Relationship Between Balance and Gait Stability in Healthy Older Adults

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Age-related adaptations during walking create a more stable walking pattern, which is less effective for forward progression and might be related to balance deficiencies. This study determined the relationship between walking stability and measures of balance in older adults. Seventeen older and 20 young adults performed the Berg Balance Test (BBT) and walked 10 m. Walking velocity (WV) and cadence were measured, and a gait-stability ratio (GSR) was calculated. Higher GSR indicated that a greater portion of the gait cycle was spent in double-limb support. Age-group comparisons established declines in BBT scores and WV and increases in GSR with age. Significant relationships were identified for BBT Item 12 (alternate stepping on a stool) with WV ($r = .58, r^2 = .34$) and GSR ($r = -.74, r^2 = .54$). The correlation of BBT Item 12 with GSR was stronger than with WV ($p < .05$). Results indicated a strong relationship between increased gait stability and decreased balance for a dynamic weight-shifting task. Therefore, GSR is a better indicator of balance deficits during walking than is WV alone.

Key Words: vestibular, walking, aging

Decreased mobility in older adults relates to impaired physical function (Gill, Williams, & Tinetti, 1995) and can lead to admission to a long-term-care facility (Guralnik et al., 1994). Consequently, preserving functional gait becomes important for maintaining mobility in older adults. Recently, the study of walking and physical-performance factors has received more attention in the literature. Walking has been studied with regard to lower extremity weakness (Schlicht, Camaione, & Owen, 2001; Vandervoort, Kramer, & Wharram, 1990; Vandervoort & McComas, 1986), decreased balance (Ringsberg, Gerdhem, Johansson, & Obrant, 1999), diminished physical performance, and inactivity (Jalha, Guralnik, Balfour, & Fried, 2001; Onder et al., 2002). Walking ability has also been related to self-perceptions of health status (Cress et al., 1995; Jalha et al.), gait efficacy (Rosengren, McAuley, & Mihalko, 1998), and fear of falling (Maki, 1997). Therefore, understanding walking and how it relates to other measures of physical performance will help in...
developing interventions to preserve mobility and improve quality of life for older adults. The focus of this study is the relationship between balance and walking stability in older adults.

Gait patterns of young adults are characterized by phases of instability that allow for efficient forward progression and lateral shifting of the body’s center of mass with each step (Nashner, 1980; Pedotti, 1977; Ralston, 1976). With aging, adaptations in older adults’ walking pattern increase stability and decrease the capacity for moving the body forward (Cromwell, Newton, & Forrest, 2001, 2002; Kerrigan, Todd, Croce, Lipsitz, & Collins, 1998; Ostrosky, VanSwearingen, Burdett, & Gee, 1994; Potter, Evans, & Duncan, 1995; Winter, Patla, Frank, & Walt, 1990). Older adults have adapted their gait pattern by restricting lower extremity joint motion. Joint-movement restriction in older adults has been documented for hip extension (Kerrigan et al.), knee extension (Ostrosky et al.), and ankle plantar flexion (Kerrigan et al.). Associated with decreased joint motion was a concomitant decrease in walking velocity (Cromwell, Newton, & Forrest, 2001, 2002; Kerrigan et al.; Ostrosky et al.; Potter et al.; Winter et al.). Cadence, however, remained similar to young adult values (Cromwell, Newton, & Forrest, 2001; Kerrigan et al.; Ober, Karsznia, & Ober, 1993; Winter et al.). Therefore, older adults shortened their step length as they covered less distance with the same number of steps. By adapting the walking pattern in this manner, older adults spend more time in the double-limb-support phase and less in the single-limb-support phase, thus creating a more stable walking pattern (Cromwell, Newton, & Forrest, 2001). This increased stability, however, proves less effective for moving the body forward.

A measure that accounts for changes in walking velocity and reflects changes in step length was introduced by Cromwell and colleagues (Cromwell, Newton, Grisso, & Edwards, 2001). This measure, the gait-stability ratio (GSR), is the ratio of cadence (steps/s) to velocity (m/s) and is expressed in units of steps per meter. The GSR provides an indication of walking stability as increases in GSR indicate that older adults take more steps per unit of distance—a greater portion of the gait cycle is spent in the double-limb-support phase, thereby reducing the dynamic components of walking.

Age-related declines in balance are well documented (Gill et al., 2001; Lord, Rogers, Howland, & Fitzpatrick, 1999; Newton, 1997; Shumway-Cook & Woollacott, 2000; Simoneau et al., 1999). The way in which these balance deficits relate to walking performance, however, is not well understood. Measurements of walking time and number of steps over a fixed distance for a group of older women were correlated with computerized measures of balance and the single-leg-stance task (Ringsberg et al., 1999). Although walking time and number of steps did not correlate well with computerized balance tests, these measures were related significantly to time on the single-leg-stance task. The single-leg stance is a simple test of balance that is also predictive of future falls (Vellas et al., 1997).

Other investigators have demonstrated that walking velocity, stride length, and double-limb-support time were strongly related to falling frequency and fear of falling (Maki, 1997). These measures of walking performance were not good predictors of future falls, but they were associated strongly with fear of falling. Fear of falling has previously been linked to poor postural performance in older adults (Maki, Holiday, & Topper, 1991). Therefore, the results of these studies might be indicative of a strong relationship between poor balance and walking performance.
Rosengren and colleagues (1998) examined balance, self-efficacy, and measures of gait in older adults walking over obstacles of different heights (0–40 cm). Results relating balance to gait measures demonstrated significant correlations between walking velocity and scores on the Berg Balance Test (BBT) for all conditions. Step length was assessed for each obstacle condition while participants approached, crossed, and recovered from crossing the obstacle. These measures of step length related significantly to scores on the BBT in many cases, thus indicating that increased balance was associated with longer step lengths.

Results of the studies described here suggest that age-related changes in gait create a more stable walking pattern, and measures of balance are related to walking performance. The purpose of this study, then, was to determine the relationship between walking stability and measures of balance in healthy older adults. Age-related declines in balance and walking measures were first established. The relationship between balance and walking measures for older adults was then assessed.

Methods

Participants

Seventeen healthy, community-dwelling older adults (6 men and 11 women) were recruited from senior-citizen centers. Although older adults who exercise were not specifically targeted for recruitment, 10 participants reported regular attendance in an exercise class. This exercise class primarily included seated tasks to improve flexibility and muscle endurance. BBT balance scores for the older adults who exercised were similar to scores of those who did not, \( t(15) = -0.553, p > .05 \) (exercise BBT = 53.0 ± 3.1, nonexercise BBT = 53.9 ± 1.6). Human-subjects approval was obtained, and participants provided informed consent before participating in this study. Ages of the older adults ranged from 67 to 90 years, with a mean of 76.2 (± 6.9) years. A control group of 20 young adults (9 men and 11 women) also participated. Ages of these adults ranged from 23 to 35 years, with a mean of 26.0 (± 3.4) years. Self-reports of health status were obtained from both participant groups (Table 1). None of the participants reported a history of diabetes, nervous-system deficits, or musculoskeletal disorders that would interfere with balance or walking, and none used an assistive device for walking, such as a cane or walker.

Visual acuity was assessed with a Snellen chart. Participants with poor vision were excluded because visual processes are important for balance, especially in older adults (Lord et al., 1999; Shumway-Cook & Woollacott, 2000; Simoneau et al., 1999). Participants with corrected vision were tested while wearing corrective lenses so that Snellen scores would reflect their best corrected visual acuity using both eyes (Attebo, Mitchell, & Smith, 1996; Ivers, Cumming, Mitchell, & Attebo, 1998). Snellen scores for older adults ranged from 20/20 to 20/50, with a mean score of 20/30. Young adults’ Snellen scores ranged from 20/13 to 20/30, with a mean of 20/20.

Procedures

The BBT was used to determine participants’ balance ability. The BBT, a valid tool for measuring balance, is used clinically for balance assessment (Berg,
Wood-Dauphinee, & Williams, 1992; Newton, 1997; Stevenson & Garland, 1996). It consists of 14 tasks that are scored on a scale of 0 to 4 points, with a total score of 56 points indicating good balance. The tasks represent activities that would be performed routinely each day and include items such as sitting, standing, transferring between chairs, turning 360°, and bending forward. Items on the BBT are arranged in order of difficulty. The most difficult tasks are alternate stepping on a stool (Item 12), tandem stance (Item 13), and single-leg stance (Item 14).

After BBT assessment, participants walked three passes of 10 m across a large room to determine average walking velocity and cadence. The MacReflex motion-analysis system (Qualisys, Glastonbury, CT) was used to collect sagittal-plane data with a single camera. Reflective markers were placed over the calcaneus of each foot to record heel contacts. The calcaneus marker on the right foot was placed laterally, and the marker on the left foot was placed medially. This placement
ensured that markers remained in view of the camera as participants walked from left to right across the camera’s field of view. A reflective marker was also placed on each participant’s back at the level of the first sacral vertebra. This marker position approximates the body’s center of mass (Clauser, McConville, & Young, 1969). As participants walked, data were sampled at 60 Hz over a 5-s time interval. Data were collected over the central portion of the walking path to ensure that measurements did not reflect accelerations and decelerations associated with starting and stopping.

ANALYSES

Cadence was determined using the calcaneus markers. Successive heel contacts were counted for the duration of the trial, and the total time from the first heel contact to the last heel contact was recorded. From these data, cadence was calculated in units of steps per second. Walking velocity in meters per second was calculated as the average horizontal linear velocity of the marker placed at the first sacral vertebra for each trial. Internal consistency of walking velocity and cadence was assessed over the three walking trials for each condition to justify averaging these values for statistical analyses. Intraclass correlation coefficients (ICCs) were used for this purpose.

From the cadence and velocity measures, GSR was calculated using the following equation: GSR = cadence/velocity. In this equation, the units of GSR are steps per meter. The GSR provides a mechanism for normalizing cadence with respect to velocity and represents a measure of walking stability. Therefore, as GSR increases, participants are taking more steps within a 1-m distance and spending a greater proportion of the walking cycle in contact with the floor. This type of pattern is more stable because participants avoid the dynamic components of walking.

Measures of cadence, walking velocity, and GSR were averaged across the three walking trials to obtain a single value of each variable for each participant. To establish age-related differences among dependent measures of the BBT, cadence, walking velocity, and GSR, these values were compared between age groups using a two-factor analysis of variance (ANOVA). Significant follow-up comparisons were determined using Fisher’s protected least-significant-difference procedure (Sheskin, 2000).

To determine the association between walking stability and balance, measures of cadence, walking velocity, and GSR were correlated against the BBT total score and scores on the more difficult items of the BBT (Items 12, 13, and 14). Because of the ceiling effect of the BBT to discriminate among balance scores of those with good balance, correlation analyses were performed only for the older adult measures. Pearson product–moment correlation was used to create a correlation matrix representing the relationship among cadence, walking velocity, GSR, and each balance measure individually. Correlation coefficients were hypothesis-tested to determine significant relationships. Significant correlation coefficients were compared using the t distribution to determine whether one particular walking variable had a better correlation with balance measures than another (Sheskin, 2000). The coefficient of determination ($r^2$) was also calculated for each significant correlation coefficient to assess the amount of variability in each walking measure that was accounted for by variability in each balance measure (Sheskin).
Results

Internal consistency of walking velocity and cadence as assessed through ICCs demonstrated good reliability of these measures. ICC(3, 1) was .91 for walking velocity and .75 for cadence.

Comparisons between age groups revealed significant age-related differences in walking measures and BBT scores (Table 2). For the walking measures, cadence was similar between age groups. However, walking velocity decreased and GSR increased significantly in the older adult group. BBT scores in this group of healthy older adults were significantly lower than those of the young adults. Young-adult BBT scores demonstrated a ceiling effect (maximum score = 56 points), because the BBT is not designed to discriminate among individuals with good balance.

The correlation matrix for walking and balance measures of the older adult participants is shown in Table 3. Relationships between cadence and BBT scores

Table 2  Average Cadence, Walking Velocity, Gait-Stability Ratio (GSR), and Berg Balance Test (BBT) Scores

<table>
<thead>
<tr>
<th>Participant group</th>
<th>Cadence (steps/s)</th>
<th>Velocity (m/s)</th>
<th>GSR (steps/m)</th>
<th>BBT (points)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Older adults</td>
<td>1.78 ± 0.16</td>
<td>1.22 ± 0.22*</td>
<td>1.48 ± 0.19*</td>
<td>53.41 ± 2.72*</td>
</tr>
<tr>
<td>Young adults</td>
<td>1.85 ± 0.11</td>
<td>1.38 ± 0.21</td>
<td>1.36 ± 0.17</td>
<td>56.00 ± 0.00</td>
</tr>
</tbody>
</table>

*Significant difference between age groups (p < .05).

Table 3  Correlation Matrix for Walking and Balance Measures

<table>
<thead>
<tr>
<th></th>
<th>Cadence</th>
<th>Walking velocity</th>
<th>GSR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berg Balance Test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total score</td>
<td>−.01</td>
<td>.20</td>
<td>−.36</td>
</tr>
<tr>
<td>Item 12</td>
<td>.37</td>
<td>.58*</td>
<td>−.74*</td>
</tr>
<tr>
<td>Item 13</td>
<td>.04</td>
<td>.24</td>
<td>−.39</td>
</tr>
<tr>
<td>Item 14</td>
<td>.04</td>
<td>.16</td>
<td>−.27</td>
</tr>
</tbody>
</table>

*aSignificantly different from the correlation for walking velocity and Berg Balance Test Item 12 (p < .05).

*Significant correlation (p < .05).
were not significantly correlated. Walking velocity and GSR were not significantly correlated with the BBT total score or BBT Items 13 (tandem stance) and 14 (single-leg stance). BBT Item 12 (alternate stepping on a stool), however, significantly correlated with walking velocity and GSR. The correlation between BBT Item 12 and GSR indicates a strong, inverse relationship in which diminished balance is associated with increased gait stability. Comparison of these significant correlation coefficients revealed that the correlation between GSR and BBT Item 12 was stronger than the correlation between walking velocity and BBT Item 12, \( r(14) = 3.51, p < .05 \). The \( r^2 \) value for the correlation between walking velocity and BBT Item 12 was .34, indicating that 34% of the variability in walking velocity was accounted for by variability in BBT Item 12. For the correlation between GSR and BBT Item 12, \( r^2 = .54 \). Therefore, 54% of the variability in GSR was accounted for by the variability in BBT Item 12.

Discussion

The aim of this study was to determine the relationship between walking stability and measures of balance in healthy older adults. Age-related differences among dependent measures were first established. Comparisons of balance and walking measures between young and older adults demonstrated differences in walking velocity, GSR, and BBT scores, whereas cadence remained similar between age groups. The results for walking velocity, cadence, and BBT are consistent with those of other investigators (Cromwell, Newton, & Forrest, 2001, 2002; Kerrigan et al., 1998; Newton, 1997; Oberg et al., 1993; Ostrosky et al., 1994; Potter et al., 1995; Winter et al., 1990) and demonstrate declines in balance and walking performance associated with age. Furthermore, GSR increased in the older adult group, indicating that older adults took more steps per unit of distance, thereby increasing stability of their walking pattern. Increased stability during walking allows older adults to compensate for reductions in balance. Therefore, by maximizing walking stability, older adults create a movement pattern that is more resistant to perturbations and serves as a mechanism to protect against falls.

From a practical viewpoint, these age-related changes in walking velocity and GSR might impede older adults from safely locomoting in situations that are constrained by time. For example, increased GSR and decreased velocity might help protect against falls but might hamper the ability of older adults to move fast enough to cross a street before the traffic signal changes. Furthermore, the age-related trends established in these data might be progressive in frail older adults, who might demonstrate greater reductions in balance and walking velocity with increased GSR. Safety of these frail older adults would be further compromised in situations in which faster walking was required.

Relationships between balance and walking measures for the older adult group were determined next. The most notable of these correlations were walking velocity with BBT Item 12 (alternate stepping on a stool) and GSR with BBT Item 12. The significance of these two correlations is most likely related to the dynamic nature of BBT Item 12. The task of placing one’s feet alternately on a stool involves two important components of the walking cycle: alternate leg movement and weight shifting associated with that leg movement. Thus, BBT Item 12 mimics two
important dynamic characteristics of the walking pattern and correlates well with measures of walking.

Correlations of walking velocity and GSR with the remaining balance measures were not significant. Four reasons might explain these weaker correlations. First, the BBT total score contains many items that test static-balance performance. BBT Items 13 and 14 represent two of these static-balance tasks. Because these tasks lack dynamic characteristics found in walking, they do not correlate well with measures of walking.

Second, the older adults who participated in this study were healthy, community-dwelling individuals. These older adults scored well on the BBT (see Table 2), indicating a higher level of balance ability in these participants. The inclusion of older adults with a broader range of balance scores might strengthen the relationships of walking velocity and GSR with the BBT. Walking velocity was significantly correlated with BBT scores when active and inactive older adults were included in the participant group (Rosengren et al., 1998).

A third explanation relates to the way in which items on the BBT are scored. Each item is scored between 0 and 4 points, a score of 4 indicating completion of the task and good balance. This range of scores might not be wide enough to demonstrate strong correlation of BBT Items 13 and 14 with walking velocity and GSR. The single-leg-stance test, the task performed for BBT Item 14, was found to correlate significantly with walking measures of time and number of steps over a 30-m distance (Ringsberg et al., 1999). These walking measures of time and number of steps for a fixed distance are similar to walking velocity and GSR used in this present study. However, scores on the single-leg-stance test were determined by assessing the length of time an individual stood on one leg (Ringsberg et al.), in contrast to scoring between 0 and 4 as in the BBT. Therefore, by measuring time for the single-leg-stance test, correlation with walking measures improved.

Fourth, a larger sample size might have produced significant correlations of walking velocity and GSR with balance measures other than BBT Item 12. A poststudy power analysis revealed that the significant correlation coefficients for BBT Item 12 with GSR and walking velocity achieved 92% power and 77% power, respectively (Portney & Watkins, 2000). These levels of power provide reasonable protection against a Type II error; however, power associated with correlations of the other balance measures was not as strong.

Comparison of significant correlations (see Table 3) and calculation of the coefficient of determination provide evidence that the GSR is a better measure than walking velocity for assessing balance during walking in older adults. GSR was correlated to a greater degree with BBT Item 12 than walking velocity. Thus, this finding demonstrates that increased stability in walking is more closely associated with decreased balance during a dynamic task. Furthermore, variability of scores for BBT Item 12 accounted for 54% of the variance in GSR. This represents a 20% increase in variance accounted for between BBT Item 12 and walking velocity. Therefore, GSR provides a better indication of balance deficits as they are manifested during walking.

Findings from this study suggest that the GSR might be a useful clinical tool to assess walking stability and determine balance deficits related to walking in older adults. In addition, GSR can be easily incorporated into gait studies with older adults that examine stability and balance during walking. Alternatively, when space or
time does not permit full assessment of walking performance, BBT Item 12 can predict balance performance during walking in healthy older adults. Future study of GSR and balance measures in a sample of older adults who fall will provide information over a broader spectrum of the older adult population and enhance the usefulness of the GSR as a clinical measure.

Conclusions

This study demonstrated a strong inverse relationship between walking stability and dynamic balance in healthy older adults. Age-related declines in walking and balance measures were documented. Significant relationships were determined for walking velocity and GSR with BBT Item 12 (alternate stepping on a stool) for older adult participants. Results suggest that GSR provides a better indication than walking velocity for assessing balance deficits during walking in older adults.

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References


Schlicht, J., Camaione, D.N., & Owen, S.V. (2001). Effect of intense strength training on


