la condición física de los músculos del tronco en poblaciones sanas y físicamente activas: 1) un protocolo isocinético de flexo-extensión del tronco para medir simultáneamente fuerza y resistencia muscular; y 2) un test de campo cronometrado para medir la resistencia abdominal en movimientos de flexo-rotación del tronco (FRT test). Los dos primeros estudios analizaron la fiabilidad y el efecto de aprendizaje de ambos protocolos, así como el efecto del sexo de los participantes sobre el rendimiento en los tests y su fiabilidad. Por otro lado, en el tercer estudio se describió la activación y la fatiga de los músculos RA, IO y RF y el rango de flexión de cadera en el FRT test. En general, los tres estudios proporcionan información sobre algunas de las características más importantes de los protocolos referidos, lo que podría facilitar el uso e interpretación de sus resultados.

A continuación se presentan las principales aportaciones de esta tesis doctoral:

Estudio 1:

1. El test isocinético de flexo-extensión del tronco es un protocolo de 10 min que permite valorar simultáneamente y de forma fiable la fuerza y la resistencia de los músculos flexores y extensores del tronco.
2. Teniendo en cuenta los buenos resultados de fiabilidad relativa y absoluta obtenidos por todas las variables de fuerza isocinética, cualquiera de ellas podría ser usada para valorar la fuerza de los músculos del tronco en hombres y mujeres jóvenes y físicamente activas.
3. La ratio de resistencia y la ratio de resistencia modificada mostraron los mejores resultados de fiabilidad de las variables de resistencia isocinética, principalmente en los movimientos de extensión y en hombres.

4. No se encontraron incrementos significativos en las variables de fuerza y resistencia a lo largo de las sesiones de registro, lo que indica que una única sesión es suficiente para valorar la fuerza y resistencia de los músculos del tronco en hombres y mujeres.

Estudio 2:

5. El FRT test mostró una alta fiabilidad relativa y absoluta tanto en hombres como en mujeres jóvenes y físicamente activas. La fiabilidad mejoró con la práctica del test.
6. Incrementos significativos en los resultados del FRT test a lo largo de las diferentes sesiones de registro mostraron el efecto de aprendizaje de este protocolo. Según los resultados de la comparación entre sesiones, se necesitan al menos tres ensayos del test para eliminar el efecto de aprendizaje.
7. Los hombres mostraron mejores resultados que las mujeres en el FRT test, así como un mayor efecto de aprendizaje, sobre todo en las dos primeras sesiones de registro.

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Estudio 3:

8. El RA mostró los mayores niveles de activación media (sobre 30% MVC) en la repetición pre-ejecución, seguido por el IO (sobre 20% MVC). Además, la frecuencia media del espectro de frecuencias de la EMG descendió de la repetición pre- a la repetición post-ejecución para el RA y el IO, mostrando la fatiga de los músculos del abdomen tras la ejecución del test.
9. Aunque en cada repetición de flexo-rotación del tronco se produjo una flexión de cadera de unos 8-14º de amplitud, la activación del RF fue menor del 10% MVC y no se produjo una reducción significativa de la frecuencia media del RF (es decir, no se observó fatiga muscular). Además, se encontraron correlaciones negativas y significativas entre los resultados del FRT test y la activación del RF.

10. En función de los resultados de este estudio, el FRT test es una prueba de campo válida para valorar la resistencia de los músculos del abdomen en acciones de flexo-rotación del tronco.

6.3. Study limitations and future research

Most limitations of this doctoral thesis have been addressed in the discussion section of each of the three studies (chapters 3, 4 and 5). In addition, this section presents several limitations which have been the origin of new research projects in the Biomechanics and Health Laboratory of the Sports Research Center of Miguel Hernandez University of Elche. Briefly, the new research purposes are the following:

1. *To evaluate the applicability of the protocols developed in this doctoral thesis to different populations.* Due to the high physical demands of the isokinetic trunk flexion–extension protocol (e.g. high angular velocity, maximal exertion, etc.) and the FRT test (e.g. high trunk flexion-rotation speeds and accelerations), they have only been used in healthy and physically active young populations in this doctoral thesis. Therefore, the results obtained in these studies cannot be generalized to other populations. Additionally, our research group has also used the isokinetic protocol to assess trunk muscle performance in high-level judokas, showing the sensitivity of this protocol to discriminate between national and international level judokas (7). However, future research should explore the applicability of these protocols to other high-performance athletes, as well as to untrained people, different age groups (older people, adolescents, etc.) and individuals with low back disorders.

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2. *To perform several protocol modifications to improve the reliability of both tests.* Although both protocols achieved good reliability values, a few protocol adjustments may increase the reliability of some variables. For example:
    a) Regarding the isokinetic trunk flexion-extension protocol, although the participants were instructed to perform the maximum effort from the beginning of the first set, some participants did not show a drop-off in work performance (maybe due to a conservative strategy at the beginning of the test), affecting the reliability of some endurance variables. Future research should assess the effect of reducing the number of sets and increasing the number of repetitions per set (e.g. performing only one set of 30 maximal repetitions), and of increasing the encouragement from the beginning of each set, on the endurance variable reliability.
    b) In relation to the FRT test, as one of the objectives was to explore the learning effect of this protocol, participants were not instructed about the most efficient performance cadence, neither encouraged during test execution. Future studies should assess the influence of modifying the instructions given to the participant during the familiarization period (e.g. recommendations about the performance cadence and technique), and of encouraging participants during the execution, on the learning effect of the FRT test.

3. *To examine the possible relationships between the variables of the new protocols.* The characteristics of the protocols presented in this doctoral thesis have been analyzed separately; however, the relationships between the variables obtained in both protocols, and between these variables and others obtained in the most widespread trunk muscle performance protocols, have not been investigated. Currently, our research group is carrying out a study which aims to examine the

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relationships between the isokinetic trunk flexion-extension protocol, the FRT test, and the Biering-Sorensen test.

4. *To analyze the effect of the participant's anthropometry on FRT test performance.* As our research group has already showed (72), the anthropometry characteristics of the participants (body mass, biileocrestal diameter, biacromial diameter, etc.) may have a significant effect on trunk field test scores, since the participants' body is used as the measuring instrument to perform the assessment. Further researcher is needed to assess the influence of participants' arm-span, upper-trunk weight, and/or other anthropometry characteristics on the FRT scores.

5. *To use the results obtained in both protocols as pre-training values to quantify and individualize the trunk training load.* As most studies on trunk muscle performance tests, the three studies presented in this doctoral thesis are descriptive, rather than experimental. Future experimental studies should analyze the effect of different training methodologies based on the outcomes of the isokinetic trunk flexion-extension protocol and the FRT test on trunk muscle performance. In this sense, our research group has already performed a study (73) in which the scores of the Bench Trunk-Curl test were used to individualize the number of repetitions performed in each exercise during an abdominal endurance training program. Using this methodology, a single training session per week was enough to increase trunk flexor endurance in adolescents without experience in trunk training programs. In addition, our research group is currently performing a project to develop new methodologies to quantify and individualize the trunk training load.

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