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Criterion-Related Validity and Reliability of the Front Plank Test in Adults: The ADULT-FIT Project

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Featured Application: Findings from this study highlight the Front Plank Test (FPT) as an ideal and accessible tool for assessing trunk muscle strength across diverse age groups and sexes. The FPT is distinguished by its simplicity, low cost, minimal space, and lack of specialized equipment, while providing reliable measurements of trunk muscle strength. Additionally, the results emphasize the importance of maintaining low body fat and trunk fat mass, especially in females and adults, to achieve optimal FPT performance times.

Abstract: Background: the validity and reliability of the front plank test (FPT) have been studied in young adults but not in adults aged 34 to 60 years. The aim of this study was to analyze the criterion-related validity and reliability of the front plank test (FPT) for evaluating trunk musculature in adults according to sex and age groups. Methods: a repeated measures design was used to study the reliability of the FPT. A total of 84 adults aged 18–62 years performed trunk muscular force tests and the FPT. Criterion-related validity was assessed using repeated measures ANOVA. Reliability was examined by ICC, error measurements, and Bland–Altman analysis across sex and age groups. Results: significant differences in the activation of the rectus abdominis and external oblique muscles were found compared with the erector spinae and multifidus muscles ($p < 0.001$). No correlations were found between FPT time and physical activity or rate of perceived exertion at the end ($p > 0.05$). Low and moderate correlations were found with body fat percentage, trunk fat mass percentage, and external oblique, regardless of sex and age groups ($p < 0.05$). Extremely high reliability was found regardless of sex and age groups (ICC > 0.98), with low error measurements (RMSE = 11.93–18.73; %CV = 4.91–6.33; SEE = 11.45–16.84). MDC90 values indicated no real change between T1 and T2. Conclusion: FPT is a valid and reliable test for assessing trunk musculature in adults regardless of sex and age groups.

Keywords: trunk; field-based physical fitness test; reproducibility; electromyography

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1. Introduction

The trunk musculature comprises abdominal wall muscles located in the abdomen, such as the rectus abdominis, which is responsible for trunk flexion, and the transverse abdominis, which primary functions to increase intra-abdominal pressure and provide spinal stability. The rotator muscles, such as the internal and external oblique, are responsible for trunk rotation, while the extensor muscles, including the multifidus, paravertebral, and quadratus lumborum muscles, contribute to trunk extension [1,2]. Studies have demonstrated the importance of trunk musculature in health and performance. Related to health, the focus has been on improving spinal stability and thus reducing pain in patients with low back pain [3]. Concerning performance, it has been related to the transfer of forces in sports gestures involving kinetic chains, such as handball throwing or tennis serving [4,5].

Assessment of trunk musculature has been performed using diverse methodologies [6–8], with isokinetic devices being the gold standard [9,10]. This method assesses the isometric and isokinetic strength of trunk muscles in different positions depending on the device type [11]. These tests have high validity and reliability [12]; however, they require specific equipment, learning, and familiarization with the measuring device, are expensive, have low portability, and have space limitations [13,14]. An alternative to laboratory tests is field-based fitness tests, in which the objective is to assess the trunk musculature without the need to use a specific device or equipment. Field-based fitness tests are cost-effective and do not require much familiarization [15].

Several field-based fitness tests have been used to assess trunk musculature [16,17]. One of these tests is the front plank test (FPT), which is not only a test to assess trunk musculature but is also one of the most used exercises in training [18]. Additionally, various studies have used the FPT in CrossFit contexts to analyze muscle function and evaluate the endurance of core-stabilizing muscles [19,20]. A recent systematic review found that only one study examined the criterion-related validity of the FPT among young adults, with limited validity. The study included in the systematic review analyzed the validity in healthy young adults, providing validity to the FPT with surface electromyography (sEMG) of muscle activation [21]. However, other studies, instead of using a gold standard such as electromyography or isokinetic devices, have attempted to validate this test using variables such as physical activity level, body composition variables, and relating it to similar exercises such as the modified V-sit [17,22,23]. Therefore, more studies are needed to examine the criterion-related validity of this test in other age ranges and populations [24]. Moreover, reliability has been studied in children (8 to 12 years), young adults (18 to under 34 years), and older adults (60 to 79 years) but not in adults ranging in age from 34 to 60 years [17,22,25,26]; a recent systematic review showed a moderate reliability in this test in young adults [27].

Considering the above, it is necessary to study the criterion-related validity and reliability of the trunk musculature assessment in adults. Therefore, the aims were to analyze the criterion-related validity and reliability of the FPT for evaluating trunk musculature in adults according to sex and age groups. We hypothesized that FPT can demonstrate high criterion validity and reliability for assessing trunk musculature in adults.

2. Materials and Methods

2.1. Study Design

A repeated measures design was used to study the reliability of the FPT. The present study is part of a national project, the ADULT-FIT study (DEP2017-88043-R), whose main aim was to propose a field-based physical fitness test battery related to health based on their criterion-related validity, predictive validity, reliability, feasibility, and safety for use in adults. Electromyography activation of the trunk musculature during the FPT and force in isokinetic device was measured to analyze criterion-related validity.

2.2. Participants

A total of eighty-four participants were included in the study (28.16 ± 12.32 years, 68.83 ± 11.13 kg; 1.71 ± 0.10 m, and 23.31 ± 2.31 kg/m^2). Participants were categorized based on sex (male (62%) and female ((38%)) and age groups (young adults, 18 to under 34 years) and adults (34 to 62 years) (Table 1), and they were instructed to maintain their habitual dietary and lifestyle habits throughout the assessment period. No specific nutritional control was applied, nor were restrictions imposed on the menstrual cycle phases for female participants. In addition, participants who had any musculoskeletal injury that prevented them from performing the assessment or any specific spinal injury were excluded from the study. Participants were asked not to perform specific strength training the day before the assessment. All participants were informed of the nature, aims, and risks associated with the experimental procedure before providing written informed consent. The study protocol was approved by the Institutional Review Board of the University of Cadiz (COD: 28-6/2019) and was conducted following the Declaration of Helsinki.

Table 1. Descriptive characteristics of the sample and differences according to sex and age groups.

	Total (n = 84)	Male (n = 52)	Female (n = 32)	Young Adults (n = 64)	Adults (n = 20)
Age (years)	28.16 ± 12.32	24.37 ± 8.75	34.31 ± 14.75 ***	21.84 ± 3.02	48.35 ± 8.37 ***
Weight (kg)	68.83 ± 11.13	74.77 ± 8.14	59.18 ± 8.20 ***	69.53 ± 11.12	66.60 ± 11.11
Height (cm)	1.71 ± 0.10	1.77 ± 0.07	1.62 ± 0.07 ***	1.72 ± 0.1	1.67 ± 0.08 *
BMI (kg/m^2)	23.31 ± 2.31	23.80 ± 2.25	22.51 ± 2.21 *	23.14 ± 2.11	23.84 ± 2.84
Waist circumference (cm)	76.40 ± 7.12	79.23 ± 5.91	71.80 ± 6.56 ***	75.71 ± 6.26	78.58 ± 9.22
Level of physical activity (d/w)	4.01 ± 1.42	4.33 ± 1.23	3.50 ± 1.57 **	4.19 ± 1.32	3.42 ± 1.61 *
Body fat (%)	19.59 ± 6.64	16.13 ± 3.81	25.10 ± 6.49 ***	17.93 ± 5.16	25.15 ± 8.08 ***
Lean Mass (kg)	52.44 ± 9.98	59.21 ± 5.08	41.63 ± 5.07 ***	54.07 ± 9.31	46.93 ± 10.42 **
Trunk Fat-free mass (kg)	29.82 ± 4.78	32.72 ± 2.86	25.20 ± 3.39 ***	30.45 ± 4.42	27.71 ± 5.44 *
Trunk Fat Mass (%)	19.26 ± 6.52	18.69 ± 4.73	20.17 ± 8.67	17.99 ± 5.87	23.54 ± 6.98 ***
Lean Trunk Mass (kg)	28.41 ± 4.57	31.18 ± 2.75	23.99 ± 3.22 ***	29.91 ± 4.24	26.38 ± 5.17 *

Data are presented as mean ± standard deviation. BMI = body mass index; d/w = days per week; kg = kilograms. The variables were compared by sex and age. Significance level * $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$.

2.3. Procedures

All test sessions were conducted in the Physical Activity and Sport laboratory of the University of Cadiz (Cadiz, Spain). Participants came to the laboratory on two different days (one week apart). On the first day, participants completed a questionnaire to determine their physical activity and injury history. Subsequently, body composition was measured, after which a warm-up was performed. The warm-up included general mobility exercises such as supine low back rotation, cat-camel, quadruped thoracic rotation, and cobra lift. Additionally, specific trunk muscle activation was performed, consisting of 3 sets of 20 s of work and 20 s of rest for front plank, and 1 set of 10 repetitions for the gluteal bridge. Once the warm-up was completed, all sensors were placed, and the maximum voluntary isometric contraction (MVIC) was performed for each muscle. Subsequently, FPT was performed. After a complete rest (5–7′), the force of the trunk musculature was measured on the isokinetic device. In the second session, the participant performed the same warm-up and the FPT was assessed without sEMG. All assessments were performed by two assessors (AR-P and JC-P), who were experienced with the measuring device (Humac Norm, CSMi, Stoughton, MA, USA), at the same time of day (±1 h) for each participant and in similar environmental conditions (∼21 °C and ∼60% humidity).

2.3.1. Physical Activity Levels

Participants were initially classified as active or non-active when following or not following World Health Organization recommendations for adults [28]. The following self-reported question was asked: How many days (in a typical week) do you practice physical activity/exercise or some sport, of at least moderate intensity, lasting at least 60 min per day?

2.3.2. Body Composition

Weight, height, and waist circumferences were measured using the protocol described by the International Society for the Advancement of Kinanthropometry [29]. Measurements were performed by trained evaluators (SS-P and PA-A) of the same sex as the participants.

All measurements were performed with bare feet, light sports clothing, and a 3-h fast. Weight was measured using an OMRON BF-400 electronic scale (Omron Healthcare Europe BV, Hoofddorp, The Netherlands; sensitivity, 100 gr). The established margin of error for which a third measurement should be performed was 1 kg. Height was measured using a TANITA HR001 portable height rod (Tanita®, Arlington Heights, IL, USA; sensitivity, 1 mm). The margin of error that was established to make a third measurement was 1 cm. Body mass index (BMI) was calculated as weight (kg) divided by the squared height (m^2). Waist circumferences were assessed using a tape measure with SECA 201 (Seca Int, Hamburg, Germany; range, 0–205 cm; sensitivity, 0.1 cm). The percentage of body fat (%BF), lean mass (kg), trunk fat-free mass (kg), the percentage of trunk fat mass (%TFM), and lean trunk mass (kg) were determined by bioimpedance Tanita MC 780-P MA (Tanita Co., Guangzhou, China), according to the protocol described by the National Institute of Health (NIH) [30]. For the correct evaluation, the participants were asked about their hydration level [31].

2.3.3. Front Plank Test

The starting position of the test was with the knees, toes, and elbows resting on the floor. The test started when the participant lifted his/her knees off the ground and only had contact with the tips of their toes and elbows. Both feet had to be together, and the palms of the hands had to be in contact with the floor. Participants were instructed to face the floor to maintain a neutral cervical curvature and to maintain a straight line between the lateral acromion, greater trochanter, and malleolus. The forearm was angled at 90° to the upper arm and the hands were placed at shoulder width. The participant was asked to maintain the front plank position for as long as possible [17,32]. A measuring rod was placed on each side of the participant, held together by an elastic band. The elastic band was used to provide direct feedback when the participant lost the correct position. The elastic band was placed 3 cm below the iliac crests (Figure 1). When the participant first contacted the elastic band, the assessors gave a verbal warning to the participants to recover the correct position. The test was completed after the participant contacted the tape a second time. The test time was monitored with a hand-held stopwatch (Casio HS-EV-1RET Digital, Casio, Tokyo, Japan) by two assessors (MC-G and CC-L). The rate of perceived exertion (RPE) was measured at the end of the test using a self-perception Borg scale (0 to 10 points) [32].

Figure 1. Set up of the front plank test.

2.3.4. Isokinetic and Isometric Test

First, the participants familiarized themselves with the device through a series of 5 consecutive repetitions of submaximal trunk flexion and extension at 120°/s over a range of 55°. Each repetition started from the trunk extension position −10° and ended at 45° of flexion. After familiarization and 3-min rest, the participants performed 15 repetitions of maximal concentric trunk flexion and extension at 120°/s [33,34]. After 5 min rest, all participants performed 2 flexors isometric test trials of 6 s duration with 3-min rest between sets. The position for the isometric assessment was neutral (0°). The trunk strength was measured using the Humac Norm 776 device (CSMi, Stoughton, MA, USA) and calibrated according to the operation manual. During the test, the participants were placed in a bipedal position. The axis of rotation of the dynamometer was aligned over the iliac crests and L5/S1. The scapula and back grips were adjusted for each participant, and the feet were placed in a fixed position on the floor of the dynamometer shoulder-width apart. The knee, tibial grip, and the hip belt helped to secure the participants correctly and minimize the involvement of the lower body musculature during the test.

2.3.5. Electromyography

To quantify muscle activity, sEMG data were acquired using the Trigno Wireless System (Delsys, Natick, MA, USA) and the Trigno Avanti Sensor (Delsys, Natick, MA, USA), with a sample rate of 1950 Hz for the EMG signal and 148 Hz for the accelerometer. Before sensor application, the skin was carefully shaved, abraded, and cleansed with alcohol. Following the surface EMG for the Non-Invasive Assessment of Muscles (SENIAM) recommendations, electrodes were placed on the upper (2 cm above the umbilicus) and lower (2 cm below the umbilicus) regions of the rectus abdominis (URA and LRA, respectively); the external oblique (EO) (lateral to the rectus abdominis and directly above the anterosuperior iliac spine, midway between the ridge and the ribs at a slightly oblique angle); the multifidus (MF) (aligned with a line from the caudal tip of the posterior superior iliac spine to the space between L1 and L2 at the level of the L5 spinous process, i.e., about 2–3 cm from the midline); and the longissimus subdivision of the erector spinae (ES) (two fingers width lateral to L1) on the dominant side [26]. Notably, for sensor placement in muscles not specified in the SENIAM protocol, the locations recommended in the study by Calatayud et al. (2019) were followed [35].

The sEMG signals from each electrode were amplified with an input impedance of 120 kΩ, a signal-to-noise ratio of 750, and an inter-electrode distance of 40 mm. The gain range was set between 500 to 5000. Surface electrodes were connected by WI-FI to the

Trigno Base Station and streamed continuously to a computer through an analogue-to-digital converter (G-42, HP notebook computer, Palo Alto, CA, USA). The sEMG data were managed using EMGworks® software (Delsys 4.1.7, Natick, MA, USA). All data were centered and filtered with a second-order IIR Butterworth filter with a 10 Hz high-pass and a 500 Hz low-pass.

To assess the sEMG recorded during testing, the root mean square (RMS) was utilized. A 60 ms moving window was used to calculate the data, and the onset and end of muscle contraction were identified through data analysis. The RMS was evaluated following previous recommendations [36].

$$RMS = \sqrt{\frac{1}{n}\sum_{n} x_{n}^{2}}$$

where Xn is the value of the sEMG signal and n is the sample number. During muscle contraction, sEMG activity was recorded and coupled with an accelerometer to detect the onset and end of the contraction. To achieve this, a sensor was placed on the knee, and behavior analysis of the acceleration signal was conducted in a pilot session before testing sessions. A distinct initial peak was observed at the beginning of the test, corresponding to the start of muscle contraction. The onset was visually identified as an increase in the amplitude of the acceleration signal above the baseline. Another peak was observed at the end of the test, indicating the end of contraction. Each RMS sEMG data were expressed as a percentage of the MVIC [37]. The reliability of these measures was previously established [36].

To perform MVIC, a partial curl was executed for the RA (Figure 2A), a lateral plank for the EO (Figure 2B), and trunk extension for the MF and ES muscles (Figure 2C). During these exercises, an assessor applied counter-resistance to achieve the maximum voluntary contraction of the muscles involved [38,39].

2.4. Statistical Analyses

The normal distribution of all data series was verified with the Shapiro–Wilk test ($p > 0.05$). Means ± standard deviations were calculated for all variables. A paired-sample *t*-test was used to determine the differences between sex and age group (young adults from 18 to under 34 years, and adults from 34 to 62 years) in all variables.

The sample size was determined using G*Power 3.1, considering the statistical analyses required for validity and reliability assessments. A bivariate correlation analysis (Pearson's correlation) was selected, with an expected moderate effect size (r = 0.30), a significance level (α) of 0.05, and a power (1-β) of 0.80, requiring a minimum of 67 participants.

2.4.1. Criterion-Related Validity

The means ± the standard deviation of the normalized EMG data for the trunk muscles were calculated. One-way repeated measurement analysis of variance (ANOVA) was utilized to determine the difference in the EMG data of the trunk muscles (URA, LRA, EO, MF, and ES). If a significant difference was detected between the muscles, post hoc analysis using Holm–Sidak's multiple comparison test was performed.

A Pearson's bivariate correlation was calculated to quantify the association between FPT and physical activity, body composition, RPE at the end, muscle activation, and force in the isokinetic device. When significant, the strength of the correlations was classified as follows: 0.00–0.25, very low; 0.26–0.49, low; 0.50–0.69, moderate; 0.70–0.89, high; and 0.90–1.00, very high [40].

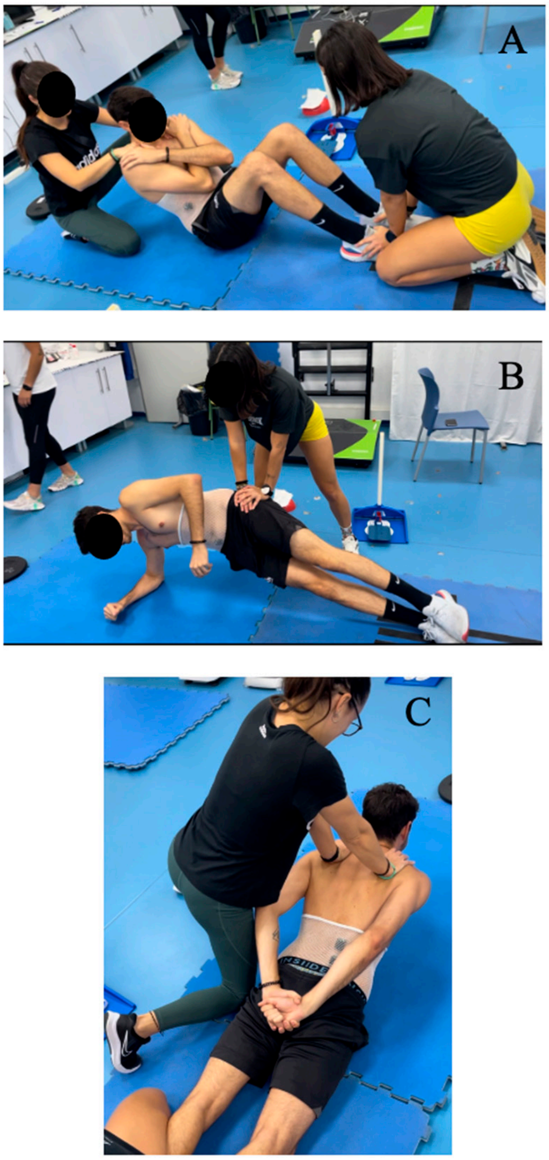

Figure 2. Exercises performed for maximal voluntary isometric contraction of (**A**) upper and lower rectus abdominis, (**B**) external oblique, and (**C**) erector spinae and multifidus.

2.4.2. Reliability

The relative reliability of the field FPT was investigated through a t-test and intraclass correlation coefficient (ICC). Following Hopkins et al. (2009), we classified the magnitude of the values of the ICC through a qualitative scale: values close to 0.1 are considered low reliability; 0.3, moderate; 0.5, high; 0.7, very high; and those close to 0.9, extremely high [40]. We also examined the differences between test and retest (hereafter called T1 and T2) using different error measures. Generally, the lower the error value, the lower the dispersion between T1 and T2 measurements. The sum of squared errors (SSE) was calculated as follows: SSE = $\sum_{i=1}^{N}(yi - \hat{y})^2$, where n is the cases to evaluate the error measurements, $\hat{y}$ is the T2, and y is the T1. The mean sum of squared errors (MSE): MSE = $\frac{1}{N}\sum_{i=1}^{N}(yi - \hat{y})^2$. The root mean sum of squared errors (RMSE) was calculated by converting MSE into domain units by taking the root square: RMSE = $\sqrt{MSE}$. The percentage error was calculated as follows: %Error = $\frac{RMSE}{y_{max}-y_{min}} \times 100$.

The following methods were used to study absolute reliability: standard error of measurement (SEM) as a percentage of the mean value of the measurements, standard error of estimate (SEE), the coefficient of variation (CV), and Bland–Altman plots [41,42], whose difference was calculated using an ANOVA test for repeated measures. These measures were calculated as follows: %SEM = mean of the difference scores between 2 trials × 100/mean of the first trial, with a value of SEM ≤ 15% considered acceptable [43]; SEE = $SD\hat{y}\sqrt{(1 - R^2 y\hat{y})}$; CV = $\frac{\delta}{\underline{X}}$ × 100, with a CV ≤ 10% considered acceptable [44]. In addition, the CV method provides useful information in the presence of heteroscedasticity (assumes that the greatest T1 and T2 variation occurs in individuals scoring the highest values in the test). Heteroscedasticity of errors was also identified in the Bland–Altman plots and was defined as a coefficient of determination (r^2) > 0.1. To estimate the smallest change in score that indicates a "real change" in 90% of participants, the minimal detectable change (MDC_{90}) [45] was calculated; MDC_{90} = SEM × $\sqrt{2}$ × 1.65.

Finally, Cohen's *d* was computed to quantify the magnitude of the difference between T1 and T2. The scale used for interpreting the magnitude of the ES was specific to training research: negligible (<0.2), small (0.2–0.5), medium (0.5–0.8), and large (≥0.8) [46]. The analyses were conducted for the whole sample, and separately by sex and age for all criterion-related and reliability analyses. All the analyses were performed using the Statistical Package for Social Sciences (IBM SPSS Statistics for Windows, version 26.0; Armonk, NY, USA) and the level of significance was set at $p < 0.05$.

3. Results

Finally, eighty-four participants and eighty-two participants were tested in the criterion-related validity and reliability analyses, respectively. Two participants could not attend the second session; thus, their data were only analyzed in the FPT criterion-related validity analysis. Table 1 shows the descriptive characteristics of the sample and the difference according to sex and age groups. The mean age of the sample was 28.16 ± 12.32 years old. Regarding sex, males had higher body composition values than females (all, $p < 0.01$), except for %BF, which was higher in females ($p < 0.001$). Non-significant differences were found in trunk fat mass (%) ($p = 0.32$) and FPT time ($p = 0.24$). Regarding age groups, significant differences were found between young adults and adults in age, height, level of physical activity, body fat, lean mass, trunk fat-free mass, trunk fat mass, and lean trunk mass (all $p < 0.05$). In the EMG activity of the trunk muscles during the FPT, no significant differences were found between males and females (all $p > 0.05$) (Supplementary Table S1) or between young adults and adults (all $p > 0.05$). However, in all the assessed force variables in the isokinetic device, males presented statistically significantly higher force values than females (all $p < 0.01$), except for the ratios such as peak torque ratio ($p = 0.90$), average power ratio ($p = 0.34$), and total work ratio ($p = 0.38$) (Supplementary Table S2). Moreover, for most of the force variables, young adults were higher than in adults (all $p < 0.05$) (Supplementary Table S3).

3.1. Criterion-Related Validity

Figure 3 shows the EMG activity of the trunk muscles during FPT. The results demonstrate significantly greater differences for the URA, LRA, and EO muscles compared with the ES and MF muscles (all $p < 0.001$). Specifically, the EO muscle exhibited the highest activity (72.25 ± 50.64%), whereas the MF and ES muscles displayed comparatively lower levels of activity (24.15 ± 34.97% and 21.29 ± 32.76%, respectively). In addition, the EO muscle demonstrated significantly ($p < 0.05$) greater activity than the LRA ($p < 0.05$). Non-significant differences were found according to sex and age groups (Supplementary Table S1).

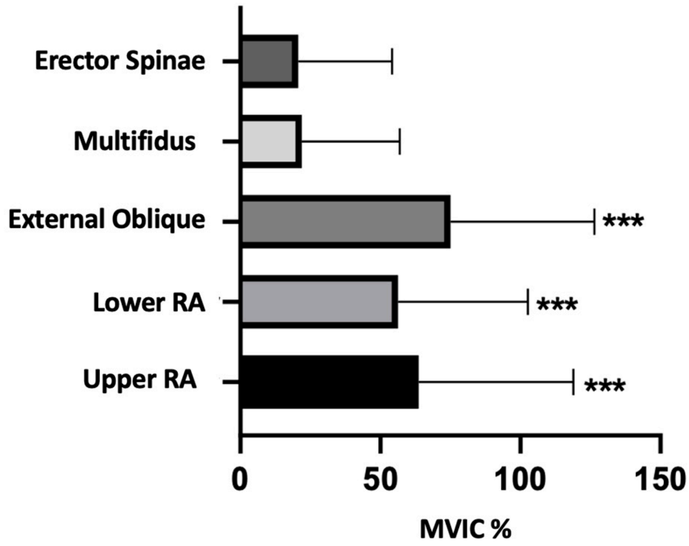

Figure 3. Electromyographic activity of trunk muscles during the front plank test. Difference in the EMG data of the trunk muscles (URA, LRA, EO, MF, and ES). MVIC = maximum voluntary isometric contraction; RA = rectus abdominis. Significance level *** = statistically significant ($p < 0.001$) for the erector spinae and multifidus muscles.

No correlations were found between FPT time and physical activity ($p > 0.05$). In body composition variables, low and moderate negative correlations were found between FPT time and body fat percentage and trunk fat mass percentage (r = 0.31–0.59; both $p < 0.05$) regardless of sex and age groups. Concerning muscle activation, a low correlation was found in the whole sample and males with FPT time and the activation of EO ($r = -0.27$ and -0.34 respectively; both $p < 0.05$) and in females a positive moderate correlation ($r = 0.59$; $p < 0.001$) was found between FPT and the activation of ES. Regarding the correlation between FPT and force in the isokinetic device, some variables showed significant low correlations in the whole sample (r = 0.24–0.30; all $p < 0.05$) (Table 2).

3.2. Reliability

Test-retest reliability of the FPT is presented in Table 3. Significant mean differences between T1 and T2 were found in the total sample (4.07 ± 1.59 s; $p = 0.012$) and in the female sample (7.27 ± 3.12 s; $p = 0.027$). The effect size (Cohen's d) of the mean differences was 0.001 in both groups. Non-significant differences were found between T1 and T2 in the male sample (2.12 ± 1.68 s; $p = 0.213$), and the ICC reported a high reproducibility, being 0.99 (0.98–0.99). All the analyzed error measurements showed low values (%Error = 4.68; %CV = 6.33; SEE = 13.97 s), and similar results were obtained when the sample was divided by sex and age groups. The MDC_{90} values were approximately 0.00 for each measure, indicating that no real change occurred between T1 and T2.

Figure 4 shows the Bland–Altman plots of the FPT for the whole sample and divided by sex and age groups. The random error was close to 0 and narrow LoA (14.39 s (95% LoA = −32.27 to 24.14; $p = 0.002$)) in the whole sample, in males (−2.41 s (95% LoA = −26.01 to 21.18; $p = 0.023$)) and females (−6.79 s (95% LoA = −42.28 to 28.70; $p = 0.020$)) (Figure 4B,C). According to age groups, the random error also was close to 0 and narrow LoA (−2.99 s (95% LoA = −31.73 to 25.75; $p < 0.001$)) in young adults and adult groups (−8.18 s (95% LoA = −36.42 to 20.07; $p = 0.899$)) (Figure 4D,E). Heteroscedasticity of errors was observed ($r^2 > 0.10$; $p < 0.05$) between T1 and T2 in all groups, excepts in adults ($r^2 = 0.0011$; $p = 0.899$) (Figure 4).

Table 2. Pearson's bivariate correlation by sex and age between FPT and physical activity, body composition variables, RPE at the end, muscle activation, and force in isokinetic device.

			Time in FPT				
				Sex		Age	
			Total (n = 84)	Male (n = 52)	Female (n = 32)	Young Adults (n = 64)	Adults (n = 20)
FPT and body composition variables and RPE at the end							
BMI (kg/m^2)			−0.11	−0.17	−0.11	−0.10	−0.15
Waist circumference (cm)			−0.05	−0.14	−0.13	−0.10	0.04
Body fat (%)			−0.32 **	−0.35 *	−0.37 *	−0.31 *	−0.55 *
Lean Mass (kg)			0.02	−0.27	−0.06	−0.04	0.25
Trunk Fat-free mass (kg)			0.02	−0.20	−0.04	−0.05	0.24
Trunk Fat Mass (%)			−0.39 ***	−0.35 *	−0.42 *	−0.37 **	−0.59 **
Lean Trunk Mass (kg)			0.02	−0.20	−0.04	−0.05	0.24
RPE at the end			0.13	−0.03	0.29	0.25 *	−0.04
FPT and muscle activation							
URA (%MVIC)			−0.04	0.08	−0.20	0.04	−0.30
LRA (%MVIC)			−0.17	−0.18	−0.22	−0.18	−0.13
EO (%MVIC)			−0.27 *	−0.34 *	−0.19	−0.24	−0.34
MF (%MVIC)			0.16	0.27	−0.18	0.25	−0.48
ES (%MVIC)			0.20	−0.04	0.59 ***	0.23	0.03
FTP and force in isokinetic device							
Isokinetic Con-Con (120°/s)	Flexors	Initial Peak Torque (Nm)	0.17	0.12	0.11	0.10	0.39
		Initial Peak Torque per BW (Nm/kg)	0.27 *	0.26	0.23	0.21	0.50 *
		Fatigue Index	0.18	0.12	0.20	0.17	0.24
		Total Work (N/m)	0.14	0.06	0.08	0.06	0.38
		Total Work per BW (N/m/kg)	0.25 *	0.25	0.19	0.19	0.49 *
		Average Power per Rep (W/av)	0.14	0.06	0.05	0.06	0.39
		Average Power per Rep per BW (W/av/kg)	0.24 *	0.25	0.16	0.18	0.49 *
		Time to Peak (s)	−0.11	−0.16	0.04	−0.05	−0.29

Table 2. *Cont.*

			Time in FPT				
				Sex		Age	
			Total (n = 84)	Male (n = 52)	Female (n = 32)	Young Adults (n = 64)	Adults (n = 20)
Isokinetic Con-Con (120°/s)	Extensors	Initial Peak Torque (Nm)	0.20	0.13	0.22	0.19	0.33
		Initial Peak Torque per BW (Nm/kg)	0.30 **	0.22	0.35	0.30 *	0.41
		Fatigue Index	0.12	0.11	0.08	0.17	0.01
		Total Work (N/m)	0.15	0.03	0.18	0.12	0.38
		Total Work per BW (N/m/kg)	0.24 *	0.13	0.31	0.24	0.44
		Average Power per Rep (W/av)	0.13	0.02	0.14	0.10	0.38
		Average Power per Rep per BW (W/av/kg)	0.22	0.12	0.26	0.21	0.44
		Time to Peak (s)	<0.01	0.19	−0.27	0.09	−0.32
Isokinetic Con-Con (120°/s)	Flexors and extensors	Ratio Peak Torque	−0.03	0.03	−0.10	−0.06	0.02
		Ratio Total Work	−0.12	−0.08	−0.13	−0.10	−0.19
		Ratio Average Power	−0.10	−0.04	−0.13	−0.07	−0.21
Isometric Con	Flexors	Peak Torque (Nm)	0.08	0.06	−0.22	0.01	0.39
		Peak Torque per BW (Nm/kg)	0.16	0.21	−0.14	0.06	0.53 *
		Average Torque (Nm)	0.12	0.14	−0.20	0.05	0.32
		Average Torque per BW(Nm/kg)	0.19	0.30 *	−0.15	0.11	0.46
		Time to Peak (s)	0.07	0.02	0.28	0.24	−0.35

Significance level * $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$. FPT = front plank test; RPE = rate of perceived exertion; BMI = body mass index; MVIC = maximum voluntary isometric contraction; URA = upper rectus abdominis; LRA = lower rectus abdominis; EO = external oblique; MF = multifidus; ES = erector spinae; ISOK = isokinetic contraction; ISOM = isometric contraction; BW = body weight; REP = repetition; Con = concentric; ° = degree; s = seconds; N = newton; kg = kilograms; m = meters; W = watts: av = average value; Nm = newton/meters.

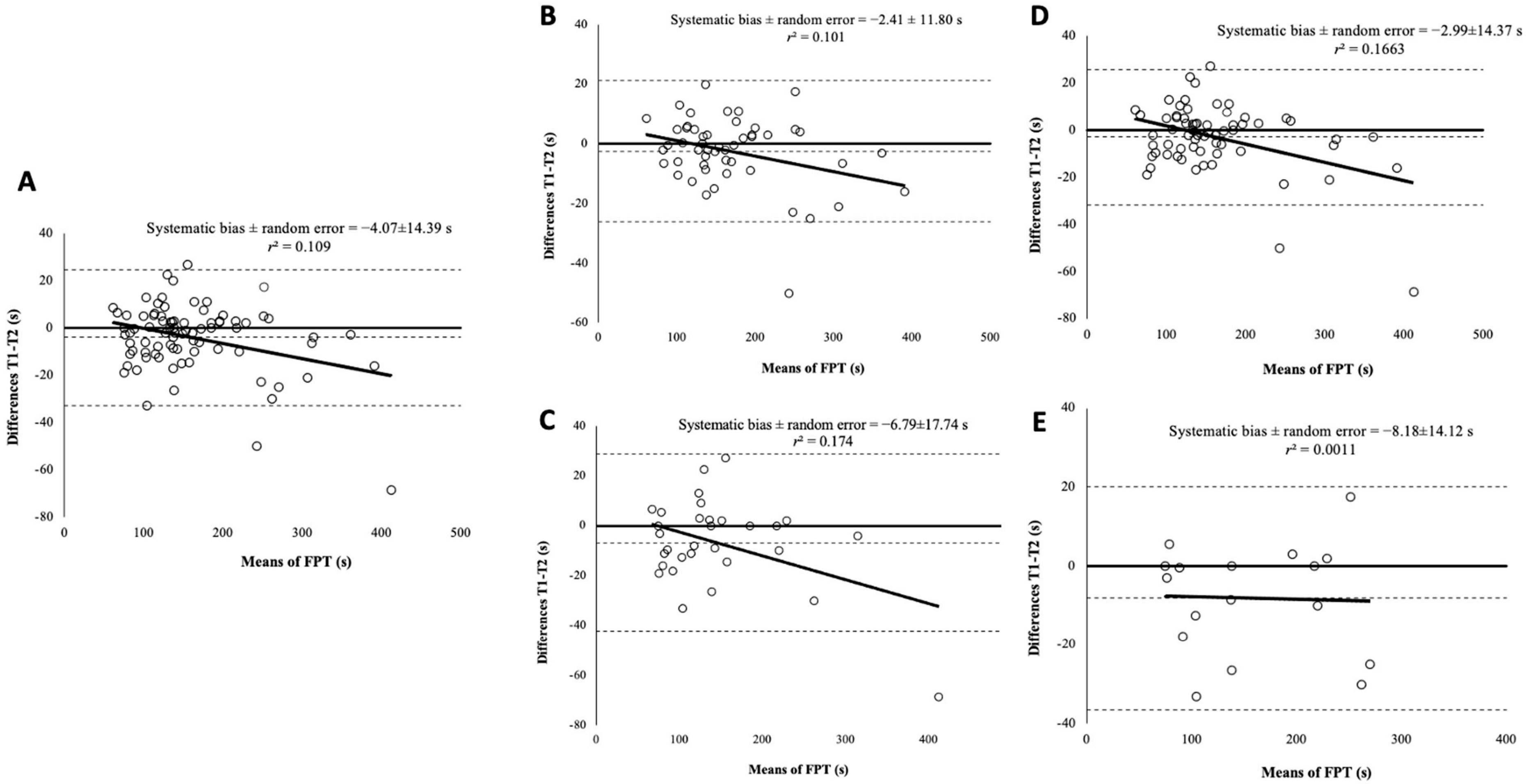

Figure 4. The Bland–Altman plot depicts the averaged difference between test and retest of FPT and 95% limits of agreement (dashed lines), along with the regression line (solid line). In addition, a solid line indicates the 0 point. (**A**) Whole sample. (**B**) Male. (**C**) Female. (**D**) Young adults. (**E**) Adults.

Table 3. Test-retest reliability of FPT (mean ± SD).

	Test (s)	Retest (s)	Intertrial Difference (T2-T1)	*p*-Value	Cohen's *d*	ICC (95% CI)	SSE	MSE	RMSE	% Error	% CV	% SEM	MDC_{90}	SEE
Total	158.65 ± 72.15	162.72 ± 76.88	4.07 ± 1.59	0.012	0.06	0.99 (0.98–0.99)	18,130.75	221.11	14.87	4.68	6.33	−2.56	−0.06	13.97
Sex														
Male	167.93 ± 70.04	170.05 ± 73.95	2.12 ± 1.68	0.213	0.03	0.99 (0.99–1.00)	7256.50	142.28	11.93	3.76	4.91	−1.43	−0.03	11.45
Female	143.39 ± 74.12	150.66 ± 81.26	7.27 ± 3.12	0.027	0.09	0.99 (0.97–0.99)	10,874.25	350.78	18.73	6.00	5.47	−1.80	−0.04	16.84
Age groups														
Young adults	159.98 ± 74.80	162.97 ± 80.50	2.99 ± 1.78	0.098	0.04	0.98 (0.97–0.99)	13,803.25	212.36	14.57	4.59	6.29	−1.87	−0.04	13.69
Adults	153.59 ± 78.33	161.76 ± 79.52	8.18 ± 3.43	0.029	0.11	0.99 (0.96–0.99)	4327.50	66.58	8.16	4.40	3.55	−1.39	−0.03	14.09

ICC = intraclass correlation coefficients; CI = confident interval; SSE = sum of squared errors; MSE = mean sum of squared errors; RMSE = root mean sum of squared errors; %Error = percentage error; %SEM = standard error of measurement; MCD = minimal detectable change; %CV = percentage coefficient of variation; SEE = standard error of estimate.

4. Discussion

The study analyzed the criterion-related validity and reliability of the FPT for evaluating trunk musculature in adults according to sex and age groups. The main findings of our study showed that the FPT was a valid and reliable test for assessing trunk musculature regardless of sex and age groups. We found that the trunk flexors and EO muscles play a key role in maintaining trunk stability during FPT, whereas the trunk extensors, such as ES and MF muscles, may play a minor role in this function. In addition, there was a low and moderate correlation between FPT time and body fat percentage and trunk fat mass percentage regardless of sex and age groups, muscle activation, and the force of the flexor and extensor trunk muscles assessed in the isokinetic device. No statistically significant differences were found in muscle activation in the FPT in any of the muscle analyzed, according to sex and age groups. Extremely high ICC and low error values were observed.

4.1. Criterion-Related Validity

The EMG activity of the trunk muscles during the FPT showed significantly greater differences for the URA, LRA, and EO muscles compared to the ES and MF muscles. These results highlight the predominance of flexor and lateral muscle activation in maintaining the front plank position. The particularly high activation of the EO muscle suggests its crucial role in providing lateral stability and counteracting rotational forces during exercise. In accordance with our findings, De Blaiser et al. (2018), Imai et al. (2010), and Youdas et al. (2018) also found a greater activation of the EO concerning the RA and of these two muscles for the back muscles [21,47,48]. In contrast, the relatively lower activation of the ES and MF muscles indicates that these muscles contribute less to the stabilization demands of the FPT. Moreover, previous studies realized by Lee et al. (2017) and Park and Park (2019) obtained similar values of ES activation to our study (24.81 and 24.32% MVIC, respectively) and slightly lower in the RA (34.93 and 51.83% MVIC, respectively) [49,50]. On the other hand, two studies observed higher values of RA than EO during a front plank exercise [51,52]. This may be because they analyzed muscle activation in a front plank for a certain time and not to failure.

As demonstrated in previous research and corroborated by the present study, the EO usually has a greater activation for the MVIC than the rest of the muscles assessed [21,48,53]. However, we found similar levels of activation of URA and EO in the adult group. Also, it has been shown that the front plank exercise activates the flexor muscles of the trunk more than the extensor muscles [54]. To increase the activation of the ES muscles, a recent review showed that free-weight exercises are those that produce the greatest activation, with back extension exercises showing high activation. In addition, if an increase in MF activation is desired, it was recommended to work on the front plank exercise on a Swiss ball or free weight, such as squat or deadlift, and other forms, such as core stability training with abdominal drawing-in maneuver technique or Pilates [54–56].

Regarding correlations, no correlations were found between FPT time with physical activity or RPE at the end. However, low and moderate correlation were found with body fat percentage and trunk fat mass percentage regardless of sex and age groups. Bohannon et al. (2018) [17] found a very low or low correlation between FPT and BMI and waist circumference as well as the end of the RPE in young adults. This may be due to the fact that the sample in the Bohannon et al. (2018) [17] had overweight (BMI = 25.4) participants, whereas our sample had normal weight (BMI < 25.00) participants. Furthermore, Bohannon et al. (2018) [17] did not carry out correlations by sex and age group, nor was body composition measured, making it difficult to compare the results of our study by groups. In the study by Ikezaki et al. (2021), they found no agreement between the fatigue presented by the electromyographic data and RPE at the end, as the mean obtained was

3.5 for the sedentary group and 3.8 for the resistance group. This may occur because the FPT is an isometric test in which there is no cardiovascular involvement, so the perceived effort may be lower, and the participants finish the test due to local fatigue. However, Cruz-Montecinos et al. (2019) [32] measured RPE every 5 s in a FPT to failure, and they found a high association between RPE and neuromuscular fatigue during the performance of this exercise.

A major finding in our study was that, both in the total sample and the sample divided by sex and age groups, there was a significant and negative correlation between the FPT time and the percentage of body fat and the percentage of trunk fat mass, indicating that the time in FPT is lower when the percentage of body fat and trunk fat mass is higher. These results suggest that the lean mass and lean trunk mass did not determine the FPT time, but fat variables did. Moreover, significant differences in body fat and trunk fat mass were found between young adults and adults. The adult group had a higher percentage of body fat than the young adult group, obtaining a lower FTP time. This may indicate that as age increases, body fat percentage and trunk fat mass increase, thus increasing the negative correlation between these variables and FPT time. Furthermore, when the sample was divided by sex, the correlation between these two variables was higher in females, highlighting the role of body fat and trunk fat mass in FPT time.

Regarding the correlation between FPT time and muscle activation, only in EO was a low correlation found in the whole sample and in males and a moderate correlation of the ES in females. Non-significant correlation of the other muscles may be due to the fact that the FPT time has been related to %MVIC and not to the total activation, activation time of that muscle, or normalized median frequency slope. However, no significant difference was found in the %MVIC during the test between sexes and age groups.

Although an attempt was made to provide criterion-related validity for the FPT with the force in the isokinetic device, the variables of time in the FPT and the isokinetic and isometric force variables obtained a low correlation with the initial peak torque by BW and the total work per BW in the flexors and extensors in the whole sample. This may be because more muscles were involved in the FPT than in the assessment of strength endurance in an isokinetic device, since in the latter, the flexor and extensor muscles of the trunk were analyzed in isolation. Furthermore, as mentioned previously, FPT time is not determined by lean mass or lean trunk mass; instead, fat variables appear to exert a significant influence on this test. It is important to note that previous studies have investigated the reasons why participants terminate the test and have found that they not only terminate the test because of fatigue in the abdominal muscles but also because of fatigue in the legs and/or arms or due to back pain [17,23].

4.2. Reliability

The reliability of the FPT time was examined in four studies [17,21,22,26]. In all cases, the values of the present ICCs ranged from 0.84 to 0.94 in young adults. Three of them showed SEM ranging from 1.38% to 3.85% [17,21,26] and Bohannon et al. obtained an MDC of 39.7%. Our results presented slightly higher reliability values, with a random error close to 0 and narrow LoA, regardless of sex and age groups, which may be because we used an elastic band placed 3 cm from the hip, individualizing the position of the line according to the initial position of the plank of each participant, to standardize the correct alignment of the position in the FPT, which Ikezaki et al. (2021) [26] pointed out as a limitation in their study.

In the studies analyzed, the test can be completed either because the participants reach their maximum effort or because the participants lose the correct position. However, the protocols used to complete the test for the latter reason differ from each other.

Bohannon et al. (2018) [17] concluded that the test was completed when the assessors considered that the participants had lost a neutral position for the third time. In the study by Durall et al. (2012) [22], the test finished when the participants failed to remain in contact with the reference rod for longer than 2 s. Ikezaki et al. (2021) [26] did not indicate how they controlled the correct body position during the test. In the study of De Blaiser et al. (2018) [21], tactile feedback was given to participants to correct the position, and if the participant did not remain in the correct position for 2 s, the test was concluded. Therefore, it is important to establish a standard FPT assessment protocol to be able to compare the results of the studies.

4.3. Limitations

The limitations of our study may be due to the fact that the sample was comprised of young participants, with 80% of the sample being under 34 years of age. It would therefore be interesting to conduct these measurements in a larger sample of adults over 34 years of age. In addition, we did not assess the reasons why the participants completed the test. Another potential limitation is the use of surface EMG to assess the MF muscle, as deep muscles are more susceptible to signal attenuation and crosstalk. Although electrode placement followed SENIAM guidelines and prior validated methodologies, future studies may benefit from using intramuscular EMG to obtain more precise and isolated recordings of MF activity.

The greatest strength of our study was the study of criterion-related validity of FPT, not only with a gold standard, such as the isokinetic device in both isokinetic and isometric modes, but we also analyzed muscle activation with electromyography. In addition, all the variables provided by this device were analyzed and not only the peak torque or average torque variable, as is the case in most sports medicine studies. On the other hand, an in depth study of the body composition variables was conducted, and the relationship with the FPT has been studied. Finally, although ICC, Bland–Altman, SEM, and CV are the most common statistics used to report reliability in sports medicine, we have also included different measurement errors for a more complete interpretation of reliability.

5. Conclusions

The results of our study indicate that FPT is a valid and reliable test for the assessment of trunk muscle strength in adults, regardless of sex and age groups. In addition, the FPT test involves greater activation of the trunk flexor muscles than the extensor muscles. Higher initial peak torque per BW and total work per BW of the flexors and extensor are associated with higher FPT time; however, total fat and trunk fat mass play a key role in the FPT time.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app15052722/s1, Table S1: Trunk muscles electromyographic activity during FPT and differences between sex and age groups in muscle activation during FPT; Table S2. Differences between sex in force variables in the isokinetic device; Table S3. Differences between age groups in force variables in the isokinetic device.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of University of Cadiz (COD: 28-6/2019).

Informed Consent Statement: Written informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data are contained within the article.

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Abbreviations

The following abbreviations are used in this manuscript:

FPT	Front Plank Test
sEMG	Surface Electromyography
MVIC	Maximum Voluntary Isometric Contraction
BMI	Body Mass Index
URA	Upper Rectus Abdominis
LRA	Lower Rectus Abdominis
EO	External Oblique
MF	Multifidus
ES	Erector Spinae
RMS	Root Mean Square
RPE	Rate of Perceived Exertion
ICC	Intraclass Correlation Coefficient
SSE	Sum of Squared Errors
MSE	Mean Sum of squared Errors
RMSE	Root Mean Sum of squared Errors
SEM	Standard Error of Measurement
SEE	Standard Error of Estimate
CV	Coefficient of Variation
MDC	Minimal Detectable Change

References

1. Takai, Y.; Nakatani, M.; Akamine, T.; Shiokawa, K.; Komori, D.; Kanehisa, H. Effect of Core Training on Trunk Flexor Musculature in Male Soccer Players. *Sports Med. Int. Open* **2017**, *1*, E147. [CrossRef] [PubMed]
2. MacDonald, D.A.; Moseley, G.L.; Hodges, P.W. The lumbar multifidus: Does the evidence support clinical beliefs? *Man. Ther.* **2006**, *11*, 254–263. [CrossRef] [PubMed]
3. Owen, P.J.; Miller, C.T.; Mundell, N.L.; Verswijveren, S.J.J.M.; Tagliaferri, S.D.; Brisby, H.; Bowe, S.J.; Belavy, D.L. Which specific modes of exercise training are most effective for treating low back pain? Network meta-analysis. *Br. J. Sports Med.* **2020**, *54*, 1279. [CrossRef]
4. Manchado, C.; García-Ruiz, J.; Cortell-Tormo, J.M.; Tortosa-Martínez, J. Effect of Core Training on Male Handball Players' Throwing Velocity. *J. Hum. Kinet.* **2017**, *56*, 177–185. [CrossRef] [PubMed]

5. Rodríguez-Perea, Á.; Reyes-Ferrada, W.; Jerez-Mayorga, D.; Ríos, L.C.; Van den Tillar, R.; Ríos, I.C.; Martínez-García, D. Core training and performance: A systematic review with meta-analysis. *Biol. Sport* **2023**, *40*, 975–992. [CrossRef]
6. Mesquita, M.M.A.; Santos, M.S.; Vasconcelos, A.B.S.; De Sá, C.A.; Pereira, L.C.D.; Silva-Santos, Í.B.M.D.; Da Silva Junior, W.M.; De Matos, D.G.; Fontes, A.D.S.; Oliveira, P.M.P.; et al. Reliability of a Test for Assessment of Isometric Trunk Muscle Strength in Elderly Women. *J. Aging Res.* **2019**, *2019*, 9061839. [CrossRef]
7. Reyes-Ferrada, W.; Chirosa-Rios, L.; Chirosa-Rios, I.; Martínez-Garcia, D.; Barboza-gonzalez, P.; Ulloa-Diaz, D.; Jerez-mayorga, D.; Rodríguez-Perea, A. A New Reliable Device to Assess Trunk Extensors Strength. *Acta Bioeng. Biomech.* **2022**, *24*, 2022. [CrossRef]
8. Rodríguez-Perea, A.; Jerez-Mayorga, D.; Morenas-Aguilar, M.D.; Martínez-García, D.; Chirosa-Ríos, I.J.; Chirosa-Ríos, L.J.; Reyes-Ferrada, W. Influence of Sex and Dominant Side on the Reliability of Two Trunk Rotator Exercises. *Appl. Sci.* **2023**, *13*, 2441. [CrossRef]
9. Moussa, A.Z.B.; Zouita, S.; Salah, F.B.; Behm, D.; Chaouachi, A. Isokinetic trunk strength, validity, reliability, normative data and relation to physical performance and low back pain: A review of the literature. *Int. J. Sports Phys. Ther.* **2020**, *15*, 160. [CrossRef]
10. Verbrugghe, J.; Agten, A.; Eijnde, B.O.; Vandenabeele, F.; De Baets, L.; Huybrechts, X.; Timmermans, A. Reliability and agreement of isometric functional trunk and isolated lumbar strength assessment in healthy persons and persons with chronic nonspecific low back pain. *Phys. Ther. Sport* **2019**, *38*, 1–7. [CrossRef]
11. Roth, R.; Donath, L.; Kurz, E.; Zahner, L.; Faude, O. Absolute and relative reliability of isokinetic and isometric trunk strength testing using the IsoMed-2000 dynamometer. *Phys. Ther. Sport* **2017**, *24*, 26–31. [CrossRef] [PubMed]
12. Estrázulas, J.A.; Estrázulas, J.A.; de Jesus, K.; de Jesus, K.; da Silva, R.A.; Libardoni dos Santos, J.O. Evaluation isometric and isokinetic of trunk flexor and extensor muscles with isokinetic dynamometer: A systematic review. *Phys. Ther. Sport* **2020**, *45*, 93–102. [CrossRef] [PubMed]
13. García-Vaquero, M.P.; Barbado, D.; Juan-Recio, C.; López-Valenciano, A.; Vera-Garcia, F.J. Isokinetic trunk flexion-extension protocol to assess trunk muscle strength and endurance: Reliability, learning effect, and sex differences. *J. Sport Health Sci.* **2016**, *9*, 692–701. [CrossRef] [PubMed]
14. Yang, S.; Wu, W.; Zhang, C.; Wang, D.; Chen, C.; Tang, Y.; Li, K.; Xu, J.; Luo, F. Reliability and validity of three isometric back extensor strength assessments with different test postures. *J. Int. Med. Res.* **2020**, *48*, 0300060519885268. [CrossRef] [PubMed]
15. Martínez-Romero, M.T.; Ayala, F.; De Ste Croix, M.; Vera-Garcia, F.J.; De Baranda, P.S.; Santonja-Medina, F.; Sánchez-Meca, J. A Meta-Analysis of the Reliability of Four Field-Based Trunk Extension Endurance Tests. *Int. J. Environ. Res. Public Health* **2020**, *17*, 3088. [CrossRef]
16. Juan-Recio, C.; Prat-Luri, A.; Galindo, A.; Manresa-Rocamora, A.; Barbado, D.; Vera-Garcia, F.J. Is the Side Bridge Test Valid and Reliable for Assessing Trunk Lateral Flexor Endurance in Recreational Female Athletes? *Biology* **2022**, *11*, 1043. [CrossRef]
17. Bohannon, R.W.; Steffl, M.; Glenney, S.S.; Green, M.; Cashwell, L.; Prajerova, K.; Bunn, J. The prone bridge test: Performance, validity, and reliability among older and younger adults. *J. Bodyw. Mov. Ther.* **2018**, *22*, 385–389. [CrossRef]
18. Zemková, E. Strength and Power-Related Measures in Assessing Core Muscle Performance in Sport and Rehabilitation. *Front. Physiol.* **2022**, *13*, 861582. [CrossRef]
19. Timón, R.; Olcina, G.; Camacho-Cardeñosa, M.; Camacho-Cardenosa, A.; Martinez-Guardado, I.; Marcos-Serrano, M. 48-hour recovery of biochemical parameters and physical performance after two modalities of CrossFit workouts. *Biol. Sport* **2019**, *36*, 283. [CrossRef] [PubMed]
20. Rios, M.; Becker, K.M.; Monteiro, A.S.; Fonseca, P.; Pyne, D.B.; Reis, V.M.; Moreira-Gonçalves, D.; Fernandes, R.J. Effect of the Fran CrossFit Workout on Oxygen Uptake Kinetics, Energetics, and Postexercise Muscle Function in Trained CrossFitters. *Int. J. Sports Physiol. Perform.* **2024**, *19*, 299–306. [CrossRef] [PubMed]
21. De Blaiser, C.; De Ridder, R.; Willems, T.; Danneels, L.; Bossche, L.V.; Palmans, T.; Roosen, P. Evaluating abdominal core muscle fatigue: Assessment of the validity and reliability of the prone bridging test. *Scand. J. Med. Sci. Sports* **2018**, *28*, 391–399. [CrossRef] [PubMed]
22. Durall, C.J.; Greene, P.F.; Kernozek, T.W. A comparison of two isometric tests of trunk flexor endurance. *J. Strength Cond. Res.* **2012**, *26*, 1939–1944. [CrossRef] [PubMed]
23. Strand, S.L.; Hjelm, J.; Shoepe, T.C.; Fajardo, M.A. Norms for an Isometric Muscle Endurance Test. *J. Hum. Kinet.* **2014**, *40*, 93. [CrossRef] [PubMed]
24. Castro-Piñero, J.; Marin-Jimenez, N.; Fernandez-Santos, J.R.; Martin-Acosta, F.; Segura-Jimenez, V.; Izquierdo-Gomez, R.; Ruiz, J.R.; Cuenca-Garcia, M. Criterion-related validity of field-based fitness tests in adults: A systematic review. *J. Clin. Med.* **2021**, *10*, 3743. [CrossRef] [PubMed]
25. Boyer, C.; Tremblay, M.; Saunders, T.J.; McFarlane, A.; Borghese, M.; Lloyd, M.; Longmuir, P. Feasibility, validity, and reliability of the plank isometric hold as a field-based assessment of torso muscular endurance for children 8–12 years of age. *Pediatr. Exerc. Sci.* **2013**, *25*, 407–422. [CrossRef]
26. Ikezaki, F.; Krueger, E.; de Souza Guerino Macedo, C. Performance, reliability and fatigue in prone bridge test and supine unilateral bridge test. *J. Bodyw. Mov. Ther.* **2021**, *26*, 238–245. [CrossRef]

27. Cuenca-Garcia, M.; Marin-Jimenez, N.; Perez-Bey, A.; Sánchez-Oliva, D.; Camiletti-Moiron, D.; Alvarez-Gallardo, I.C.; Ortega, F.B.; Castro-Piñero, J. Reliability of Field-Based Fitness Tests in Adults: A Systematic Review. *Sports Med.* **2022**, *52*, 1961–1979. [CrossRef]
28. World Health Organization. Global Recommendations on Physical Activity for Health. 2010. Available online: https://apps.who.int/iris/bitstream/handle/10665/44399/9789245599975_chi.pdf (accessed on 5 April 2023).
29. Marfell-Jones, M.; Olds, T.; Stewart, A.; Carter, L. ISAK Accreditation Handbook. 2006. Available online: https://researchportal.vub.be/en/publications/isak-accreditation-handbook (accessed on 5 April 2023).
30. Bioelectrical impedance analysis in body composition measurement: National Institutes of Health Technology Assessment Conference Statement. *Am. J. Clin. Nutr.* **1996**, *64*, 524S. [CrossRef] [PubMed]
31. Armstrong, L.E.; Soto, J.A.H.; Hacker, F.T.; Casa, D.J.; Kavouras, S.A.; Maresh, C.M. Urinary Indices during Dehydration, Exercise, and Rehydration. *Int. J. Sport Nutr. Exerc. Metab.* **1998**, *8*, 345–355. [CrossRef]
32. Cruz-Montecinos, C.; Bustamante, A.; Candia-González, M.; González-Bravo, C.; Gallardo-Molina, P.; Andersen, L.L.; Calatayud, J. Perceived physical exertion is a good indicator of neuromuscular fatigue for the core muscles. *J. Electromyogr. Kinesiol.* **2019**, *49*, 102360. [CrossRef]
33. Reyes-Ferrada, W.; Chirosa-Rios, L.; Rodriguez-Perea, A.; Jerez-Mayorga, D.; Chirosa-Rios, I. Isokinetic trunk strength in acute low back pain patients compared to healthy subjects: A systematic review. *Int. J. Environ. Res. Public Health* **2021**, *18*, 2576. [CrossRef] [PubMed]
34. Yeom, S.; Jeong, H.; Lee, H.; Jeon, K. Effects of Lumbar Stabilization Exercises on Isokinetic Strength and Muscle Tension in Sedentary Men. *Bioengineering* **2023**, *10*, 342. [CrossRef] [PubMed]
35. Calatayud, J.; Escriche-Escuder, A.; Cruz-Montecinos, C.; Andersen, L.L.; Pérez-Alenda, S.; Aiguadé, R.; Casaña, J. Tolerability and Muscle Activity of Core Muscle Exercises in Chronic Low-back Pain. *Int. J. Environ. Res. Public Health* **2019**, *16*, 3509. [CrossRef]
36. González-Izal, M.; Malanda, A.; Gorostiaga, E.; Izquierdo, M. Electromyographic models to assess muscle fatigue. *J. Electromyogr. Kinesiol.* **2012**, *22*, 501–512. [CrossRef] [PubMed]
37. Walker, S.; Davis, L.; Avela, J.; Häkkinen, K. Neuromuscular fatigue during dynamic maximal strength and hypertrophic resistance loadings. *J. Electromyogr. Kinesiol.* **2012**, *22*, 356–362. [CrossRef]
38. Szpala, A.; Rutkowska-Kucharska, A.; Drapała, J.; Brzostowski, K. Choosing the right body position for assessing trunk flexors and extensors torque output. *Hum. Mov.* **2011**, *12*, 57–64. [CrossRef]
39. Vera-Garcia, F.J.; Moreside, J.M.; McGill, S.M. MVC techniques to normalize trunk muscle EMG in healthy women. *J. Electromyogr. Kinesiol.* **2010**, *20*, 10–16. [CrossRef]
40. Hopkins, W.G.; Marshall, S.W.; Batterham, A.M.; Hanin, J. Progressive statistics for studies in sports medicine and exercise science. *Med. Sci. Sports Exerc.* **2009**, *41*, 3–12. [CrossRef] [PubMed]
41. Bland, J.M.; Altman, D. Statistical Methods for Assessing Agreement Between Two Methods of Clinical Measurement. *Lancet* **1986**, *327*, 307–310. [CrossRef]
42. Bland, J.M.; Altman, D.G. Comparing methods of measurement: Why plotting difference against standard method is misleading. *Lancet* **1995**, *346*, 1085–1087. [CrossRef]
43. Weir, J. Quantifying test-retest reliability using the intraclass correlation coefficient. *J. Strength Cond. Res.* **2005**, *19*, 231–240.
44. Brown, C.E. Coefficient of variation. Applied Multivariate Statistics in Geohydrology and Related Sciences. In *Applied Multivariate Statistics in Geohydrology and Related Sciences*; Springer: Berlin/Heidelberg, Germany, 1998; pp. 155–157. [CrossRef]
45. del Corral, T.; Sánchez, Á.G.; López-de-Uralde-Villanueva, I. Test-retest reliability, minimal detectable change and minimal clinically important differences in modified shuttle walk test in children and adolescents with cystic fibrosis. *J. Cyst. Fibros.* **2020**, *19*, 442–448. [CrossRef] [PubMed]
46. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences*, 2nd ed.; Lawrence Erlbaum Associates: New York, NY, USA, 1988.
47. Imai, A.; Kaneoka, K.; Okubo, Y.; Shiina, I.; Tatsumura, M.; Izumi, S.; Shiraki, H. Trunk muscle activity during lumbar stabilization exercises on both a stable and unstable surface. *J. Orthop. Sports Phys. Ther.* **2010**, *40*, 369–375. [CrossRef] [PubMed]
48. Youdas, J.W.; Coleman, K.C.; Holstad, E.E.; Long, S.D.; Veldkamp, N.L.; Hollman, J.H. Magnitudes of muscle activation of spine stabilizers in healthy adults during prone on elbow planking exercises with and without a fitness ball. *Physiother. Theory Pract.* **2018**, *34*, 212–222. [CrossRef] [PubMed]
49. Park, D.J.; Park, S.Y. Which trunk exercise most effectively activates abdominal muscles? A comparative study of plank and isometric bilateral leg raise exercises. *J. Back Musculoskelet. Rehabil.* **2019**, *32*, 797–802. [CrossRef]
50. Lee, D.; Lee, Y.; Cho, H.Y.; Lee, K.B.; Hong, S.; Pyo, S.; Lee, G. Investigation of trunk muscle activity for modified plank exercise: A preliminary study. *Isokinet. Exerc. Sci.* **2017**, *25*, 209–213. [CrossRef]
51. Kim, S.Y.; Kang, M.H.; Kim, E.R.; Jung, I.G.; Seo, E.Y.; Oh, J.S. Comparison of EMG activity on abdominal muscles during plank exercise with unilateral and bilateral additional isometric hip adduction. *J. Electromyogr. Kinesiol.* **2016**, *30*, 9–14. [CrossRef]

52. Harris, S.; Ruffin, E.; Brewer, W.; Ortiz, A. Muscle activation patterns during suspension training exercises. *Int. J. Sports Phys. Ther.* **2017**, *12*, 42. [CrossRef]
53. Czaprowski, D.; Afeltowicz, A.; Gebicka, A.; Pawłowska, P.; Kedra, A.; Barrios, C.; Hadała, M. Abdominal muscle EMG-activity during bridge exercises on stable and unstable surfaces. *Phys. Ther. Sport* **2014**, *15*, 162–168. [CrossRef]
54. Oliva-Lozano, J.M.; Muyor, J.M. Core Muscle Activity during Physical Fitness Exercises: A Systematic Review. *Int. J. Environ. Res. Public Health* **2020**, *17*, 4306. [CrossRef]
55. Martuscello, J.M.; Nuzzo, J.L.; Ashley, C.D.; Campbell, B.I.; Orriola, J.J.; Mayer, J.M. Systematic review of core muscle activity during physical fitness exercises. *J. Strength Cond. Res.* **2013**, *27*, 1684–1698. [CrossRef] [PubMed]
56. Tsartsapakis, I.; Pantazi, G.A.; Konstantinidou, A.; Zafeiroudi, A.; Kellis, E. Spinal Muscle Thickness and Activation During Abdominal Hollowing and Bracing in CrossFit® Athletes. *Sports* **2023**, *11*, 159. [CrossRef] [PubMed]