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# Are trunk stability and endurance determinant factors for whole-body dynamic balance in physically active young males? A multidimensional analysis

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## Abstract

**Objectives:** Determine if (a) a better trunk stability and endurance are associated with an improved whole-body dynamic balance, and if (b) the assessment tests can be interchanged within each capability.

**Methods:** Sixty-three physically active young males performed three trunk stability (i.e., the lumbopelvic stability, the unstable sitting and the sudden loading sitting tests), three trunk muscle endurance (i.e., the Biering–Sørensen, the side bridge and the front bridge tests) and four whole-body dynamic balance (i.e., the tandem and the single-leg stance, the Y-Balance, and the single-leg triple hop tests) tests two times. After assessing the reliability of the variables, a Pearson correlation analysis was performed.

**Results:** The correlations between trunk stability and endurance tests with dynamic balance tests were non-significant except for the unstable sitting test with both the tandem ($r=0.502$) and the single-leg stance ($r=0.522$) tests. Moreover, no relationships were observed between the trunk stability and the trunk muscle endurance tests. Interestingly, no relationships were found between most tests within each capability (i.e., trunk stability, trunk endurance, and dynamic balance) except: (i) the front bridge stability test and the back ($r=0.461$) and the side ($r=0.499$) bridge stability tests; (ii) the two side bridge endurance tests ($r=0.786$); (iii) the tandem and the single-leg stance tests ($0.439 \leq r \leq 0.463$); (iv) the Y-Balance and the single-leg triple hop tests ($0.446 \leq r \leq 0.477$).

**Conclusion:** Better trunk function does not seem to be a relevant factor for dynamic balance in young active males. In this population, specific measures are needed as the test interchangeability is questioned.

KEYWORDS
association, core endurance, core stability, postural balance, screening

# 1 | INTRODUCTION

Trunk exercises, such as those that challenge trunk stability (i.e., the capability to maintain or resume a relative position or trajectory of the trunk following internal or external forces[1]) or trunk muscle endurance (i.e., the capability to exert trunk muscle force continuously over the long periods of time[2]), have become common elements of training programs to improve whole-body balance (i.e., the capability to maintain the center of mass within the body's base when performing a standing movement in order to perform multiple actions safely and accurately[3]) in a wide range of populations, such as athletes,[4] sedentary people,[4] stroke patients,[5] and older adults.[6] In this sense, as the upper body is usually far from the ground and accounts for approximately two-thirds of the total body weight,[7] trunk muscle function seems to play a relevant role in actions that require large dynamic balance demands so even small uncoordinated trunk movements may hamper body control.[8] Moreover, deficits in trunk performance could affect athletic performance[9] negatively and increase the risk of lower limb injury.[10]

The importance of trunk performance for whole-body balance has obtained some support from correlational studies in healthy[3,11,12] and in clinical[13–15] populations. However, there is little evidence supporting this relationship, as the significance and magnitude of this association varies greatly depending on the trunk test chosen[3,11–14] and the study population.[3,11,14] Therefore, there is a need to analyze whether different tests assessing trunk stability and endurance parameters are related to different dynamic balance tests. Elucidating the real relationship between tests would help to clarify the impact of trunk function on whole-body balance. Moreover, there are a high number of tests that have been specifically developed to assess trunk stability,[1,16,17] trunk muscle endurance[18,19] or whole-body dynamic balance[15,20,21] which, although they are generally grouped within the same capability, according to preliminary evidence they seem to be uncorrelated.[1,19,21] Analyzing the relationship between those tests designed to assess the same specific capability would help coaches, physical trainers, clinicians, and researchers to know the extent to which those tests can or cannot be used interchangeably.

Based on the above-mentioned limitations, it is necessary to establish which specific trunk performance measurements are related to different dynamic balance assessments[22] to be able to improve the understanding of the role of the trunk muscle function in athletic performance[9] and lower limb injury prevention[10] in physically active young adults. To address this issue, the main objective of this study was to analyze the relationship between trunk stability and endurance with whole-body dynamic balance in physically active young male adults, using some of the most well-known gold standard protocols and recent field tests [(i) *trunk stability tests*: the lumbopelvic stability, the unstable sitting and the sudden loading sitting tests; (ii) *trunk muscle endurance tests*: the Biering–Sørensen, the side bridge endurance, and the front bridge endurance tests; (iii) *whole-body dynamic balance tests*: the tandem and the single-leg stance, the Y-Balance and the single-leg triple hop tests]. In addition, the relationships between the tests associated with each capability were analyzed to understand the possible relationship between them better and to know if they are interchangeable. Based on the specificity principle and on previous findings from other studies,[15,21,23] it was hypothesized that there would be no correlations between most of the parameters obtained from the different tests, but it was expected that moderate correlations[15] would be found between the posturographic tests (unstable sitting, tandem stance, and single-leg stance tests), as the capability to adjust the center of pressure position to a target point moving in a circular trajectory was evaluated in all of them.

# 2 | MATERIALS AND METHODS

## 2.1 | Participants

Taking the hypothesis into account, a correlation coefficient of $r=0.5$ was expected for the sample size estimation, considering previous studies which examined the relationship between trunk performance test and dynamic balance test[15] and the interchangeability between trunk performance tests.[1] The software G*Power 3.1 (v3.1, University of Düsseldorf, Germany) was used with the following parameters: $r=0.5$; $\alpha=0.002$; $1-\beta=0.8$. Calculations suggested a sample size of ~55 participants. Sixty-three healthy young male adults (age: $23.5\pm4.5$ years) were recruited for the study. They were physically-active, with a work-out frequency of 30–120 min of light to vigorous physical exertion 2–5 days per week for a total of 120–300 min per week, approximately. Participants who had taken part in a structured or specific balance training or in a trunk muscle conditioning program and/or who were elite athletes and their sport modality required high demands of trunk performance, (i.e., judokas or gymnasts) were excluded from this study. Furthermore, those participants with any injury or disorder that impaired balance control were also ruled out. All the participants completed an informed consent form and completed a questionnaire on their health status and exercise habits. The University Office for Research Ethics (DPS.FVG.02.14) approved this study according to the Declaration of Helsinki.

## 3 | EXPERIMENTAL PROCEDURE

Height (176.3 ± 6.3 cm), mass (74.9 ± 8.4 kg), height of center of mass position of the head, arm and trunk (estimated at 62.6%[24] of the trunk height, measured as the distance between the greater trochanter and the glenohumeral joint: 34.6 ± 2.2 cm) and leg length (from the anterior superior iliac spine to the most prominent point on palpation of the medial malleolus[25]: preferred leg [93.5 ± 5.1 cm] and non-preferred leg [93.8 ± 5 cm]) were registered before testing. The participant's preferred leg was established as the leg that the participant would use to kick a ball. Participants carried out two testing sessions with a day's rest in-between and these sessions were repeated 1 week later. The first assessment session consisted of a trunk stability assessment through lumbopelvic stability tests (using a randomized block design to avoid fatigue influence) during the back bridge, the preferred side bridge, the front bridge and the bird-dog positions.[26] The second assessment session consisted of trunk stability, trunk muscle endurance and dynamic balance tests performed in the following order (applying first those tests in which their performance is most likely to be affected by fatigue): (a) the unstable sitting posturographic test, (b) the sudden loading sitting test in frontal, lateral and posterior directions (the directions were counterbalanced), (c) the tandem and (d) the single-leg balance stance posturographic tests, (e) the Y-Balance test, (f) the single-leg triple hop test, and (g) the Biering–Sørensen, the side bridge endurance and the front bridge tests (trunk muscle endurance tests were also counterbalanced). A warm-up was performed with the same characteristics as the one carried out by Heredia-Elvar et al.[27]

### 3.1 | Testing protocol description and data processing

#### 3.1.1 | Tunk stability tests

The lumbopelvic acceleration ($m \cdot s^{-2}$), recorded at 200 samples per second from a tri-axial smartphone-accelerometer, was registered using a free mobile application (Accelerometer Analyzer, Mobile Tools, Sopot, Poland) during the lumbopelvic stability tests from seven 15-s variations of the back bridge, the preferred side bridge, the front bridge and the bird-dog positions (for a total of 28 variations) following the protocol previously described by Heredia-Elvar et al.[26] The smartphone was placed between the iliac crest and the great trochanter of the support leg in the single-leg positions (the subjects' preferred leg), held by an elastic belt to reduce smartphone movement caused by muscle contractions. Those variations with the highest acceleration values (i.e., the most challenging variations) that were performed by at least 85% of the participants were selected for further analysis (Figure 1C). The signal was low-pass filtered at 10 Hz (4th-order, zero-phase-lag, Butterworth), in which the first (due to the non-stationarity of the signal) and the last seconds of each trial were discarded. The mean acceleration from the 3-axis (vertical, anterior–posterior and medial-lateral) was calculated through an "ad hoc" software developed by our research group with LabView 9.0 environment (v9.0, National Instruments, Austin, Texas, USA). The best of the two recorded lumbopelvic acceleration values (i.e., the lowest acceleration values) were used for further analysis.

The unstable sitting posturographic test[1] was used to assess the participants' ability to control their trunks during a circular tracking task while sitting on an unstable seat placed on a force platform (9287CA, Kistler®, Switzerland) (Figure 1A). The measure was to display real-time feedback about the center of pressure displacement on a screen. Additionally, a target point (which moved in a circular trajectory) was presented to assess the subject's ability to adjust his center of pressure position to this point. The mean radial error was used to quantify the trunk performance and it was calculated as the average of the vector distance magnitude (mm) of the center of pressure from the target point. The participant's arms were crossed over their chest, and they performed five 70-s trials with a 60-s rest between trials.

The sudden loading sitting test[23] was used to assess the participant's passive and reflex trunk response against sudden external perturbations. Participants sat in a semi-sitting position on a stable and rigid wooden chair, maintaining a neutral spine position, and lower limb movement was restricted through straps (Figure 1B). They received five sudden loads from frontal, lateral right side, and posterior directions with a 1-min rest between repetitions and a 5-min rest between directions. A pneumatic piston attached by a steel cable tensioner to a harness at the height of the center of mass position of the head, arm and trunk pulled with 4.2 bars of pressure and 0.5 m/s of speed to load the trunk. The maximal trunk angular displacement (°) was calculated following the method proposed by Cholewicky et al.[16] to analyze trunk response to sudden external perturbations in the sudden loading sitting test. Calculations were carried out for the first 110 ms, considering that voluntary responses do not usually occur in the first 120–150 ms[28] after the perturbation. To reduce the translation of the fulcrum (L5 marker) and ensure the angular movement of the trunk, only those trials with an L5 marker displacement of less than 2.5 mm were considered

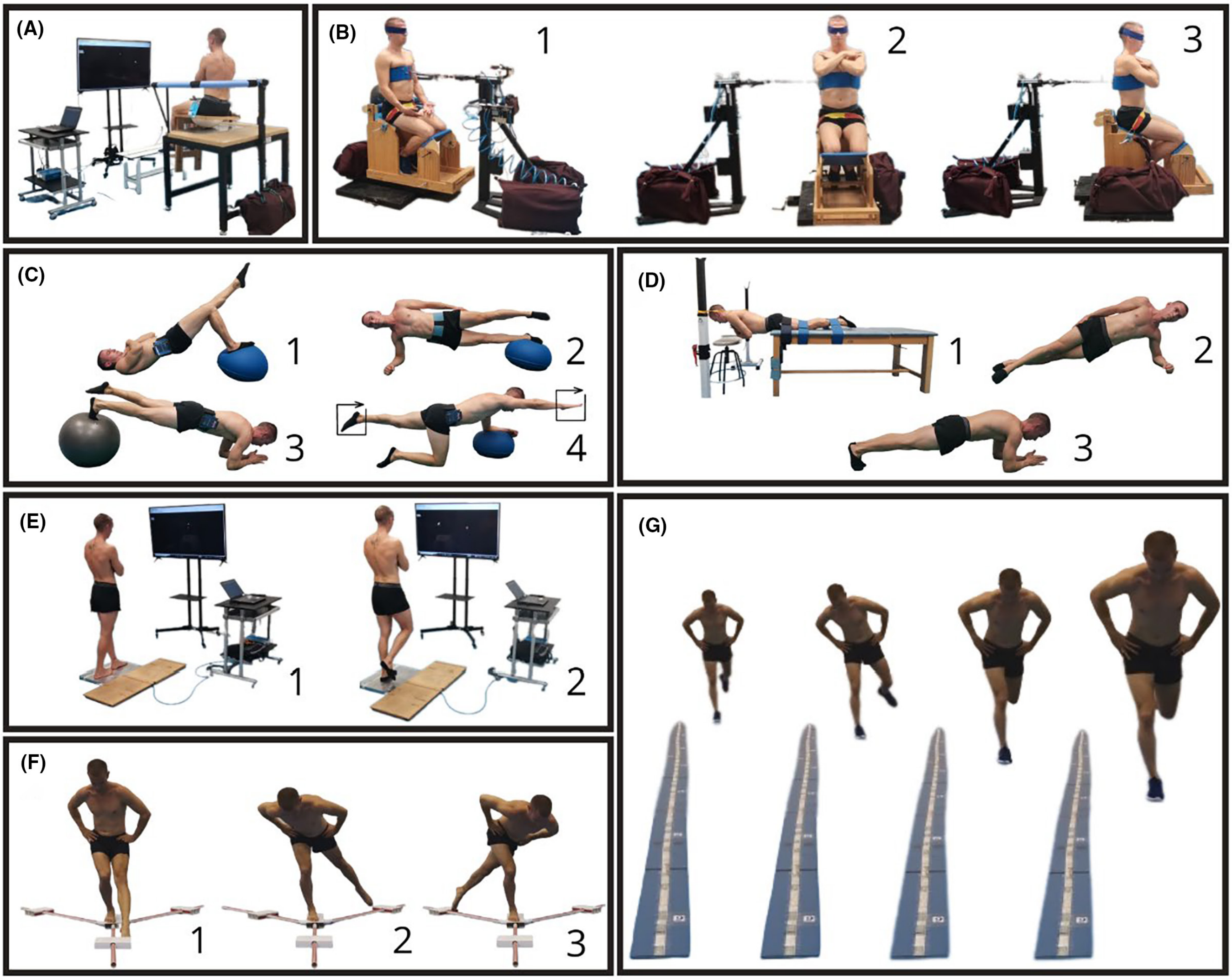


**FIGURE 1** Trunk function and whole-body dynamic balance tests. (A) The set-up for the unstable sitting test; (B) The sudden loading sitting test in the frontal (1), lateral (2) and posterior (3) load directions; (C) The lumbopelvic stability tests from variations of the back bridge (1), preferred side bridge (2), front bridge (3), and bird-dog (4) positions; (D) trunk muscle endurance tests, the Biering-Sørensen test (1), the preferred and non-preferred side bridge tests (2) and the front bridge test (3); (E) the tandem (1) and the single-leg stance (2) posturographic tests; (F) the anterior (1), posteromedial (2), and posterolateral (3) directions of the Y-Balance test; (G) the initial position and the landing phases of the three hops during the single-leg triple hop test.

valid, and the recordings with an accentuated translational behavior (displacement of more than 2.5 mm of the L5 marker) were discarded. To control for possible variability in the positioning of the harness (Figure 1B) between the first and the second session, comparisons were only made to calculate the reliability of the measurement between recordings with a difference in mechanical impulse of less than 20 N·m.

### 3.1.2 | Trunk muscle endurance tests

The Biering–Sørensen test,[29] the preferred and non-preferred side bridge tests[29] and the front bridge test[30] were used to assess the endurance of trunk extensors, trunk lateral flexors, and trunk flexors, respectively (Figure 1D). Participants were asked to maintain the position for as long as possible while they received verbal encouragement.

### 3.1.3 | Whole-body dynamic balance tests

The tandem and the single-leg stance posturographic tests (Figure 1E) were used to measure the whole-body dynamic balance through circular tracking tasks (with the same characteristics as the ones used in the unstable sitting posturographic test) while standing on a force platform (9286AA, Kistler®, Switzerland).[15] The participants performed the tandem test with their preferred lower limb placed ahead of the other limb, while the single leg test was performed with both limbs (preferred and non-preferred limb). During the single leg test, the tip of the toe of the non-tested leg was placed at the height of the medial malleolus of the supporting leg. The participants' arms were crossed over their chest during both tests, and they performed each task three times with a 1-min rest between tasks, with a trial duration of 70 s and 35 s for the tandem and single-leg tasks, respectively. The mean radial error was calculated for the unstable sitting test and the tandem and the single-leg stance posturographic tests. The signal was previously filtered by a low-pass-Butterworth filter with a cut-off frequency of 5 Hz. The initial 10-s were discarded because of the non-stationarity of the signal.[1] These outcomes were calculated using an "ad hoc" software developed by our research group through LabView 9.0 environment (v9.0, National Instruments, Austin, Texas, USA). The average of the two best attempts (i.e., the lowest mean radial error values) was used for the statistical analyses.

The Y-Balance test was performed to explore stability limits in single-leg stance in three directions (Figure 1F: anterior, posteromedial, and posterolateral directions) with both limbs (preferred and non-preferred).[31] Participants had to push a measuring plug along the pipe as far as possible while maintaining a single-leg stance. The measuring plug remained above the pipe after the test was performed, making the determination of the measure of the distance more precise. Three trials were registered and they had to meet the ensuing criteria to be valid: (a) participants had to maintain their hands placed on the hips; (b) they had to reach as far as possible in a controlled way (i.e., not kicking the measuring plug, just pushing it from the marked zone); (c) they could not lift the foot of the tested limb during the test. They were instructed to compensate for the weight transference with trunk leaning and flexing lower limb joints (e.g., ankle, knee, and hip). The mean of the two highest scores for each direction was normalized to the participant's leg length (value expressed in percentage relative to the leg length) for the subsequent analyses. A composite index of the three directions was also calculated.

The single-leg triple hop test was performed using a 6-m mat. Participants had to perform three consecutive maximal hops forward (Figure 1G) using the same leg. After the last hop, participants had to land without losing their balance.[20] Three trials were registered and they had to meet the ensuing criteria to be valid: (a) the take-off had to be performed with their hands placed on their hips; (b) the landing had to be stable and controlled (i.e., not tripping during the landing, hands still placed on their hips); (c) they had to maintain balance (i.e., the non-tested limb could not touch the other limb and it could not touch the floor). The two closest values were averaged and normalized to the participant's leg length (value expressed as the number of the "leg length" reached).

## 3.2 | Statistical analyses

Data (presented as mean and standard deviation) from those participants who carried out all the testing sessions were used for the statistical analyses. The normality of the data distribution was explored through the Kolmogorov–Smirnov and the Shapiro–Wilk tests. A one-way analysis of variance was performed for each test score to explore the existence of statistically significant mean differences between sessions.

The typical error (TE) and the intra-class correlation coefficient ($ICC_{3,1}$) were calculated (confidence limits set at 95%) to evaluate the absolute and relative test–retest reliability, respectively, and to determine which variables could be used in subsequent correlational analyses, to avoid possible bias due to the low consistency of certain variables. The TE was calculated as the standard deviation of the difference between the two testing sessions divided by $\sqrt{2}$. Furthermore, TE values were also expressed as percentages to facilitate data extrapolation, interpretation and comparison with the pertinent literature. Percentage TE was calculated as the TE × 100 and divided by the average of test–retest means. Intra-class correlation coefficient values were interpreted according to the following criteria: values lower than 0.5, between 0.5 and 0.75, between 0.75 and 0.9, and greater than 0.90 are indicative of poor, moderate, good, and excellent reliability, respectively.[32] Both absolute and relative reliability indexes were calculated through the spreadsheet proposed by Hopkins.[33]

The data obtained in the second assessment session for the variables that obtained a moderate-to-excellent level of relative reliability[32] (i.e., ICC >0.50) were used to perform a Pearson correlation analysis ($r$) between them. Correlational analyses were performed with JASP 0.16.2 software (Eric-Jan Wagenmakers, Department of the Psychological Methods, University of Amsterdam, Nieuwe Achtergracht 129B, Amsterdam, Netherlands). The correlation coefficient was interpreted as: low (0.30–0.49), moderate (0.50–0.69), high (0.70–0.89), and very high (≥0.90).[34] In order to minimize the probability of obtaining significant correlations by chance, the pre-specified significance level ($p < 0.05$) was divided by the number of comparisons analyzed, 25 (Bonferroni's correction). Thus, the level of adjusted significance was $p < 0.002$.

## 4 | RESULTS

The Tables S1 and S2 show the descriptive statistics and the absolute and relative between-session reliability for the trunk stability and endurance tests and whole-body dynamic balance tests, respectively. The reliability analyses showed a moderate-to-excellent level of reliability in the trunk stability and the trunk muscle endurance tests ($0.51 \leq ICC \leq 0.86$, $9.45\% \leq TE \leq 17.99\%$; see Table S1) and in the dynamic balance tests ($0.59 \leq ICC \leq 0.90$, $2.18\% \leq TE \leq 12.26\%$; see Table S2), and thus all the variables were used to perform the correlation analysis. Significant between-session differences were found in most of the participants' lumbopelvic accelerations during the lumbopelvic stability tests, in the mean radial error during the unstable sitting test and the tandem stance test, in the distance reached during posterolateral reach direction of the Y-Balance test and in the single-leg triple hop test of the non-preferred limb, showing that there was a learning/repetition effect in these tests and therefore a significantly higher performance in these tests in session two.

As seen in Table 1, for the trunk stability tests, only the front bridge stability test correlated significantly with the back bridge ($r=0.461$, $p<0.002$) and the side bridge ($r=0.499$, $p<0.002$) stability tests. Similarly, regarding the trunk muscle endurance tests, a significant correlation was only observed between the preferred and the non-preferred side bridge endurance tests ($r=0.786$, $p<0.002$). Moreover, no significant relationships were observed between the trunk stability tests and the trunk muscle endurance tests.

With respect to the correlational analyses between the dynamic balance tests (Table 2), the tandem and the single leg stance posturographic tests showed a significant relationship ($0.439 \leq r \leq 0.463$, $p<0.002$). The posteromedial reach direction of the Y-Balance test performed with the preferred and non-preferred leg, as well as the composite score with the preferred leg were significantly associated with the single-leg triple hop test ($0.446 \leq r \leq 0.477$, $p<0.002$).

Concerning the correlation analysis of the trunk stability and endurance tests with the dynamic balance tests (Table 3), most correlations were not significant, except for those between the unstable sitting test and both the tandem ($r=0.502$, $p<0.002$) and the single-leg stance with the non-preferred leg ($r=0.522$, $p<0.002$) posturographic tests.

## 5 | DISCUSSION

The main findings of this study were the predominant absence of significant correlations between the different tests used for measuring trunk stability and endurance with dynamic balance, questioning the relevance of trunk function for enhancing balance in physically active young male adults. Additionally, there were no significant correlations between most of the trunk stability and trunk muscle endurance tests and few and low correlations were observed between the different tests used for measuring dynamic balance. This would reinforce the idea that these tests represent different manifestations for the same physical capabilities, probably due to different measurement conditions. Thus, these tests cannot be used interchangeably.

### 5.1 | Different manifestations of trunk stability, trunk muscle endurance, and whole-body dynamic balance

Regarding the trunk stability tests, the absence of relations between loading directions in the sudden loading sitting test supports the idea that the trunk response is very specific to the loading direction, which is consistent with previous results.[1] In addition, no correlation was found between trunk response against perturbation and the trunk balancing control during the unstable sitting test, which is also in agreement with previous results.[1] The specific test performance seems to be associated with the neuromuscular control mechanism involved in each test. While the performance during the sudden loading test depends mainly on passive trunk structures and spinal reflex responses,[16,28] unstable sitting performance is associated with voluntary control and the cerebellar-cortical feedback mechanisms.[17,35] In addition, low relationships were found between the front bridge position in the lumbopelvic stability tests with the back bridge and the side bridge position and few relationships were found between the trunk muscle endurance tests (Table 1), which is consistent with previous studies.[19] Furthermore, previous research observed that young active individuals showed a different performance even when the same muscle group was assessed in different positions (i.e., the front bridge test vs. the v-sit test)[18] or different types of muscle action (i.e., isometric vs. dynamic).[36] This suggests that physical performance in young individuals highly depends on many different biomechanical demands (muscle group type, position, muscle action, duration, speed, recovery time, and resistance).[2] Considering the results of all the trunk performance tests together (i.e., trunk stability and trunk muscle endurance tests), coaches, physical trainers, clinicians, and researchers must be careful when selecting these tests for young individuals based on individual criteria or aims.

**TABLE 1** Relationship between trunk stability and endurance tests.

| | Sudden loading sitting test | | | Lumbopelvic stability tests | | | | Trunk muscle endurance tests | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Frontal direction | Lateral direction | Posterior direction | Back bridge[a] | Side bridge[a] | Front bridge[b] | Bird-dog[c] | Biering–Sørensen test | Side bridge test (P) | Side bridge test (NP) | Front bridge test |
| Unstable sitting test | | | | | | | | | | | |
| Mean radial error (mm) | | | | | | | | | | | |
| | 0.099 | −0.030 | −0.020 | 0.111 | 0.266 | 0.029 | −0.067 | −0.056 | −0.151 | −0.175 | 0.115 |
| Sudden loading sitting test | | | | | | | | | | | |
| Maximal angular displacement at 110 ms (°) | | | | | | | | | | | |
| Frontal direction | - | 0.248 | −0.008 | 0.024 | 0.241 | −0.144 | 0.092 | −0.264 | 0.130 | −0.080 | 0.155 |
| Lateral direction | | - | 0.065 | −0.100 | −0.154 | −0.063 | −0.284 | 0.165 | 0.408 | 0.260 | 0.287 |
| Posterior direction | | | - | −0.087 | −0.020 | −0.051 | −0.277 | 0.225 | −0.200 | −0.227 | −0.061 |
| Lumbopelvic stability tests | | | | | | | | | | | |
| Mean acceleration ($m/s^2$) | | | | | | | | | | | |
| Back bridge[a] | | | | - | 0.381 | 0.461* | 0.391 | −0.015 | 0.044 | 0.003 | 0.044 |
| Side bridge[a] | | | | | - | 0.499* | 0.384 | −0.159 | −0.126 | −0.182 | −0.200 |
| Front bridge[b] | | | | | | - | 0.331 | −0.083 | −0.269 | −0.222 | 0.030 |
| Bird-dog[c] | | | | | | | - | −0.173 | −0.128 | −0.096 | −0.207 |
| Trunk muscle endurance tests | | | | | | | | | | | |
| Maximal holding time (s) | | | | | | | | | | | |
| Biering–Sørensen test | | | | | | | | - | 0.342 | 0.383 | 0.375 |
| Side bridge test (P) | | | | | | | | | - | 0.786* | 0.326 |
| Side bridge test (NP) | | | | | | | | | | - | 0.428 |
| Front bridge test | | | | | | | | | | | - |

Abbreviations: NP, non-preferred side with respect to the leg; P, preferred side with respect to the leg.

[a]Bridging with single leg support on a bosu.

[b]Bridging with single leg support on a fitball.

[c]Two-point bird-dog position with the forearm on a bosu moving arm and leg free following a square trajectory.

*Correlation significance: $p < 0.002$.

**TABLE 2** Relationship between whole-body dynamic balance tests.

| | | Single-leg stance test | | Y-Balance test | | | | | | | | Single-leg triple hop test | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Anterior direction | | Posteromedial direction | | Posterolateral direction | | Composite index[a] | | | |
| | | P | NP | P | NP | P | NP | P | NP | P | NP | P | NP |
| Tandem stance test | | | | | | | | | | | | | |
| Mean radial error (mm) | | | | | | | | | | | | | |
| | | 0.439* | 0.463* | −0.046 | 0.045 | −0.232 | −0.123 | −0.130 | −0.060 | −0.157 | −0.054 | −0.058 | −0.019 |
| Single-leg stance test | | | | | | | | | | | | | |
| Mean radial error (mm) | | | | | | | | | | | | | |
| | P | - | 0.675* | 0.030 | 0.103 | −0.339 | −0.156 | −0.216 | −0.174 | −0.208 | −0.093 | −0.243 | −0.153 |
| | NP | | - | −0.041 | −0.068 | −0.419* | −0.193 | −0.253 | −0.224 | −0.278 | −0.182 | −0.247 | −0.194 |
| Y-Balance test | | | | | | | | | | | | | |
| Distance reached normalized to the leg length (%) | | | | | | | | | | | | | |
| Anterior direction | P | | | - | 0.791* | 0.632* | 0.641* | 0.656* | 0.537* | 0.841* | 0.704* | 0.319 | 0.214 |
| | NP | | | | - | 0.592* | 0.760* | 0.649* | 0.713* | 0.753* | 0.886* | 0.217 | 0.261 |
| Posteromedial direction | P | | | | | - | 0.799* | 0.776* | 0.747* | 0.909* | 0.782* | 0.477* | 0.404 |
| | NP | | | | | | - | 0.708* | 0.815* | 0.807* | 0.936* | 0.446* | 0.450* |
| Posterolateral direction | P | | | | | | | - | 0.833* | 0.918* | 0.802* | 0.405 | 0.362 |
| | NP | | | | | | | | - | 0.801* | 0.930* | 0.287 | 0.371 |
| Composite index | P | | | | | | | | | - | 0.858* | 0.453* | 0.372 |
| | NP | | | | | | | | | | - | 0.346 | 0.396 |
| Single-leg triple hop test | | | | | | | | | | | | | |
| Distance reached normalized to the leg length ($n$ times the leg length) | | | | | | | | | | | | | |
| | P | | | | | | | | | | | - | 0.864* |
| | NP | | | | | | | | | | | | - |

Abbreviations: NP, non-preferred leg; P, preferred leg.

[a]Composite index: composited score calculated from the three directions.

*Correlation significance: $p < 0.002$.

**TABLE 3** Relationship of trunk stability and endurance tests with whole-body dynamic balance tests.

| | Tandem stance balance test | Single-leg stance balance test | | Y-Balance test: Anterior direction | | Y-Balance test: Posteromedial direction | | Y-Balance test: Posterolateral direction | | Y-Balance test: Composite index[d] | | Single-leg triple hop test | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | P | NP | P | NP | P | NP | P | NP | P | NP | P | NP |
| Unstable sitting test | | | | | | | | | | | | | |
| Mean radial error (mm) | 0.502* | 0.384 | 0.522* | 0.131 | −0.024 | −0.135 | −0.045 | −0.108 | −0.146 | −0.051 | −0.083 | 0.041 | 0.006 |
| Sudden loading sitting test | | | | | | | | | | | | | |
| Maximal angular displacement at 110 ms (°) | | | | | | | | | | | | | |
| Frontal direction | 0.056 | 0.158 | −0.017 | 0.014 | −0.084 | −0.101 | −0.157 | −0.305 | −0.297 | −0.149 | −0.199 | 0.023 | −0.122 |
| Lateral direction | 0.117 | −0.292 | −0.356 | 0.067 | 0.058 | 0.001 | −0.044 | −0.167 | −0.100 | −0.040 | −0.034 | −0.256 | −0.314 |
| Posterior direction | −0.124 | 0.140 | −0.055 | −0.332 | −0.247 | −0.086 | −0.111 | −0.080 | −0.053 | −0.177 | −0.143 | −0.210 | −0.172 |
| Lumbopelvic stability tests | | | | | | | | | | | | | |
| Mean acceleration ($m/s^2$) | | | | | | | | | | | | | |
| Back bridge[a] | 0.180 | 0.114 | 0.274 | −0.152 | −0.093 | −0.240 | −0.151 | −0.242 | −0.314 | −0.241 | −0.210 | 0.164 | 0.229 |
| Side bridge[a] | −0.020 | 0.167 | 0.273 | 0.054 | −0.145 | −0.272 | −0.167 | −0.138 | −0.246 | −0.144 | −0.205 | −0.096 | −0.210 |
| Front bridge[b] | 0.090 | −0.075 | 0.035 | −0.222 | −0.207 | −0.296 | −0.164 | −0.180 | −0.267 | −0.258 | −0.232 | 0.071 | 0.075 |
| Bird-dog[c] | −0.032 | 0.221 | 0.231 | −0.078 | −0.022 | −0.211 | −0.068 | −0.143 | −0.175 | −0.165 | −0.102 | 0.175 | 0.217 |
| Trunk muscle endurance tests | | | | | | | | | | | | | |
| Maximal holding time (s) | | | | | | | | | | | | | |
| Biering–Sørensen Test | −0.112 | −0.196 | −0.180 | −0.128 | −0.037 | 0.088 | 0.100 | 0.048 | 0.078 | 0.011 | 0.055 | 0.072 | 0.081 |
| Side bridge test (P) | 0.078 | −0.182 | −0.248 | −0.011 | 0.113 | 0.158 | 0.195 | 0.040 | 0.104 | 0.074 | 0.149 | 0.219 | 0.146 |
| Side bridge test (NP) | −0.068 | −0.317 | −0.345 | −0.033 | 0.034 | 0.242 | 0.209 | 0.220 | 0.165 | 0.171 | 0.153 | 0.271 | 0.273 |
| Front bridge test | 0.049 | −0.324 | −0.346 | −0.221 | −0.138 | 0.035 | 0.058 | −0.089 | −0.019 | −0.095 | −0.035 | 0.173 | 0.100 |

Abbreviations: NP, non-preferred side with respect to the leg; P, preferred side with respect to the leg.

[a]Bridging with single leg support on a bosu.

[b]Bridging with single leg support on a fitball.

[c]Two-point bird-dog position with the forearm on a bosu moving arm and leg free following a square trajectory.

[d]Composite index: composited score calculated from the three directions.

*Correlation significance: $p < 0.002$.

Regarding the dynamic balance tests, the low correlations observed in this study (Table 2) are consistent with previous evidence.[37] Therefore, single balance measures of young individuals could only provide partial information on an individuals' postural control. Thus, a proper test selection or, in the worst-case scenario, an extensive battery of tests are needed to avoid missing the balance conditions of interest (related to athletic performance[9] and/or injury[10] prevention) for each individual.[38] Specifically, the results of this study show that the tandem and the single leg stance tests could belong to a different subgroup than the Y-Balance and the single-leg triple hop tests. Clearly all tests require coordination, proprioception, and balance, but the tandem and the single-leg stance tests are apparently more specifically designed to evaluate the ability to carry out small whole-body adjustments when performing a circular tracking task with visual feedback.[39] In contrast, although there is a low correlation between the Y-Balance and the single-leg triple hop tests, performance in these tests may be compromised by common variables such as foot type, ankle dorsiflexion range of motion and quadriceps and gluteus medius condition.[3,40]

## 5.2 | Potential influence of trunk stability and endurance on whole-body dynamic balance

The few correlations observed in this study question the relevance of trunk stability and endurance for enhancing dynamic balance in physically active young males. Again, it must not be forgotten that the reference values and relationships observed in this study cannot be generalized due to the specificity of the population. Thus, it must be considered that population-specific requirements (e.g., age, sex, and sport/activity)[31] may change the magnitude and nature of the potential relationship between variables. For example, the trunk stability performance in the unstable sitting test seems to be related to dynamic balance performance in the Y-Balance test of female soccer players.[3] In contrast, the unstable sitting test in physically active young male adults does not seem to be relevant in the Y-Balance test but it may be somewhat relevant in the posturographic standing tests due to the moderate correlations observed in this study. Interestingly, trunk muscle endurance seems to play a relevant role for dynamic balance in women with postmenopausal osteoporosis,[13] while trunk muscle strength seems to be relevant for dynamic balance in people with chronic low back pain as well as in asymptomatic adults.[14] Considering previous results[3,13–15,31] and those obtained in the present study, trunk-related capabilities seem to be conditional capabilities for physically active young male adults. That is, once a minimum level of trunk performance is reached, it might no longer contribute to improving dynamic balance, which would explain why these capabilities seem to be irrelevant in physically active young male adults but they may be important in populations with neuromuscular deficits or disorders (e.g., older adults, multiple sclerosis, stroke, and low back pain…). Another consideration that could explain the lack of relationships could be related to the different measurement conditions of trunk stability and endurance tests with respect to dynamic balance tests, as the body position assumed in the trunk stability and the trunk muscle endurance tests (sitting, bridging or quadruped positions) differs greatly from the standing position in the dynamic balance tests. Based on the correlational nature of the analyses performed in this study, it is not possible to discard the potential role of trunk performance for dynamic balance; nevertheless, from the authors' point of view, to clarify this issue, future studies should evaluate trunk participation in the specific tests designed for quantifying dynamic balance in physically active young male adults.

As with any research, it is important to highlight some limitations. A much larger sample would be desirable in each direction of the sudden loading sitting test and in the front bridge endurance test (Table S1) to minimize the probability of a type II error due to under-sampling. Second, our results should only be applied to physically active young male adults, so future studies would need to examine the relationships of these tests in other populations such as physically active young female adults, sedentary population and/or high-performance sports population. Finally, although we analyzed the most well-known gold standard protocols and recent field tests to quantify trunk stability, trunk muscle endurance and dynamic balance, there are many different laboratory and field tests in the literature that also measure these capabilities, so we could have chosen other tests, and therefore, could have obtained different results.

## 5.3 | Perspective

This study is one of the first to analyze the assumption of trunk stability and endurance as determining factors for dynamic balance in physically active young male adults using some of the most well-known gold standard protocols and recent field tests to quantify these capabilities. Coaches, physical trainers, clinicians, and researchers should be aware that: (i) obtaining an adequate performance in a trunk stability or trunk muscle endurance test does not necessarily mean achieving an adequate performance in a dynamic balance test in physically active young male adults; and (ii) the tests grouped under the same capability (i.e., trunk stability, trunk muscle endurance, or dynamic balance) are not interchangeable. Overall, these results highlight the importance of a proper selection of the most suitable test for each individual and situation. Future studies should continue to investigate to identify the manifestations of trunk-related capabilities that are determinants of whole-body dynamic balance, considering population-specific requirements (e.g., age, sex, and sport/activity).

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## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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## REFERENCES

1. Vera-Garcia FJ, López-Plaza D, Juan-Recio C, Barbado D. Tests to measure core stability in laboratory and field settings: reliability and correlation analyses. *J Appl Biomech*. 2019;35(3):223-231. doi:10.1123/jab.2018-0407
2. Juan-Recio C, López-Plaza D, Barbado Murillo D, García-Vaquero MP, Vera-García FJ. Reliability assessment and correlation analysis of 3 protocols to measure trunk muscle strength and endurance. *J Sports Sci*. 2018;36(4):357-364. doi:10.1080/02640414.2017.1307439
3. López-Valenciano A, Ayala F, De Ste Croix M, Barbado D, Vera-Garcia FJ. Different neuromuscular parameters influence dynamic balance in male and female football players. *Knee Surg Sports Traumatol Arthrosc*. 2019;27(3):962-970. doi:10.1007/s00167-018-5088-y
4. Barrio ED, Ramirez-campillo R, Garcia de Alcaraz Serrano A, RaquelHernandez-García R. Effects of core training on dynamic balance stability: a systematic review and meta-analysis. *J Sports Sci*. 2022;40(16):1815-1823. doi:10.1080/02640414.2022.2110203
5. Prat-Luri A, Moreno-navarro P, García JA, Barbado D, Vera-García FJ, Elvira JLL. Do initial trunk impairment, age, intervention onset, and training volume modulate the effectiveness of additional trunk exercise programs after stroke? A systematic review with meta-analyses. *Int J Environ Res Public Health*. 2020;17(23):8714. doi:10.3390/ijerph17238714
6. Granacher U, Gollhofer A, Hortobágyi T, Kressig RW, Muehlbauer T. The importance of trunk muscle strength for balance, functional performance, and fall prevention in seniors: a systematic review. *Sports Med*. 2013;43(7):627-641. doi:10.1007/s40279-013-0041-1
7. Winter DA. Human balance and posture standing and walking control during. *Gait Posture*. 1995;3(4):193-214.
8. Oddsson LI. Control of voluntary trunk movements in man. Mechanisms for postural equilibrium during standing. *Acta Physiol Scand Suppl*. 1990;595:1-60.
9. Zemková E, Zapletalová L. The role of neuromuscular control of postural and core stability in functional movement and athlete performance. *Front Physiol*. 2022;13:796097. doi:10.3389/fphys.2022.796097
10. Song Y, Li L, Dai B. Trunk neuromuscular function and anterior cruciate ligament injuries: a narrative review of trunk strength, endurance, and dynamic control. *Strength Cond J*. 2022;44(6):82-93. doi:10.1519/SSC.0000000000000727
11. Kuniki M, Iwamoto Y, Yamagiwa D, Kito N. Relationship among 3 different Core stability tests in healthy young adults: validity and gender differences. *J Sport Rehabil*. 2021;31(4):385-390. doi:10.1123/jsr.2021-0014
12. López-Plaza D, Juan-Recio C, Barbado D, Ruiz-Pérez I, Vera-Garcia FJ. Reliability of the star excursion balance test and two new similar protocols to measure trunk postural control. *PM R*. 2018;10(12):1344-1352. doi:10.1016/j.pmrj.2018.05.012
13. Özmen T, Gafuroğlu Ü, Aliyeva A, Elverici E. Relationship between core stability and dynamic balance in women with postmenopausal osteoporosis. *Turk J Phys Med Rehabil*. 2017;64(3):239-245. doi:10.5606/tftrd.2018.1674
14. Behennah J, Conway R, Fisher J, Osborne N, Steele J. The relationship between balance performance, lumbar extension strength, trunk extension endurance, and pain in participants with chronic low back pain, and those without. *Clin Biomech*. 2018;53:22-30. doi:10.1016/j.clinbiomech.2018.01.023
15. Barbado D, Gomez-Illan R, Moreno-Navarro P, Valero-Conesa G, Reina R, Vera-Garcia FJ. Postural control quantification in minimally and moderately impaired persons with multiple sclerosis: the reliability of a posturographic test and its relationships with functional ability. *J Sport Health Sci*. 2020;9(6):677-684. doi:10.1016/j.jshs.2018.06.008
16. Cholewicki J, Simons APD, Radebold A. Effects of external trunk loads on lumbar spine stability. *J Biomech*. 2000;33(11):1377-1385. doi:10.1016/S0021-9290(00)00118-4
17. Cholewicki J, Polzhofer GK, Radebold A. Postural control of trunk during unstable sitting. *J Biomech*. 2000;33(12):1733-1737. doi:10.1016/S0021-9290(00)00126-3
18. Mcgill S, Belore M, Crosby I, Russell C. Clinical tools to quantify torso flexion endurance: normative data from student and firefighter populations. *Occup Ergon*. 2010;9(1):55-61. doi:10.3233/OER-2010-0181
19. Juan-Recio C, Barbado-Murillo D, López-valenciano A, Vera-garcía FJ. Test de campo para valorar la resistencia de los músculos del tronco. *Apunt Educ Fis y Deporte*. 2014;3(117):59-68.
20. Riemann BL, Schmitz R. The relationship between various modes of single leg postural control assessment. *Int J Sports Phys Ther*. 2012;7(3):257-266.

21. Ringhof S, Stein T. Biomechanical assessment of dynamic balance: specificity of different balance tests. *Hum Mov Sci*. 2018;58:140-147. doi:10.1016/j.humov.2018.02.004
22. Shumway-Cook A, Woollacott M. *Motor Control: Translating Research into Clinical Practice*. Lippincott Williams and Wilkins; 2006.
23. Barbado D, Barbado LC, Elvira JLL, van Dieën JH, Vera-Garcia FJ. Sports-related testing protocols are required to reveal trunk stability adaptations in high-level athletes. *Gait Posture*. 2016;49:90-96. doi:10.1016/j.gaitpost.2016.06.027
24. Winter DA. *Biomechanics and Motor Control of Human Movement*. John Wiley & Sons; 2009.
25. Gogia PP, Braatz JH. Validity and reliability of leg length measurements. *J Orthop Sports Phys Ther*. 1986;8(4):185-188. doi:10.2519/jospt.1986.8.4.185
26. Heredia-Elvar JR, Juan-Recio C, Prat-Luri A, Barbado D, de los Ríos-Calonge J, Vera-Garcia FJ. Exercise intensity progressions and criteria to prescribe core stability exercises in young physically active males: a smartphone accelerometer-based study. *J Strength Cond Res*. 2024;38(2):266-273. doi:10.1519/JSC.0000000000004630
27. Heredia-Elvar JR, Juan-Recio C, Prat-Luri A, Barbado D, Vera-Garcia FJ. Observational screening guidelines and smartphone accelerometer thresholds to establish the intensity of some of the most popular core stability exercises. *Front Physiol*. 2021;12:751569. doi:10.3389/fphys.2021.751569
28. Cort JA, Dickey JP, Potvin JR. Trunk muscle contributions of to L4–5 joint rotational stiffness following sudden trunk lateral bend perturbations. *J Electromyogr Kinesiol*. 2013;23(6):1334-1342. doi:10.1016/j.jelekin.2013.09.006
29. McGill SM, Childs A, Liebenson C. Endurance times for low back stabilization exercises: clinical targets for testing and training from a normal database. *Arch Phys Med Rehabil*. 1999;80(8):941-944. doi:10.1016/S0003-9993(99)90087-4
30. Bohannon RW, Stef M, Glenney SS, et al. The prone bridge test: performance, validity, and reliability among older and younger adults. *J Bodyw Mov Ther*. 2018;22(2):385-389. doi:10.1016/j.jbmt.2017.07.005
31. Plisky P, Schwartkopf-Phifer K, Huebner B, Garner MB, Bullock G. Systematic review and meta-analysis of the Y-balance test lower quarter: reliability, discriminant validity, and predictive validity. *J Sports Phys Ther*. 2021;16(5):1190-1209. doi:10.26603/001c.27634
32. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J Chiropr Med*. 2016;15(2):155-163. doi:10.1016/j.jcm.2016.02.012
33. Hopkins WG. Spreadsheets for analysis of validity and reliability. *Sportscience*. 2015;19:36-44.
34. Hinkle DE, Wiersma W, Jurs SG. *Applied Statistics for the Behavioral Sciences*. Houghton Mifflin Company; 2003.
35. Jacobs JV, Horak FB, Health O. Cortical control of postural responses. *J Neural Transm (Vienna)*. 2007;114(10):1339-1348. doi:10.1007/s00702-007-0657-0
36. Lin K-H, Tang W, Chang Y, Liu Y, Liu C. Correlation of static and dynamic trunk muscle endurance and bat swing velocity in high school aged baseball players. *Isokinet Exerc Sci*. 2013;21(2):113-119. doi:10.3233/IES-130486
37. Kiss R, Schedler S, Muehlbauer T. Associations between types of balance performance in healthy individuals across the lifespan: a systematic review and meta-analysis. *Front Physiol*. 2018;9:1366. doi:10.3389/fphys.2018.01366
38. Sibley KM, Beauchamp MK, Van Ooteghem K, Straus SE, Jaglal SB. Using the systems framework for postural control to analyze the components of balance evaluated in standardized balance measures: a scoping review. *Arch Phys Med Rehabil*. 2015;96(1):122-132.e29. doi:10.1016/j.apmr.2014.06.021
39. Glave AP, Didier JJ, Weatherwax J, Browning SJ, Fiaud V. Testing postural stability: are the star excursion balance test and Biodex balance system limits of stability tests consistent? *Gait Posture*. 2016;43:225-227. doi:10.1016/j.gaitpost.2015.09.028
40. Ghulam HS. Factors that Influence the Performance of Hop Tests. Thesis. University of Salford. http://usir.salford.ac.uk/40000/ 2016.


## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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