Adaptive Changes in Gait of Older and Younger Adults as Responses to Challenges to Dynamic Balance

Helen L. Rogers, Ronita L. Cromwell, and James L. Grady

The study proposed to identify balance strategies used by younger and older adults during gait under proprioceptive, visual, and simultaneous proprioceptive–visual challenges. Participants ambulated under 4 conditions: consistent, noncompliant surface; inconsistent, compliant surface (C); consistent, noncompliant surface with vision obscured (NCVO); and inconsistent, compliant surface with vision obscured (CVO). Balance adaptations were measured as changes in gait velocity, cadence, and gait-stability ratio (GSR). Participants were 5 younger (mean age = 27.2) and 5 older (mean age = 68) healthy adults. Significant age differences were found for GSR \( (p = .03) \) on all surfaces. Older adults adopted a more stable gait pattern than younger adults regardless of the challenge presented by surface. Significant condition differences were found for velocity \( (p < .001) \) and cadence \( (p = .001) \). All participants exhibited significantly decreased velocity and increased cadence on surfaces C and CVO. Gait speed and cadence did not significantly change in NCVO. Younger and older adults exhibited similar adaptive balance strategies, slowing and increasing steps/s, under proprioceptive and proprioceptive–visual challenges to dynamic balance.

Keywords: proprioception, healthy elderly, balance perturbation

It is well documented that age-related deficits in balance are a major contributor to the incidence of falls (Gill et al., 2001; Maki, Holliday, & Topper, 1994; Speers, Kuo, & Horak, 2002). As many as 70% of older adults who fall do so while walking (Menz, Lord, & Fitzpatrick, 2003b; Winter, Patla, Frank, & Walt, 1990; Woollacott & Tang, 1997), usually as a result of a slip or trip (Chen et al., 1996; Maki et al.; Wu, 1998). To prevent loss of balance or a fall, older adults must have both adequate balance and functional mobility. Current research suggests that older adults display adaptive motor strategies during dynamic activities in an attempt to compensate for diminished balance resulting from age-related deficits in sensory systems (Cromwell, Newton, & Forrest, 2001; Menz et al., 2003b; Willems & Vandervoort, 1996). Age-related sensory deficits in vision and proprioception contribute to diminished balance and falls in older adults (Speers et al.; Menz, Lord, & Fitzpatrick, 2003a;
Cromwell et al., 2001; Cromwell, Newton, & Forrest, 2002). Therefore, examining adaptive motor strategies that compensate for these deficits is critical toward understanding the strategies that are successful and those that place older adults at risk for falls. This study examined adaptive motor strategies in healthy older adults in response to proprioceptive and visual challenges during gait.

Dynamic balance, as seen during gait, is the ability to remain balanced while the body is in motion (Cromwell et al., 2002); this definition includes the ability to successfully respond to balance challenges (MacKinnon & Winter, 1993; Patla, 1996). Older adults use specific gait adaptations to maintain dynamic balance during unobstructed gait, including changes in gait speed, stride length, and duration of double-limb support (Winter et al., 1990). The slowing of gait that occurs with age is well documented (Bohannon, 1997; Hageman & Blanke, 1986; Winter et al.). Decreasing stride length is another identified adaptive gait strategy; a shorter stride contributes to a decreased risk of falling because of a shorter forward progression per step (Cromwell & Newton, 2004; Maki, 1997; Murray, Mollinger, Gardner, & Sepic, 1984; Winter et al.) and increased time spent in double-limb support (Murray et al.; Winter et al.). The literature supports the hypothesis that older adults use these adaptive balance strategies to stabilize their gait against challenges to dynamic balance (Cromwell et al., 2004; Maki; Rosengren, McAuley, & Mihalko, 1998).

Older adults demonstrate specific gait adaptations in response to challenging sensory conditions such as altered vision or disrupted proprioception, proprioception being defined as “the sense of position and movement of the limbs and body without using vision” (Gardiner, Martin, & Jessell, 2000, p. 443). Vision is an especially important sensory mechanism for older adults, who rely primarily on vision, especially when balance is challenged (Chen et al., 1996; Cromwell et al., 2002; Lord & Ward, 1994; Speers et al., 2002). Older adults slow their gait, decrease step length, increase double-limb support time, and increase gait stability when challenged by decreased visual accuracy (Chen et al.; Speers et al.) or when walking with their eyes closed (Chen et al.; Cromwell et al., 2002; Gill et al., 2001; Speers et al.). Similar adaptive balance strategies are produced during proprioceptive challenge. Proprioception is as important to older adults as vision for maintaining a stable posture during static stance (Lord, Clark, & Webster, 1991). In fact, the loss of sensation from peripheral proprioceptive receptors might cause the greatest disruption to postural sway during static standing (Lord et al., 1991). Studies investigating standing balance show decreased postural stability in response to conditions that challenge proprioception, such as standing on foam (Gill et al.; Lord & Ward). Proprioception is equally important to dynamic balance. Older women were noted to slow their gait speed and adopt a more stable pattern when walking over surfaces that offered proprioceptive challenge (Thies, Richardson, & Ashton-Miller, 2005).

Maintaining dynamic balance during gait involves the interplay of multiple sensory and motor systems (Lord et al., 1991; Speers et al., 2002). The risk of balance loss is known to increase when multiple systems are affected (Tinetti, Williams, & Mayewski, 1986) or when multiple sensory challenges are presented (Cromwell et al., 2001; Shumway-Cook & Woollacott, 2000). A limited number of studies, however, have identified how older adults respond under multiple sensory-system
changes. Examination of standing posture under conditions that challenged visual and proprioceptive systems revealed that older adults increased postural sway when each system was challenged individually (Shumway-Cook & Woollacott). Postural sway increased to an even greater degree when both systems were compromised. In fact, older adults with a history of falls could not complete tasks in which vision and proprioception were challenged simultaneously. Studies examining visual and proprioceptive challenges individually during gait determined that each of these modalities plays a significant role in maintaining dynamic balance for older adults (Cromwell et al., 2001, 2002; Menz et al., 2003a, 2003b). Thies et al. (2005) recently investigated the combined effects of an irregular surface and low lighting on the gait of older and younger women. Step width, step time, and variability of these measures were significantly affected by the irregular surface. The addition of low lighting, however, did not cause any greater effect when combined with the irregular surface (Thies et al.). Therefore, the condition of low light might not have presented a significant visual challenge to these older adults.

Consequently, further study is needed to assess the relative roles of vision and proprioception in adaptive strategies used to maintain dynamic balance in older adults during walking. Therefore, the purposes of this study were to determine the differences between older and younger adults in gait adaptations to balance challenges and to identify the specific adaptive gait strategies used by healthy older and younger adults in response to significant proprioceptive, visual, and combined proprioceptive–visual challenges.

**Methods**

**Participants**

This study employed a 2 (group) × 4 (condition) factorial design and was carried out as a preliminary study before a larger project. Five younger (range 21–35 years, mean 27.2) and 5 older adults (range 65–85 years, mean 68.0) participated in the study. As much as possible given the small sample size, individuals were chosen to reflect area ethnic, racial, and age demographics (see Table 1). The study was

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Young adults (n = 5)</th>
<th>Older adults (n = 5)</th>
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<tbody>
<tr>
<td>Age (years, $M \pm SD$)</td>
<td>$27.20 \pm 4.09^*$</td>
<td>$68.00 \pm 1.87^*$</td>
</tr>
<tr>
<td>Height (m, $M \pm SD$)</td>
<td>$1.68 \pm .102$</td>
<td>$1.69 \pm .077$</td>
</tr>
<tr>
<td>Weight (kg, $M \pm SD$)</td>
<td>$66.42 \pm 14.24$</td>
<td>$78.74 \pm 21.72$</td>
</tr>
<tr>
<td>Gender M/F, n (% of age group)</td>
<td>2 (40%)/3 (60%)</td>
<td>2 (40%)/3 (60%)</td>
</tr>
<tr>
<td>Race, Black/Hispanic/White, N (% of age group)</td>
<td>0 (0%)/1 (20%)/4 (80%)</td>
<td>1 (20%)/1 (20%)/3 (60%)</td>
</tr>
<tr>
<td>Timed up-and-go (s, $M \pm SD$)</td>
<td>$8.32 \pm .82$</td>
<td>$8.91 \pm 1.19$</td>
</tr>
<tr>
<td>Berg Balance Test score* ($M \pm SD$)</td>
<td>$56 \pm 0.0$</td>
<td>$55.80 \pm 0.45$</td>
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</tbody>
</table>

*Highest possible score on Berg Balance Test is 56.

*Significant difference between age groups ($p < .05$).
approved by the institutional review board, and all eligible participants signed an informed-consent form.

To determine eligibility, all participants took part in an initial screening visit. Inclusion criteria required that participants be free from any orthopedic, neurologic, or cardiovascular pathology affecting movement; demonstrate visual acuity within a range of 20/20 to 20/50; score above 45 on the Berg Balance Test (BBT; Bogle Thorbahn & Newton, 1996); and demonstrate a timed up-and-go (TUG) score of less than 14 s (Shumway-Cook, Brauer, & Woollacott, 2000).

During the screening visit, participants completed a self-report questionnaire to document demographic and health information. Any individuals who reported pathology affecting their movement or balance were excluded. Three clinical measures were also used to establish eligibility. First, the Snellen chart was used to assess visual acuity; this test is an accepted method of screening visual acuity in older adults (AAFP, 1999–2000). Second, the TUG was used to assess functional mobility. It is a reliable, valid measure that correlates well with functional independence and activity level (Podsiadlo & Richardson, 1991). The TUG involves rising from a chair, walking 3 m, returning, and sitting down. A time of 14 s discriminates well between independent older adults (complete test in <14 s) and older adults who exhibit decreased mobility and a higher risk of falls (complete in >14 s; Bischoff et al., 2003; Shumway-Cook et al., 2000). Finally, the BBT was used as a clinical measure of balance. The BBT is a reliable and valid tool that is widely accepted (Berg, Wood-Dauphinée, Williams, & Maki, 1992). The test involves a rating of 0–4 on 14 items; the maximum score of 56 indicates good balance, and a score below 45 indicates an increased fall risk (Bogle Thorbahn & Newton, 1996; Chiu, Au-Yeung, & Lo, 2003; Shumway-Cook, Baldwin, Polissar, & Gruber, 1997).

Procedures

Participants walked under four experimental conditions, completing three trials per condition. The order of conditions was randomized to remove any potential learning or order effect. To prevent falls, all participants wore a lightweight harness attached to a pulley running along an overhead cable positioned over the entire length of the walkway. The harness–pulley system offered no resistance or assistance to gait as the participant completed the trials and was present only as a safety precaution. Any sensory input to the trunk in terms of spatial awareness, orientation, or a sense of support that might have been created by the presence of the harness was constant for all participants. All participants walked barefoot in all conditions to eliminate possible effects of different types of footwear (Robbins, Gouw, & McClaran, 1992).

This study employed four gait conditions: gait on a noncompliant and consistent surface with normal vision (NC), gait on a compliant and inconsistent surface with normal vision (C), gait on a noncompliant surface with vision obscured (NCVO), and gait on a compliant and inconsistent surface with vision obscured (CVO). Each surface was positioned in an 8-m walkway. The noncompliant and consistent surface consisted of a linoleum floor. The compliant and inconsistent surface was constructed from four panels, each 200 cm long and 100 cm wide, resulting in a walkway 8 m in length and 1 m in width (see Figure 1[a]). Each panel consisted of two layers of 5-cm-thick foam. The top layer of foam was solid and uncut (see
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Figure 1[b]). Wooden blocks were embedded in the bottom layer of foam in such a way that the solid blocks were separated by areas of foam (see Figure 1[b]). These blocks, 28 per panel, were 10 cm wide, 10 cm long, and 5 cm thick. The blocks in the bottom layer were arranged in rows; the location of the blocks was marked on the upper layer to allow for visual reference during stable and unstable conditions (See Figure 1[a]). The marks on the upper layer were the same size as the blocks beneath and presented a high-contrast visual reference. The foam-and-block arrangement of this walkway was used to create an inconsistency in the compliant surface. We chose foam as a material in this study because it has been shown to degrade ankle proprioceptive feedback and therefore affect postural-control dynamics (Jeka, Kiemel, Creath, Horak, & Peterka, 2004; Peterka & Loughlin, 2004).

During the two visual-challenge conditions, participants wore a lightweight foam-board collar that obscured visual reference to their feet. This collar was worn around the participant’s neck and protruded horizontally 33 cm in the forward direction and 28 cm laterally to either side. Participants walked over both the noncompliant, consistent walkway and the compliant, inconsistent walkway while wearing the collar. The collar was intended to prevent participants’ visual reference of the ground immediately in front of them, thus preventing them from being able to look down while walking. This type of selective visual occlusion has not, to our knowledge, been previously studied in conjunction with disruption of proprioception during gait. Vision is a unique sensory system that contributes significantly to gait control (Patla, 1998); recent studies suggest that visual regard of the surface less than two steps before an obstacle is essential for successful obstacle avoidance (Mohagheghi, Moraes, & Patla, 2004; Patla & Greig, 2006; Patla & Vickers, 2003). Consequently, the visual condition of this study was designed to challenge dynamic balance by removing specific visual information during gait. Participants were given the same instructions for each trial: “Walk to the end of the walkway at your normal, comfortable pace looking ahead as if walking down a sidewalk.”
Data collection and cessation were triggered using two infrared photo detectors placed 6 m apart in the center portion of the walkway. A photo detector and its corresponding reflector were placed on each side of the walkway with the infrared light beam directed across the walkway. Breaking the first infrared light beam started and breaking the second infrared light beam stopped data collection. The photo detectors were linked to a timer that recorded the number of seconds taken to walk across the 6-m data-collection space. The number of steps taken in the collection space was also recorded.

**Data Processing**

The parameters of gait speed, cadence, and gait-stability ratio (GSR) were calculated from the step count and the time taken to walk across the 6-m data-collection space. Gait speed (m/s) was calculated by dividing the 6-m walking distance by the time taken to cover this distance. Cadence (steps/s) was calculated by dividing the number of steps taken in the 6-m data-collection space by the time it took to walk this distance. The GSR (steps/m) was calculated by dividing the value for cadence by the value for gait speed (Cromwell & Newton, 2004). The GSR provides an indication of the amount of adaptation an individual makes to increase gait stability. An increase in GSR indicates an increase in the number of steps taken within a meter and a decrease in step length. A decrease in step length results in decreased forward progression and increased amount of time spent in double-limb support (Cromwell & Newton; Murray et al., 1984; Winter et al., 1990). Gait speed, cadence, and GSR have all been used effectively to assess individuals’ adaptation to balance challenges (Cromwell & Newton; Maki, 1997; Rosengren et al., 1998; Winter et al.).

**Statistical Analysis**

All data were analyzed at a significance level of $\alpha = .05$. Descriptive statistics were used to describe the demographics of both groups (see Table 1). An independent-samples $t$ test was employed to determine whether there were differences between younger and older adults for height, weight, and BBT and TUG scores (see Table 1).

A repeated-measures analysis of variance (ANOVA) was performed using SPSS statistical software to determine whether there were differences between groups for age or within groups for gait conditions (NC, C, NCVO, and CVO) for the variables of gait speed, cadence, and GSR. In the event of a significant difference within groups (gait condition), each condition was compared with every other condition using a paired-sample $t$-test procedure with SPSS.

**Results**

There was no significant difference in height, weight, or TUG or BBT score between younger and older adults (see Table 1). Results of the repeated-measures ANOVA demonstrated a main effect of age for one of the three gait variables. A significant difference was found between age groups for GSR ($F = 6.96, p = .03$). The results
also demonstrated a main effect of condition for two of the three variables. A significant difference was found between conditions for gait speed (Wilks’s $\Lambda = 31.08$, $p < .0004$) and cadence (Wilks’s $\Lambda = 27.30$, $p = .001$). No interaction effect ($\text{Age} \times \text{Condition}$) was demonstrated by these results. Although the sample seems small, a power analysis performed after the completion of the study showed the power of this sample to be sufficient to distinguish differences within gait conditions (power > .90 for both velocity and cadence). The power was less than optimal for detecting differences between groups (power = .64 for GSR). More participants would likely have improved the power for this particular variable; the small sample size of this study presents a limitation that should be addressed with any further studies in this area. These results will have limited generalizability to a larger population of older adults.

A series of paired-sample $t$ tests was performed to identify differences between gait conditions. Significance of these $t$ tests was assessed at an adjusted alpha level of .008 to protect against Type I errors.

The comparisons of conditions NC with NCVO and C with CVO were not significantly different for either gait speed or cadence. These results suggest that obscuring the participants’ view of their feet failed to offer a significant perturbation to balance above that of the proprioceptive challenge alone.

Comparison of values for cadence by condition demonstrated a significant difference between conditions NC and C ($p < .0001$), NC and CVO ($p = .004$), C and NCVO ($p < .0001$), and NCVO and CVO ($p < .0001$). Gait speed was significantly different between conditions NC and C ($p = .003$), NC and CVO ($p = .005$), C and NCVO ($p < .0001$), and NCVO and CVO ($p < .0001$; see Table 2).

<table>
<thead>
<tr>
<th>Table 2 Differences by Gait Condition ($M \pm SD$)</th>
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<tbody>
<tr>
<td>Gait speed (m/s)</td>
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<tr>
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<tr>
<td><strong>Young adults</strong></td>
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<td>Condition NC</td>
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<td>Condition NCVO</td>
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<td>Condition CVO</td>
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<td><strong>Older adults</strong></td>
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<td>Condition NC</td>
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<td>Condition C</td>
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<tr>
<td>Condition NCVO</td>
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<td>Condition CVO</td>
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*Significant difference between gait conditions NC and both C and CVO. †Significant difference between gait conditions NCVO and both C and CVO.
Discussion

In this study, the variable GSR exhibited a main effect for age. Older adults exhibited a higher value for GSR than did the younger adults under all four gait conditions. This suggests that older adults take more steps in a given distance than do younger adults, regardless of the intensity of the sensory challenge. Taking a greater number of steps per meter allows older adults to adopt a more stable gait pattern by increasing the amount of time spent in double-limb support (Cromwell & Newton, 2004, Murray et al. 1984, Winter et al. 1990). The consistently higher GSR exhibited by the older adults in this study illustrates that older adults adopt a more stable gait under all conditions, with or without challenges to balance. This practice of adopting a more stable gait regardless of level of challenge to balance further demonstrates that age-related changes to balance alone are sufficient to compel older adults to exhibit adaptive balance strategies to maintain a sufficient level of dynamic balance.

The variables of cadence and gait speed, however, differed by gait condition but showed no effect for age. This indicates that all participants, older and younger, exhibited different adaptive balance strategies depending on which specific conditions of sensory challenge were presented. The results of this study demonstrate, therefore, that when the challenge to balance is of sufficient intensity, younger adults exhibit a magnitude of adaptation to cadence and gait speed that is equal to that of older adults.

In this study, the effect of gait condition was significant for cadence and gait speed. Cadence decreased for all participants during conditions of proprioceptive and combined visual and proprioceptive challenge. Participants in both groups also decreased their gait speed during these two conditions. These findings demonstrate that both older and younger adults adapt the parameters of gait to adopt a more stable pattern during significant sensory challenge. Regardless of age, the participants’ adjustments in gait were similar in magnitude for conditions C and CVO. This similarity in adaptation noted for condition C and CVO demonstrates that although the proprioceptive condition used in this study was sufficiently challenging, the visual challenge was not. The addition of the challenge of obscured vision to the condition of proprioceptive disruption did not require the participants to make additional adaptations to maintain balance.

Previous studies have demonstrated that certain gait adaptations are common for older adults because of age-related changes in balance; older adults in general walk more slowly (Bohannon, 1997; Hageman & Blanke, 1986; Murray, Kory, & Clarkson, 1969; Winter et al., 1990), demonstrate a decrease in stride length (Murray et al., 1969; Murray et al., 1984; Oberg, Karszniea, & Oberg, 1993; Ostrosky, Van-Swearingen, Burdett, & Gee, 1994), and spend more time in double-limb support (Winter et al.). Similar adaptations were produced during this study, as well. Some studies have also demonstrated changes in the gait of younger adults. Younger adults have adapted their gait to increase stability under conditions of significant visual challenge (Cromwell et al., 2004) and proprioceptive challenge (Menz et al., 2003a). Previous studies have also found, however, that younger adults exhibited fewer gait adaptations and that the magnitude of those adaptations was less in younger
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adults than in older adults (Cromwell et al., 2002; Menz et al., 2003b). The results of this study differ in that the older and younger adults showed gait adaptations under the most challenging conditions that were similar in type and magnitude. This is an interesting finding, suggesting that there are common adaptive strategies for balance control and that both healthy younger and healthy older adults exhibit these adaptations during significant sensory challenge to gait. In fact, in this study significant challenges to dynamic balance produced adaptations to gait substantial enough to obscure the usual age-related differences in gait parameters.

In this study, the visual conditions consisted of obscuring the participants’ view of their feet during gait on a noncompliant, consistent surface (condition NCVO) and on a compliant, inconsistent (condition CVO) surface. The results demonstrated no appreciable difference between conditions NC and NCVO or C and CVO. This finding suggests that the visual challenge was not an adequate perturbation alone and did not contribute significantly to the perturbation created by the proprioceptive challenge. This also suggests that the participants did not find it necessary to rely on looking down at their feet as a balance strategy. Rather, they most likely fixed their gaze on some aspect of the environment ahead of them as they walked down the walkway. Although selectively obscuring vision has been shown to significantly affect successful obstacle avoidance (Mohagheghi et al., 2004; Patla, 1998; Patla & Greig, 2006), reducing a portion of the visual field did not represent a significant challenge to the participants in this study, nor did it result in a significant difference in gait measures between the age groups. In a similar study, Thies et al. (2005) employed conditions of an irregular surface and low lighting as challenges to gait. In that study, the low-light condition showed no effect on gait, although there was a significant effect of surface type. The results of this study and that of Thies et al. suggest that older adults are able to adequately compensate for balance challenges during gait along a clear path as long as some degree of visual referencing remains available. The results found in both this study and that of Thies et al. also suggest that visual disruption during gait on a path without obstacles might produce levels of effect on gait different than those noted during studies of obstacle avoidance or imposed constraints on step position (Patla & Greig; Patla & Vickers, 2003; Vickers & Patla, 1999).

In this study the variable of GSR showed a significant difference by age, whereas the variables of cadence and gait velocity did not. GSR, measured in steps per meter, might therefore provide a more sensitive measure of dynamic-balance ability than either cadence or gait velocity alone (Cromwell & Newton, 2004). Both older and younger adults exhibited adaptation in gait velocity during gait under very challenging conditions, but under low-challenge conditions these variables were unaffected. The value of GSR, however, was higher for older adults under all conditions including normal gait. This indicates that GSR provides a more sensitive measure of dynamic balance because it demonstrates a difference between older and younger adults even when dynamic balance is not significantly challenged. Older adults seek a more stable gait pattern to compensate for age-related changes that challenge balance (Winter et al., 1990). In this study GSR measured the degree to which older adults exhibited adaptations to the parameters of gait even under conditions for which the variables of gait speed and cadence showed no differences.
Further research in this area should continue to quantify the specific adaptive balance strategies used by healthy older and younger adults. Both older and younger adults exhibit adaptation under conditions of proprioceptive challenge to maintain dynamic balance. The way in which adults adapt, however, depends on both the age of the individual and the unique properties of the sensory challenge. Older adults who exhibit a deficit in dynamic balance, therefore, might require more assistance in some circumstances than in others.

Consequently, efforts to use gait changes as predictors of balance loss or as metrics by which to measure the success of a rehabilitation program must take into account what specific adaptive balance strategies might be relevant to a given situation. To be successful, rehabilitation programs designed to improve balance and function in older adults should account for the environmental conditions under which the older adults must ambulate or the sensory challenges they face. Furthermore, to adequately assess balance in older adults, clinical balance tools must recognize what environments present sufficient challenges to dynamic balance and what metrics are sensitive enough to identify the changes in gait used by older adults as adaptive balance strategies.

References


