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Do timed up and go and five times sit to stand test outcomes correlate with trunk stability? A pilot-study

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HIGHLIGHTS
- Dynamic balance stability was measured through mediolateral trunk acceleration.
- Evaluation of clinical tests Five Times Sit-Stand (FTSS) and Timed Up and Go (TUG).
- Evaluation of a new version of TUG requiring increased dynamic balance stability.
- FTSS completion time correlated with trunk accelerometry reflecting balance stability.
- TUG accelerometry seems to be more related to movement speed than to body balance.

ABBREVIATIONS

FTSS	Five Times Sit to Stand
ML	Mediolateral
η_p^2	Partial eta squared
RMS	Root mean square
r_p	Pearson's correlation
r_p^2	Squared correlation values
TUG	Timed Up and Go
TUG_C	Conventional version of the test
TUG_{DT}	In addition to a dual task
TUG_{OL}	New overline version

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BACKGROUND: Five Times Sit to Stand (FTSS) and Timed Up and Go (TUG) are clinical tests in which performance is evaluated through completion time, which can be thought to reflect dynamic balance. Completion time in these tests, however, can be affected not only by balance stability but also by other important components, such as legs' muscular strength and velocity.
AIM: This investigation aimed to evaluate the correlation of completion times in these clinical tests and mediolateral (ML) balance stability measured through lower trunk accelerometry in older individuals.
METHOD: Fifteen volunteers were evaluated, aged 60-86 years (M = 69.56±5.89 years). For TUG, we evaluated the conventional version of the test (TUG_C), in addition to a dual task (TUG_{DT}) and a new overline (TUG_{OL}) version featured by increased balance demand. Balance stability during test performance was measured through ML accelerations of the lower trunk.
RESULTS: The results indicated negative time-acceleration correlations for TUG_C ($r_p = -.71$, $r_p^2 = .50$, $p < .01$) and TUG_{DT} ($r_p = -.77$, $r_p^2 = .59$, $p < .01$) and a positive correlation for FTSS ($r_p = .73$, $r_p^2 = .53$, $p < .01$). The TUG_{OL} test failed to show significant time-acceleration correlations.
INTERPRETATION: Our results suggest that completion time in the FTSS test importantly reflects dynamic balance stability in older individuals. On the other hand, ML trunk acceleration when performing TUG seems to be more related to movement speed than body balance. Our results suggest that completion time can be considered a predictor of dynamic balance in the FTSS test.

KEYWORDS: Dynamic balance | Accelerometry | Aging | TUG | Five Times Sit to Stand

INTRODUCTION

The aging process leads to several consequences to the neuromuscular system, such as impoverished motor control and reduced muscular strength, with implications for body balance [1]. Neural and muscular factors can limit the completion of whole-body skills requiring dynamic balance in older individuals, such as getting up from a chair and walking [2]. Critically, reduced body balance stability associated with aging can lead to falls [3]. A large percentage of falls involve instability in the mediolateral (ML) direction [4,5], which is related to the challenge of controlling the center of mass over a narrow support base as while walking [6]. Previous results have shown that step width is increased in older individuals [7] and that ML displacement of the pelvis is a stronger predictor of falls than other gait variables [8]. Assessing dynamic balance stability in the ML direction, then, can be considered particularly relevant for evaluating upright stability in older individuals.

Some well-known tests for clinical evaluation requiring dynamic balance frequently applied to older individuals are Five Times Sit-to-Stand (FTSS) [9,10] and Timed Up and Go (TUG) [11–13]. The FTSS consists of performing five repetitions of sitting on a chair and standing up, completing the sequence as fast as possible. Performance is measured through time for test completion. Despite being a task constantly performed in everyday life, getting up from a chair is complex, requiring dynamic balance control, movement coordination between the trunk and upper-lower limbs, and lower limb muscle strength [1,14,15]. Of particular interest as a tool for balance evaluation, previous studies have shown that the FTSS is able to predict risk of recurrent falls [9] and to reveal balance disorders [16]. From these findings, completion time in this test can be expected to be associated with measures of dynamic balance.

The TUG test requires the participant to get up from a chair, walking quickly toward a frontal target 3 m away on the floor, circumvent the target (180 degrees turning), return to the chair and sit down. This is a straightforward mobility test [17,18], but it has also been described as a reliable clinical balance test [19], having been suggested as a predictor of fall risk [8]. Further studies have shown that during TUG performance, the addition of a secondary task (cognitive or motor) can increase the test's ability to discriminate fallers [13,20]. Similar to the FTSS, this test has a limitation as a tool for direct measurement of dynamic balance, given that it can be assumed to be affected by factors other than body balance, such as lower limb muscular strength and movement speed. In this regard, completion times observed on performance of both FTSS and TUG can be thought to reflect relevant factors not directly related to dynamic balance.

Trunk accelerometry has been widely used for the assessment of balance control, both in quiet upright posture [21] and in dynamic tasks [22–24]. Trunk acceleration indicates the rate of velocity change of the largest body segment, representing then a sensitive measurement of trunk stability over time in static and dynamic balance tasks. By using a triaxial accelerometer, one can evaluate trunk (balance) stability both the anteroposterior and mediolateral directions. This measuring tool that has been shown to be reliable and valid for the evaluation of balance stability in healthy individuals [25]. Evaluation of trunk accelerometry through root mean square values has been shown to be one of the most sensitive, reliable, and valid measurement of balance stability for healthy and neurological older individuals [26], indicating the central tendency of the acceleration magnitude. With an accelerometer attached to the lower trunk, acceleration data expresses the magnitude of the trunk oscillation, serving as an index of postural stability, allowing for a direct and accurate assessment of body balance. In different studies, accelerometry has been used to assess stability components in clinical tests [22–24,27]. However, there is a scarcity of tests in the literature objectively assessing dynamic balance in older individuals. In addition to analyzing whether the already established tests actually correlate with balance through a direct measurement of trunk stability, a test that more faithfully indicates dynamic balance is lacking in clinical evaluations. Since the tests currently employed in clinical research have important extraneous components to balance affecting completion time, it becomes evident the relevance of understanding the extent to which the completion time in the clinical tests TUG and FTSS is associated with direct measurements of balance stability during their performance. Additionally, it is possible that a variation of TUG requiring increased body balance may be more discriminative of dynamic balance than the conventional version in older participants. In this regard, walking on a narrow path has been shown to discriminate between fallers and non-fallers in older individuals [28]. When used in association with trunk acceleration measurements, walking on a straight line can provide useful information on balance stability in healthy older adults [29]. Measurement of trunk acceleration in the mediolateral (ML) direction, in particular, can reflect the lateral trunk stability of the different components of the tests requiring chair standing up and sitting (TUG and FTSS), in addition to walking straight forward and 180˚ body turning (TUG). All these test components can be thought to be improved by having increased lateral trunk stability during their performance. From these findings, employment of a narrow support base for the gait component of the TUG test, requiring walking on a straight line, might make the completion time more representative of the balance component of this test [30].

In the current investigation, we performed an exploratory pilot investigation in older individuals with the following primary aims: (1) to evaluate the correlation of completion times observed in the FTSS and in different versions of the TUG test with a direct measurement of trunk stability given by accelerometry while performing these tests; (2) to compare completion time and trunk stability of a new version of the TUG test requiring increased dynamic balance with the versions being currently used of this test. As a secondary aim, we evaluated the correlation between tests for both completion time and trunk acceleration to estimate the extent to which performance in one test can predict performance in the others.

METHODS

Participants

Fifteen physically active individuals without history of falls, aged 60-86 years (*M* = 69.56±5.89 years), 5 men and 10 women, participated in this study. All of them were contacted in programs for physical activity for seniors. The inclusion criteria were as follows: ability to get up from a chair and walk unassistedly, and no reports of illness (e.g., neurologic), injury (e.g., orthopedic) or medication consumption (e.g., muscle relaxant) that might affect performance in the applied tests. The single exclusion criterion was the inability to perform one or more of the tests. The participants signed an informed consent form, which was approved by the local university ethics committee.

Test and equipment

In all tests, a sequence of movements was to be performed in the shortest time, with the interpretation that short completion times indicate higher performance. Completion times were measured through a stopwatch, with visual detection of the onset and end of each trial. The following tests were evaluated:

Five Times Sit to Stand (FTSS). The test was initiated with the participants sitting on a regular-sized chair (approximately 45 cm high), without armrests, keeping their feet hip-width apart fully supported on the floor. The test consisted of getting up and sitting down five times in the shortest time, refraining from discharging the whole body weight on the chair accent when sitting, while keeping their arms crossed over the chest.

Timed Up and Go (TUG). For this test, three versions were analyzed. For the conventional version (TUG_C), participants started sitting on the chair, keeping both hands resting on the thighs and the feet hip-width apart fully supported on the floor. Following the examiner's verbal prompt, participants were to stand up, walk as quickly as possible toward a cone positioned 3 m away on the ground in front of the participant, circumvent the cone (180 degrees turning), return to the chair, turn and sit down [31]. The path was clear, flat and without distractors. For the TUG dual-task version (TUG_{DT}), participants performed the test as described for the conventional version while simultaneously performing a cognitive task [13]. The cognitive component of this test consisted of speaking aloud names of colors, fruits or animals throughout the test duration, according to the initial letter spoken by the examiner immediately before trial onset [32]. We also analyzed a new version of the TUG requiring increased dynamic balance. In this version, participants were to perform the gait component of the test by stepping during the whole gait over a 5-cm width straight line, marked through a tape on the floor. The cone used in the other versions of this test was replaced by a transversal line crossing the end of the walking line. Participants were to cross this line with one foot before returning, stepping over the line throughout their displacement. This test was named overline TUG (TUG_{OL}). This new version of the TUG test is proposed to pose a higher demand for ML balance by preventing participants from moving their feet laterally during gait to increase ML body stability [7]. By introducing this modification to the TUG test, it is assumed that the completion time is more representative of dynamic balance than the conventional and dual-task versions of this test. During the performance of all tests, dynamic balance stability was evaluated through trunk acceleration in the ML direction. This measurement was made by using a triaxial accelerometer (Delsys Trigno) attached to the lumbar region over the L3-L4 vertebrae of the trunk. Assessment of performance on the TUG test based on an accelerometer attached to this body region has been shown to be effective in differentiating fallers and non-fallers [20]. To identify the start and end times of the trial, a manual electronic key was used. Recording of accelerometer signals was performed using a Vicon system (Oxford, UK, Nexus 2.7).

Procedures

In all tests, a single familiarization trial was provided before the performance of three probing trials. In cases of failure to perform a trial, it was replaced immediately. The sequence of tests was randomized across participants. Sitting rest intervals of 1 minute between trials and 2 minutes between tests were provided to prevent fatigue. Data collection was completed in a single session of approximately 40 minutes.

Accelerometer signals were sampled at a frequency of 1 kHz, and were recorded during the full duration of the tests. This implies that for the three versions of the TUG test we did not differentiate the phases of standing up, walking, turning and sitting down. After preliminary visual inspection of the signals, raw data were exported to a personal computer and processed offline by using MATLAB routines (Mathworks, Natick, MA). Raw signals were amplified with a gain of 1000 and filtered through a 10 Hz fourth-order double pass Butterworth filter.

Data analysis

Analysis was conducted for the total duration of each trial. Individual values were based on the average of the 3 probing trials for each test. The following variables were analyzed: 1) time for test completion and 2) root mean square (RMS) of lower trunk acceleration in the ML direction during the entire duration of the trial. Time for test completion was measured through a stopwatch operated by a single examiner (LSR). We analyzed RMS acceleration in the ML direction, considering the visually determined whole time duration of each trial (movement onset-end). Individual data were based on the average for three trials in each task. Acceleration data were processed through a custom-written MATLAB software (MathWorks Inc., MA) routine.

Analysis of data distribution normality was performed through the Shapiro-Wilk test. Comparisons of completion time and trunk acceleration between the three versions of the TUG test were made through one-way analyses of variance for repeated measures. Post hoc comparisons were made through the Bonferroni test, with effect size indicated by partial eta squared (η_p^2). The main statistical analysis was performed through Pearson's correlation (r_p) tests between completion time and RMS of lower trunk acceleration in the ML direction for each test. In addition, we tested for the correlation of performance across the tests. The reference values for magnitude of Pearson’s correlation coefficient are as follows: up to .30 negligible, .31 to .50 low, .51 to .70 moderate, .71 to -.90 high, and .91 to 1.0

very high [33]. Squared correlation values (r_p^2) are presented as a quantification of shared variance. Analyses were performed by using SPSS software (v.24, IBM Statistics, USA), with statistical significance set at p <.05.

RESULTS

Data from all tests were normally distributed. Data from one outlier (2 standard deviations above the mean) were excluded for the following tests: TUGC, TUGDT and FTSS. Raw data are available as Supplementary material.

Comparison between the three versions of the Timed Up and Go test

Completion time

The results for completion time indicated a significant effect of TUG version, $F(2, 40) = 18.46$, p <.01, η_p^2 =.48. Post hoc comparisons indicated significant differences in all comparisons, as follows: (1) TUG_{DT} > TU_{GC} (p =.02), (2) TUG_{OL} > TUG_C (p <.01), and (3) TUG_{OL} > TUG_{DT} [p =.01] (Figure 1A).

RMS_{ml} trunk acceleration

Results for RMS_{ml} trunk acceleration indicated a significant effect of TUG version, $F(2, 40) = 8.63$, p <.01, η_p^2 =.30. Post hoc comparisons indicated the following significant differences: higher acceleration values for the TUG_C compared to TUG_{DT} and TUG_{OL} (p values <.01), with lack of a significant difference between the latter (Figure 1B).

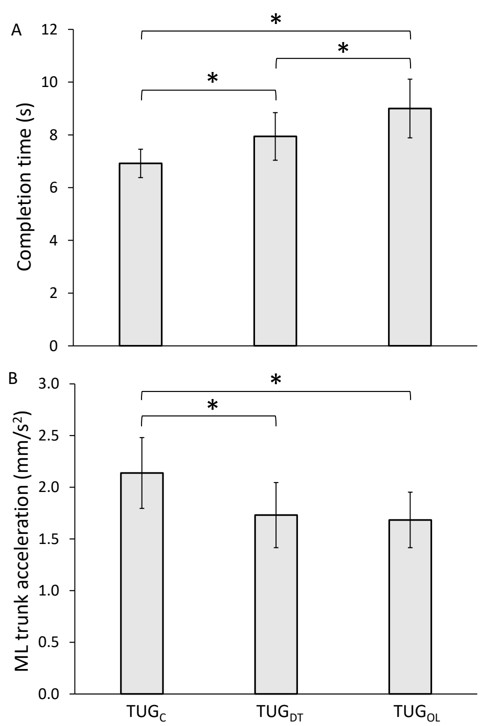

Figure 1. Comparison between mean values (standard errors in bars) between (A) completion time and (B) RMS_{ML} of the three TUG versions; *p <.05

Correlation between RMS_{ml} and completion time

Timed Up and Go

Analysis indicated high negative correlation between completion time and trunk acceleration for the conventional (r_p = -.71, r_p^2 =.50, p <.01, Figure 2A) and dual-task (r_p = -.77, r_p^2 =.59, p <.01, Figure 2B) TUG versions, while for the overline TUG version a negligible correlation was found (r_p = -.06, r_p^2 = zero, p =.82, Figure 2C).

Five Times Sit-to-Stand (FTSS)

Results for the FTSS test showed a high positive correlation (rp =.73, rp2 =.53, p <.01) between completion time and trunk acceleration (Figure 2D).

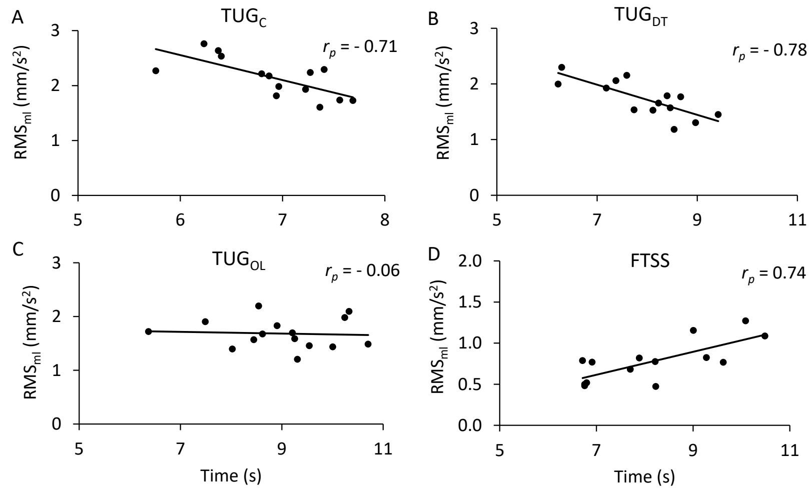

Figure 2. Correlation between completion time and root mean square (RMS) of mediolateral lower trunk acceleration in each test: (A) conventional TUG (TUG$_C$), (B) dual-task TUG (TUG$_{DT}$), (C) overline TUG (TUG$_{OL}$), and (D) Five Times Sit-to-Stand (FTSS)

Correlation between tests

The correlation analysis of completion time between tests indicated a high correlation between TUG$_C$ and TUG$_{DT}$ (r_p =.71, rp2 =.50, p <.01). Results for ML trunk acceleration indicated a high correlation between TUG$_C$ and TUG$_{DT}$ (r_p = .78, r_p^2 = .60, p < .01), and moderate correlations between TUG$_C$ and TUG$_{OL}$ (r_p = .54, r_p^2 = .29, p = .05), TUG$_{OL}$ and FTSS (r_p = .67, r_p^2 = .44, p < .01), and TUG$_{DT}$ and TUG$_{OL}$ (r_p = .52, r_p^2 = .27, p = .05) (Figure 3).

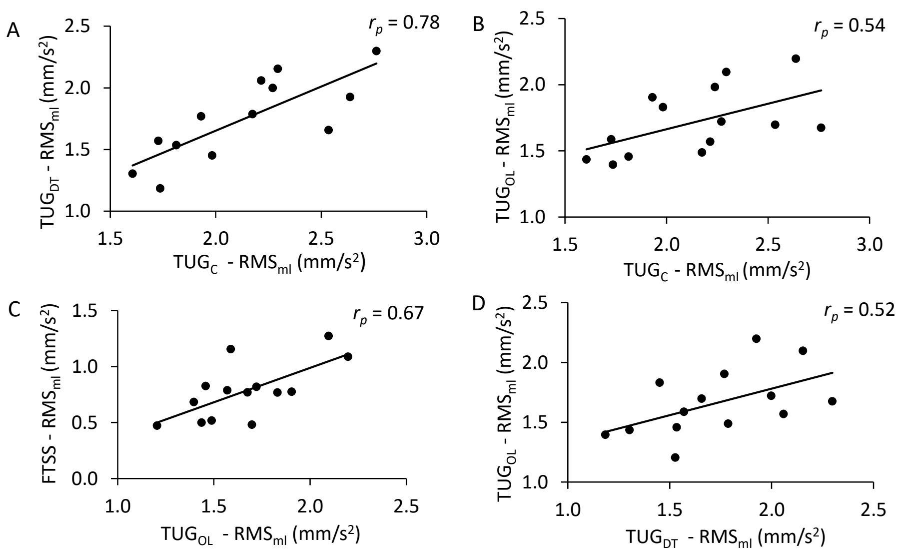

Figure 3. Correlation of root mean square (RMS) of mediolateral trunk acceleration between the following: (A) conventional TUG (TUG$_C$) and dual task TUG (TUG$_{DT}$), (B) conventional TUG and overline TUG (TUG$_{OL}$), (C) overline TUG and Five Times Sit-to-Stand (FTSS), (D) overline TUG and dual task TUG.

DISCUSSION

This study aimed to evaluate the correlation of completion times observed in the FTSS and in different versions of the TUG test with acceleration-based measurement of trunk stability and to compare conventional and a new version of the TUG test. The results indicated that the overline TUG test led to a longer completion time than the conventional and dual-task versions of this test, while trunk acceleration values were lower for the overline and dual-task versions than the conventional version. As a primary outcome, correlation analysis showed a strong negative correlation between completion time and trunk acceleration for the conventional and dual-task TUG versions, while no such a correlation was found for the overline version. A positive correlation between completion time and trunk acceleration was found for the FTSS test only. As a secondary outcome, we found moderate to high correlations for ML trunk acceleration between some of the evaluated tests, with particular interest in the positive correlation of trunk acceleration between the tests requiring dynamic balance stability in the ML direction: FTSS and the overline TUG.

A relevant point in the interpretation of our results was the longer completion time (Figure 1A) and lower trunk acceleration (Figure 1B) values in the TUG variation proposed in this study of walking over a straight line for the gait component. This result indicates that the higher demand for ML balance while walking in this version of the test was dealt with by reducing movement speed, leading to completion times even longer than those observed in the dual-task TUG version. Then, speed reduction in this case can be seen as a strategy to increase ML balance stability, leading to lower acceleration values of trunk oscillation in the ML direction in comparison with the conventional version of the test. This result is consistent with the expected effect of balance demand on test completion time. Performance on dual-task TUG was characterized by longer completion times and reduced trunk acceleration than the conventional version. A point worth noting in this result is that performing a cognitive task during TUG completion could be supposed to represent a challenge to dynamic balance. In this sense, due to the use of attentional resources potentially relevant for balance control [34], one would expect that the dual-task TUG version would lead to increased rather decreased ML body sway during the test execution. The opposite effect, with reduced acceleration of ML trunk sway in comparison with the conventional version of this test, may indicate that trunk acceleration is more related to movement speed than to body balance properly. This interpretation is reinforced by strong negative correlations between completion time and acceleration for the conventional and dual-task versions of the test, with short completion times being associated with high ML trunk accelerations. It seems that as one moves faster, quick stepping movements during TUG performance lead to higher accelerations of ML trunk sway, which can be expected to be particularly true in the gait component of the test. As the accelerometer was attached to the lower trunk, it can be thought that fast hip lateral displacements for fast walking respond to the main component of the observed high time-acceleration correlation. This interpretation is consistent with previous findings from the evaluation of trunk acceleration showing that when increasing gait speed trunk acceleration in the ML direction increased as well [35]. Thus, it is apparent that ML lower trunk acceleration when performing the TUG test mainly reflects movement speed in healthy older individuals rather than stability of dynamic balance. The lack of a significant correlation between test completion time and trunk acceleration for the overline TUG, but not for the other versions, is consistent with this interpretation. It seems that by constraining ML body sway when walking over a straight line dampened lateral accelerations, leading to a reduced amplitude of center of mass displacements [36], making them dissociate from its completion time. From this interpretation, ML lower trunk acceleration seems to not represent a faithful index of balance stability when performing any versions of the TUG test.

The results from the FTSS were consistent with the expected relationship between completion time and trunk acceleration for a test loading on dynamic balance control, with a strong positive correlation between those variables. Our results indicated that individuals who performed the test in a shorter time had lower ML trunk accelerations. This finding suggests that an important component to achieve low completion times in this test is maintaining trunk stability in the ML direction, which can be thought to result from predominantly symmetrical movements between the two legs during the fast sequence of sitting down and standing up movements. Preventing increased ML sway when performing the test while letting the center of mass oscillate back and forth over the support base to repeatedly stand up and sit down may be a requisite to achieve high performance in this test. From this proposition, we conceive that completion time in FTSS reflects ML balance stability in an important way. Another result converging to this interpretation was the positive correlation of trunk acceleration between FTSS and the overline TUG (Figure 3, panel C). As these two tests required ML trunk stability for higher performance, it is plausible that this correlation reflects a common component of ML balance stability between these tests. Thus, although performance on the FTSS can be considered to result from the combination of multiple components beyond body balance, like muscle strength, mobility and interlimb coordination [1,14,15], dynamic balance seems to have a high weight in the completion time of these two tests. This conclusion is convergent with previous results indicating that the FTSS is able to predict risk of recurrent falls [9] and to be sensitive to balance disorders [16]. From this perspective, our results suggest that in healthy older individuals, completion time in the FTSS test can be considered to be associated with dynamic balance.

This is a preliminary investigation aiming to test the dynamic balance component of clinical tests frequently used to evaluate dynamic balance deficits in older individuals, and as such has limitations. Attaching the accelerometer at the lumbar region of the trunk seems to have captured the lateral displacements of the hip during the gait, making it difficult to use trunk acceleration values as an index of ML balance stability. By analyzing the data from the different components of the TUG test together, we were not able to differentiate the specific dynamic balance requirements of standing up, turning, walking in a straight line and sitting down. The limited number of participants prevents a confident generalization of the results to healthy older adults. From these limitations, this study should be taken as pilot-study potentially leading to further investigation.

CONCLUSION

Results from the present study lead to the following conclusions: (1) The proposed overline TUG led to an increased test completion time, supposedly due to the greater balance demand in the mediolateral direction compared to the conventional version of this test; then, this modification of the conventional test could be considered appropriate to increase balance demand of the test. (2) TUG versions currently used in research and clinical practice (conventional and dual-task) showed a strong negative correlation between task completion time and ML lower trunk acceleration, a relationship possibly due to movement speed. (3) The strong positive correlation found between completion time and ML trunk acceleration in the FTSS test suggests that the completion time in this test can be considered a valid indirect index of dynamic balance. As such, the completion time in the FTSS test seems to reflect more faithfully the demand for balance control than the three versions of the TUG test.

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