Age-related differences in time-limit performance and force platform-based balance measures during one-leg stance

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A B S T R A C T

Poor posture control has been associated with an increased risk of falls and mobility disability among older adults. This study was conducted to assess the test–retest reliability and sensitivity to group differences regarding the time-limit (TLimit) of one-leg standing and selected balance parameters obtained with a force platform in older and young adults. A secondary purpose was to assess the relationship between TLimit and these balance parameters. Twenty-eight healthy older adults (age: 69 ± 5 years) and thirty young adults (age: 21 ± 4 years) participated in this study. Two one-leg stance tasks were performed: (1) three trials of 30 s maximum and (2) one TLimit trial. The following balance parameters were computed: center of pressure area, RMS sway amplitude, and mean velocity and mean frequency in both the anterio-posterior and medio-lateral directions. All balance parameters obtained with the force platform as well as the TLimit variable were sensitive to differences in balance performance between older and young adults. The test–retest reliability of these measures was found to be acceptable (ICC: 0.40–0.85), with better ICC scores observed for mean velocity and mean frequency in the older group. Pearson correlations coefficients (r) between balance parameters and TLimit ranged from –0.16 to –0.54. These results add to the current literature that can be used in the development of measurement tools for evaluating balance in older and young adults.

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1. Introduction

Poor posture control has been associated with an increased risk of falls in older adults (Berg et al., 1992; Tinetti et al., 1988). In the present study, posture control will be referred to as “balance”, which is a generic term used to describe the body’s ability to adjust the center-of-pressure (COP) in order to maintain projection of the center of mass (COM) within the manageable limits of the base of support (Winter, 1995).

Several clinical and laboratory methods have been developed to assess different dimensions of balance in order to assist clinical decision-making with respect to interventions for balance-related deficits, and thus fall prevention. Functional balance tests such as Tinetti and Berg scales (Berg et al., 1992; Tinetti et al., 1988), which use the maximum time a person can stand on one leg without sup-port (namely here: TLimit) as a scale item, have been used with good reliability to estimate a subject’s risk of falling (Godi et al., 2013). However, as with any single domain measure (TLimit), critical information about balance may not be optimal. On the other hand, COP parameters calculated from force platform data can provide finer information related to biomechanical and neuromuscular control strategies for maintaining balance among different populations (Howe et al., 2009; Lacour et al., 1997; Melzer et al., 2004; Nardone and Schieppati, 2010).

Commonly used measures of COP displacement can be calculated in the time (e.g., velocity) and frequency (e.g., median frequency) domains (Bauer et al., 2008; Corriveau et al., 2000; Gribble and Hertel, 2004; LeClair and Riach, 1996). However, because these variables originate from biological systems, they also have an intrinsic variability that can affect their reliability and validity. Different studies using different experimental protocols have documented the reliability of these variables for both healthy young adults and older subjects (Bauer et al., 2008; Corriveau et al., 2000; Gribble and Hertel, 2004; LeClair and Riach, 1996; Goldie et al., 1989; Lin et al., 2008; Pinsault and Vuillerme, 2009; Santos...
et al., 2008). These studies reported excellent reliability (>0.75) for several balance parameters (Bauer et al., 2008; Corriveau et al., 2000; Lin et al., 2008; Pinsault and Vuillerme, 2009; Lafond et al., 2004) during a bipedal quiet standing task. However, maintaining a quiet standing position using two legs is not a major challenge to our balance control system (Clifford, 2010). Thus, the clinical usefulness of data obtained under such conditions, i.e., when documenting balance deficits in young adults, the older or rehabilitation patients, is limited. Few studies have investigated these balance parameters for the one-leg stance and still fewer have determined their reliability (Pinsault and Vuillerme, 2009), which is of concern when these are used to determine the efficacy of a specific balance intervention for fall prevention in older individuals. Furthermore, some studies (Hughes et al., 1996; Holbein-Jenny et al., 2007) have correlated the T\textsubscript{limit} from functional performance with COP balance parameters obtained in bipedal tasks only. It is likely that such an association would be stronger for balance parameters obtained during a one-leg stance condition, and this could have implications for the prediction/prevention of falls (Michikawa et al., 2009).

The aims of the present study were to assess (1) the test–retest reliabilities of T-limit and four measures of the COP, (2) the sensitivities of these measures to group differences (older and young adults), and (3) the relationships between T\textsubscript{limit} and each of the four COP measures.

2. Methods

2.1. Subjects

Twenty-eight healthy older (20 women) and 30 young adult volunteers (16 women) participated in this study. All participants were recruited by convenience between 2010 and 2011; older adults from the local community who were participants in a physical exercise program for seniors at the Universidade Norte do Paraná (enrolled for at least 1 year) and young adults from the university community. The characteristics of the subjects are presented in Table 1. Inclusion criteria were as follows: (1) older adults: aged over 60 years, living independently, no falls in the past year and a cognitive status of >21 on the Mini-Mental State Examination (Hughes et al., 1996); (2) young adults: aged between 18 and 30 years and not enrolled in any physical activity program at the time of the study. General exclusion criteria were as follows: self-reported injuries, illnesses, musculoskeletal disorders, systemic–neurological–degenerative diseases, severe labyrinthitis and chronic diseases of the cardiovascular or respiratory system. Subjects were informed about the experimental protocol and the potential risks of the study and gave written consent before their participation. The protocol and the consent form had been previously approved by the local Ethics committee (##PP/0114/09).

2.2. Procedures

Two approximately 2-h sessions separated by a maximum of 2 weeks were required. The same investigator performed the procedures and tasks with all participants in the same laboratory environment to ensure uniformity. To assess reliability, all subjects performed the same experimental protocol after a 2-week interval.

2.3. Tasks

Each participant was allowed to practice the one-leg stance before testing and, since only one leg was being tested, the subjects were free to choose which leg they preferred to stand on. The participants performed two tasks: (1) three 30-s trials of the one-leg stance on a force platform (Gil et al., 2011), with a rest period of approximately 30 s between trial. The mean of these three trials for each balance measure was retained to assess: (i) the sensitivity of the balance parameters for discriminating between groups (session one only) and (ii) the test–retest reliability between the measures across two sessions. This approach was used because averaging the balance parameters values across three trials improves reliability (Bauer et al., 2008).

After 5 min of rest from task one a second task, consisting of a one legged-stance maintained until loss of balance (T\textsubscript{limit}), was performed. The T\textsubscript{limit} criterion in the present study was defined as the maximum time it took until a subject suddenly abandoned the posture due to loss of balance, i.e., when the lifted foot touched either the force platform or the floor. This task was used to assess the relationship between T\textsubscript{limit} of one-leg standing and selected balance parameters from the force platform.

During all trials in both tasks, the participants were instructed to stand on one leg (see Fig. 1 for illustration) under the following standardized conditions: barefoot, eyes open and looking at a target (cross) placed on a wall at eye level 2 m away, arms at their sides or parallel to their trunk. To prevent falls or injuries during all testing, an investigator stood close to each participant.

Table 1

<table>
<thead>
<tr>
<th>Characteristics of Subjects.</th>
<th>Older (n = 28)</th>
<th>Young adults (n = 30)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>69 (5)</td>
<td>21 (4)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.56 (7.8)</td>
<td>1.69 (6.9)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>64.2 (8.8)</td>
<td>65.6 (13.4)</td>
</tr>
<tr>
<td>BMI (kg/m\textsuperscript{2})</td>
<td>27 (4)</td>
<td>23 (4)</td>
</tr>
<tr>
<td>Cognitive status*</td>
<td>27 (2)</td>
<td>/</td>
</tr>
</tbody>
</table>

Note: Mean values with standard deviation (SD). BMI: Body Mass Index. *Mini-Mental State Examination (normal range based in a cutoff >21).
2.4. Computation of COP-based balance parameters

The vertical ground reaction force data from the force platform (BIOMEC400, EMG System do Brasil, Ltda., SP) were sampled at 100 Hz. All force signals were filtered with a 35-Hz low-pass second-order Butterworth filter and converted into COP data using proper software, which was compiled with MATLAB routines (The Mathworks, Natick, MA). Stabilographic analysis of COP data led to the calculation of the four main balance parameters: (1) 95% confidence ellipse area of COP (A-COP in cm²), (2) Root Mean Square (RMS) amplitude of COP sway (RMS in cm), and (3) mean velocity (MVeloc in cm/s) and (4) mean frequency (MF in Hz) of COP for both antero-posterior (A/P) and medio-lateral (M/L) directions. For both tasks, these balance parameters were calculated for the total duration of the trial for each subject.

2.5. Statistical analysis

All statistical analyses were performed with NCSS statistical software (version 6.0 for Windows) with an alpha level of 0.05. All variables were normally distributed, as verified with the Shapiro–Wilk test. Student unpaired $t$-test was used to assess between-group (older vs. young adults) differences in $T_{\text{Limit}}$ and in four COP variables in order to determine the sensitivity of these measures for discriminating of balance between the two groups. Pearson’s correlation coefficients were used to assess the relationship between four balance parameters (A-COP, RMS, MVeloc, MF) and the $T_{\text{Limit}}$ computed in task two.

To assess the test–retest reliability across the two sessions in task one, ICC$_{2,1}$ and SEM were calculated as described in Shrout and Fleiss (Shrout and Fleiss, 1979), based on two-way ANOVAs, which allowed a contrast between the within-subject variability and the between-subject variability. To classify the ICCs, we used Fleiss’ Classification, where an ICC below 0.4 was considered as “poor” reliability, between 0.40 and 0.75 as “fair to good” reliability and above 0.75 as “excellent” reliability (Fleiss, 1997).

3. Results

3.1. Reliability assessment

The reliability of $T_{\text{Limit}}$ was excellent with an ICC of 0.87 for older and 0.75 for young adults across two sessions. The ICC scores of older and young adult volunteers varied between the four balance parameters, ranging from 0.40 to 0.85 (SEM: 0.08–6.66); i.e., showing fair to excellent reliability (Table 2). Mean velocity was the most reliable measure, followed by the MF parameter, especially in older group, showing excellent ICC values (>0.80) and lower SEM values in both directions. Excellent reliability was observed for sway area of COP in young adults only (Table 2), whereas the RMS parameter presented the poorest reliability across both groups.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Older ($n = 20$)</th>
<th>Young adults ($n = 30$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-COP (cm²)</td>
<td>0.60</td>
<td>0.83</td>
</tr>
<tr>
<td>RMS (cm)</td>
<td>0.51</td>
<td>0.55</td>
</tr>
<tr>
<td>RMS (cm)</td>
<td>0.40</td>
<td>0.60</td>
</tr>
<tr>
<td>MF (Hz)</td>
<td>0.82</td>
<td>0.68</td>
</tr>
<tr>
<td>MF (cm/s)</td>
<td>0.85</td>
<td>0.72</td>
</tr>
<tr>
<td>MVeloc (cm/s)</td>
<td>0.82</td>
<td>0.75</td>
</tr>
</tbody>
</table>

**Table 2**: Test–retest reliability results COP-based balance parameters (task one).

* ICC: intra-class correlation coefficient; SEM: standard error of measurement (absolute error); SEM (%): standard error of measurement relative to the grand mean.

* Significant differences ($P < 0.05$ from Student’s $t$-test) were found between elderly and young adults for all balance parameters.

**Fig. 2.** Balance parameters (95% ellipse A-COP and RMS, MF, MVeloc in A/P and M/L directions of movement) values (error bars correspond to standard deviations) from the BIOMEC400 force platform. *Significant differences ($P < 0.05$ from Student’s $t$-test) were found between elderly and young adults for all balance parameters.
3.2. Age-related differences on COP parameters and \( T_{\text{Limit}} \)

The comparison between older and young adults using session one data is depicted in Fig. 2. All selected COP balance parameters proved to be sensitive to differences between the two groups (\( P < 0.05 \)) for this specific one-leg stance task. Greater COP values were observed for the older than the young adults.

The older adults showed significantly shorter \( T_{\text{Limit}} \) values than the younger subjects for the \( T_{\text{Limit}} \) task (Table 3), ranging from 6 to 74 s (mean: 25 ± 15 s), whereas values for young adults ranged between 30 and 350 s (mean: 162 ± 113 s).

Only two balance-related variables were significantly associated with \( T_{\text{Limit}} \): A/P MF correlated moderately with \( T_{\text{Limit}} \) in both groups; whereas A-COP correlated with \( T_{\text{Limit}} \) only in the older group (Table 3). Other than A-COP, correlation values were not shown to be systematically higher than the other across balance parameters.

4. Discussion

The test–retest reliability of the three measures (\( T_{\text{Limit}} \), MF, and MVeloc) was found to be acceptable for evaluating balance in older and young adults during one-leg stance test. Also, all four balance parameters obtained with the force platform as well as the time-limit variable were sensitive enough to discriminate the balance between older and young adults. Both MF and MVeloc balance parameters showed an association with \( T_{\text{Limit}} \). These results add to the literature concerning the development of measurement tools for evaluating balance deficits in older adults, especially during a challenging task.

4.1. Reliability assessment

To the authors’ knowledge and based on a brief recent literature search concerning the reliability of COP measures (Goldie et al., 1989), the reliability of balance parameters computed during a one-leg stance test in both older and young individuals has not been reported. Despite differences in experimental protocol and statistical models of reliability measurements, our results are in agreement with other studies (Bauer et al., 2008; Corriiveau et al., 2000; Lin et al., 2008; Pinsault and Vuillerme, 2009). Balance parameters can present quite diverse levels of reliability. Our results indicated that mean velocity (MVeloc) was the most reliable balance parameter (ICC = 0.72–0.85; SEM = 0.2–1.3) across groups (older and younger) and for both directions (A/P and M/L), which is consistent with results from previous studies of older adults during bipedal quiet standing (Lin et al., 2008; Lafond et al., 2004).

Furthermore, our results pointed out the excellent reliability of mean frequency (MF) in the A/P direction, especially for the older group, suggesting that this parameter, in addition to being associated with the \( T_{\text{Limit}} \) variable, also presents stability over time under this experimental condition. This suggests that this parameter, as well as MVeloc, could be used with relevance for clinical decision-making concerning the effects of a rehabilitation program over the course of several days for improving balance in older adults. Interestingly, ICC scores for MF and MVeloc were slightly higher for the older adults, as also observed by Lin et al. (2008) during a bipedal task. This may be related, at least in part, to a higher variation of measures across older individuals, which in turn contributes to higher ICC scores (Portney and Watkins, 2000).

4.2. Age-related differences

It is well known that aging is associated with neuro-musculoskeletal alterations and decreased physiological functions, which in turn can lead to problems such as muscular weakness and lack of mobility, as well as other sensory-motor deficits and a consequent loss of balance and falls (Orr, 2010; Piirtola and Era, 2006). In the present study, the performance of the older adults was worse in both tasks (30-s balance trials and \( T_{\text{Limit}} \)). These results agree with previous studies conducted with older adults (Corriiveau et al., 2000; Pinsault and Vuillerme, 2009; Lafond et al., 2004). In contrast to these previous studies, which assessed healthy community-dwelling older adults using double-leg stance tasks, the present study included a more challenging balance-control task, which may be more predictive of balance problems and, consequently, a better indicator of falls (Hurvitz et al., 2000).

Typical measurements used to evaluate balance and fall risk in older adults (Berg et al., 1992; Tinetti et al., 1988; Lord et al., 2001; Persad et al., 2010; Rubenstein, 2006) include the time necessary for carrying out functional tasks, such as getting up from a chair, circling a cone and returning, maintaining a one-legged stance, or walking a distance of 10 m as fast as possible (Persad et al., 2010; Mancini and Horak, 2010; Flegel et al., 1973). As expected, age-related differences were found in the present study regarding \( T_{\text{Limit}} \) during the one-leg stance trial (which was not stopped at 30 s), suggesting a possible balance deficit in the older adults that could be associated with poor lower-limb muscular endurance (Shrot and Fleiss, 1979). The mean \( T_{\text{Limit}} \) in this study corresponds to earlier reports resulted for older (Mancini and Horak, 2010), as well as for young adults (Flegel et al., 1973).

Take out, factors regulating balance are multifaceted (i.e., the integration of different systems) and this could explain the weak (> 0.16) to moderate (< 0.54) correlations between \( T_{\text{Limit}} \) and balance COP parameters. Our correlation results supplement those of previous studies (Hughes et al., 1996; Lindmark et al., 1999; Tang...
et al., 1998) that correlated different balance parameters with the time taken during different bipedal functional balance tests. The results of this study identified two balance parameters (MF and A-COP) from the force platform data that were found to be associated with a unipodal balance deficit by the $T_{limit}$ in older adults. Compared with previous studies, the relationships we documented have to do with a task that has greater fall-related relevance in older adults (Hughes et al., 1996), and could thus have implications for both the prevention and rehabilitation of balance problems in older adults. Nevertheless, a dysfunction in an individual’s ability to maintain or restore a state of balance implies a deficit in postural control (Pollock et al., 2000). Any cognitive, proprioceptive (sensory and motor), muscular strength or motor coordination impairment could result in postural control deficits, and clinical balance assessment tools, such as the $T_{limit}$ variable or COP parameters, can provide some information on a variety of dimensions of postural control deficits (Hughes et al., 1996; Michikawa et al., 2009; Hurvitz et al., 2000, 2000; Mancini and Horak, 2010; Pollock et al., 2000). Functional tests can measure balance deficit indirectly through the recorded time-limit of physical performance (i.e., one aspect of physical condition or muscular capacity of individual), while COP parameters from a force platform can directly analyze balance deficits related to proprioception and postural adjustments (feedback and feedforward) of the neuromuscular system (Winter, 1995; Laour et al., 1997; Lafond et al., 2004; Hughes et al., 1996; Holbein-jenny et al., 2007; Pollock et al., 2000). This is further supported by a recent study (Nguyen et al., 2012) suggesting that clinical functional tests such as time-limit to stand one leg and laboratory-based measures from COP parameters may capture different aspects of balance and likely complement each other.

4.3. Study limitations

The overall results of this study cannot necessarily be generalized to older adults because of the limited size of our sample (n = 28), which likely does not represent the heterogeneity of balance status of all older individuals. Another limitation is that there was no comparison between sexes because we used a convenience sample that was not matched for sex. Also, EMG complementary analysis of muscular pattern during unipodal balance test would be relevant to help in interpretation of results from relationship between $T_{limit}$ and balance COP parameters.

5. Conclusion

The test–retest reliability of the balance measures was found to be acceptable, with better ICC scores observed for MVeloc and MF in the older group. All four balance parameters obtained with the force platform as well as the $T_{limit}$ were sensitive enough to discriminate from older youth in a one-leg stance task. Our results suggest that the two parameters, showing an association with $T_{limit}$. MF and MVeloc, are likely more optimal in the context of clinical decision-making concerning the effects of a rehabilitation program for improving balance in older adults.

Conflict of interest

None declared.

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