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Falls and motor behavior in older adults

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HIGHLIGHTS
- Faller older adults have alterations in balance and gait.
- Faller older adults exhibit modifications in upper limb control.
- Fallers seem to have a global change in motor behavior.

ABBREVIATIONS
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ABSTRACT
This mini-review focuses on intrinsic risk factors for falls, particularly the changes in motor behavior of faller older adults. Our purpose is to present evidence that faller older adults exhibit motor behavior changes beyond the typically investigated standing and walking tasks. We showed initially that postural control alterations with more prominent differences for fallers than non-fallers seem to depend on postural demands, availability of sensory information, and tasks performed concomitantly with the balancing task. We also provided evidence that walking speed is the most consistent aspect to differentiate fallers from non-fallers. This reduction in walking speed may be a strategy to improve gait stability to avoid a fall. More recent studies have shown that fallers presented modifications in the control of the prehension movement. These changes suggest that fallers have changes in movement categories other than balancing and walking, suggesting that fallers' difficulties are broader than previously thought. The fact that faller older adults have modifications in the control of upper and lower limbs is indicative of a change in motor behavior involving gross and fine motor behaviors. The understanding of a faller as an individual with global changes in motor behavior has important implications for fall prevention and rehabilitation programs for these individuals.

KEYWORDS: Aging | Balance | Gait | Prehension

INTRODUCTION

The most recent population-based study showed that the prevalence of falls is 25.1% among older adults in Brazil.[1] These falls were associated, among other factors, with fear of falling due to defective sidewalks and fear of crossing streets, two walking-related factors. It is known that falls occur very often during walking in older adults.[2,3] Therefore, the investigation of changes in walking in older adults with and without a history of falls (fallers and non-fallers, respectively) has become a vital paradigm to identify factors that can differentiate fallers from non-fallers and understand why some older adults fall.

Falls represent a critical health problem for older adults. It may restrict activities of daily life, cause fractures and hospitalization, and is one of the leading causes of unintentional injury deaths amongst this age group.[4,5] Hence, it is essential to know the reasons that lead older adults to fall to thoughtfully plan intervention programs to reduce the risk of falls.

The fact that not all older adults fall, suggests that the fallers share some characteristics that make them more predisposed to these events than the non-fallers. Risk factors for falls are categorized into extrinsic and intrinsic factors.[4] The extrinsic factors relate to environmental characteristics, whereas the intrinsic factors include characteristics of the individual. Among the intrinsic factors for falls, impaired balance and gait are considered as the major risk factors.[4,6] This mini-review focuses on intrinsic factors, particularly the changes in motor behavior of faller older adults. The studies we included in this mini-review investigated only older adults. Studies about falls in younger adults were not considered. Therefore, when we refer to fallers and non-fallers throughout the text, we consider only older adults.

As impaired balance and gait are relevant risk factors for falls, we first briefly review studies to provide evidence of balance and gait problems in fallers. In the sequence, we will review studies that have assessed the influence of fall history in manipulative tasks (i.e., reaching and grasping). The studies about upper limb tasks suggest that motor behavior in older adult fallers is not characterized only by balance and gait problems, but also by changes in upper limb control. These results led us to propose that fallers have a change in their motor behavior that goes beyond the typically observed balance problems of this population. Therefore, our aim is to present evidence that older adult fallers exhibit changes in their motor behavior beyond the typically investigated standing and walking tasks. We argue that these broad changes in motor behavior reflect a common mechanism characterizing the motor control of these individuals.

POSTURAL CONTROL IN FALLER AND NON-FALLER OLDER ADULTS

An increase in postural sway in older adults can be interpreted in different ways.[7] A more traditional approach favors the interpretation that an increase in postural sway and speed indicates an impaired postural control (i.e., postural imbalance). In contrast, a different approach claims that this increase in postural sway could result from an exploratory phenomenon. Based on the traditional approach, an increase in postural sway and speed has been identified as a risk factor for falls in older adults.[8–11]

Although older adult fallers show greater postural sway and speed than non-fallers,[8–11] these findings are not consistent across studies.[8,9,12–14] Melzer et al.[8] found that fallers increased postural sway and speed compared to non-fallers, but only when standing in a narrow base of support. In a wide base of support, they observed no difference between those groups. On the other hand, Johansson et al.[11] identified an increase in postural sway for fallers using a wide base of support with eyes open and closed. Batistela et al.[12] tested fallers and non-fallers in a narrow base condition and did not find any difference between these groups in postural sway and speed measures. Lázaro et al.[15] observed that recurrent fallers showed greater postural instability than non-fallers when visual and proprioceptive conditions changed, especially when both sensory inputs were simultaneously abolished. Müjdeci et al.[14] indicated that dynamic balance was negatively affected in faller older adults. Moreover, the use of the Sensory Organization Test showed that fallers differed from non-fallers only in conditions involving swayed-referenced surround and/or support surface.[9,14] These findings indicate that fallers could not compensate for challenges to balance, particularly when visual and proprioceptive inputs were unreliable.

The task of standing is most often completed while simultaneously performing additional cognitive tasks such as talking or reading (i.e., dual-task situation). Thus, coupling upright standing with a cognitive task can further contribute to understanding postural control in fallers. Studies investigating balancing tasks combined with cognitive tasks (e.g., mental tracking/working memory tasks, verbal fluency tasks, discrimination tasks) showed divergent results when comparing fallers and non-fallers.[16–19] Dual-task either increased[18] or did not contribute to the prediction of future falls.[20]

In retrospective studies, the presence of a cognitive task performed silently (i.e., mentally counting the number of a stimulus) reduced postural sway in fallers and non-fallers. Batistela et al.[12] investigated postural control when standing upright while performing a cognitive-visual task (i.e., a Stroop task). They observed no difference in postural sway between fallers and non-fallers with eyes open and feet together. Similarly, Uiga et al.[19] did not find any difference between fallers and non-fallers in several postural sway parameters in the presence of an auditory-cognitive task (counting the number of high-pitched tones) while standing with eyes open and feet apart. Both groups reduced postural sway and speed when performing the auditory-cognitive task. These findings suggest a functional integration between postural and cognitive tasks such that fallers and non-fallers reduced postural sway to facilitate the execution of the cognitive task. Therefore, the ability to functionally modulate postural sway in support of a supra-postural task does not seem to be degraded in fallers.

Since fallers seem to increase their postural sway in more challenging balancing tasks, a recent study from our group attempted to increase the demand of the balancing task by combining feet-together posture with the absence of visual information[i]. We tested the effect of haptic inputs on postural sway in fallers and non-fallers. Even with this additional manipulation, there was no difference in postural sway between fallers and non-fallers. These results suggest that older adults, irrespective of their history of falls, could still combine the haptic input provided by light touch and anchors to further reduce postural sway. These results highlight that fallers have a preserved adaptive capability to modulate postural sway in the presence of a cognitive task and additional sensory input.

These findings are not completely surprising. Recently, Hortobágyi et al.[13] proposed a debate about the accuracy of postural sway to measure fall risk and predict future falls in older adults. The lack of predictive validity suggests that postural sway may not be sensitive enough to capture differences between fallers and non-fallers. Differences between fallers and non-fallers seem to be more robust and visible in dynamic tasks like walking.[21] In fact, most falls in older adults occur while walking, especially on uneven terrains.[2,3] Therefore, even in a high-demand balancing task, some studies[12,i] did not find differences in postural sway between fallers and non-fallers, reflecting that the upright stance may not be an adequate task to differentiate between older adults with and without a history of falls.

In summary, the history of falls is indicative that fallers have balance impairments, but the upright stance task may not adequately capture these problems. Differences between fallers and non-fallers in postural sway were not often observed, except when sensory input was less reliable. Interestingly, fallers were able to reduce postural sway in the same way as non-fallers in the presence of a cognitive task and when haptic inputs were available by means of light touch and anchors, which indicate they have the ability to modulate postural sway.

[i] Moraes R, Bedo BLS, Arpini VM, Batistela RA, Santiago PRP, Mauerberg-deCastro E. Light touch with two contact points reduces postural sway more effectively in older adult fallers and non-fallers than do haptic anchors. Submitted for Publication.

CONTROL OF WALKING IN FALLER AND NON-FALLER OLDER ADULTS

The performance of successful locomotion depends on progression, stability, and adaptation to environment and task demands.[22] To cope with that, older adults change their walking, including a reduction in gait speed and an increase in step width to ensure gait stability.[23,24] In addition, there are differences in gait variables among older adults who have suffered at least one fall in recent months compared to older people who have not experienced recent falls.[21,25–27]

Different studies revealed spatial-temporal gait parameter changes between fallers and non- fallers when walking on a flat terrain.[28] One of the major changes in fallers' walking is speed reduction. In a systematic review, Mortaza et al.[28] examined twelve studies that compared fallers and non-fallers, and they found that eight of those studies identified a reduction in walking speed for the fallers. Another important observation of this systematic review was that fallers increased step width and double support duration compared to non-fallers. Fujimoto and Chou[29] showed that fallers exhibited a larger margin of stability than non-fallers. The increase in double support duration contributes to body stability. The changes in walking speed and step width can also be interpreted as stability-related since slower walking speed and a large base of support are associated with a larger margin of stability during walking,[29–31] although some authors have argued that reduction in gait speed can compromise stability.[32–35] This modification can be interpreted as a compensatory strategy such that older adults, particularly fallers, seem to emphasize stability and reduce the weight of other cost functions during walking (e.g., oxygen consumption).[36]

Fallers exhibited higher stride time variability than non-fallers.[26,27] Svoboda et al.[37] showed that fallers increased gait variability in both self-selected and imposed gait speeds. When walking over an obstacle, fallers showed greater variability in step length and time than non- fallers.[38] This increase in gait variability has been associated with a higher risk of falling;[26] however, it is not possible to establish whether variability is a cause of falls or a consequence of cautious gait due to previous falls.[38]

When dealing with adaptive locomotion, fallers also present differences in the anticipatory control compared to non-fallers. When stepping on targets during walking, older adults with a high risk of falling deviated their gaze from the target before stepping on it when requested to step on a second target place three steps ahead, whereas older adults with a low risk of falling deviated their gaze from the first target only after stepping on it.[39,40] This early gaze shift correlated to medial-lateral foot placement variability, which is associated with falls in older adults. Similarly, when stepping over a small obstacle, fallers shifted their gaze from the obstacle earlier than non-fallers, but only in the dual-task context.[41] Moreover, when walking in a real-world environment (with other people walking around), fallers fixated their gaze on the immediate surrounding environment for a shorter duration than non-fallers.[21] Chapman and Hollands[39,40] suggested that fallers prioritized planning future actions over the accurate execution of the ongoing step during demanding walking tasks. This strategy may increase the risk of falling as it compromises the execution of the ongoing step. In addition, this earlier gaze transfer was associated with a higher level of anxiety in older adults with a high risk of falling.[42] The presence of threats to stability in the environment can increase anxiety and make the individuals with a high risk of falling to transfer their gaze earlier. Additionally, when walking in high-threat environments, fallers have more worries or disturbing thoughts (i.e., negative consequences of a fall) than non-fallers, which can reduce the availability of attentional resources that could be used for gait control.[43]

Falls in older adults occur very often following trips and slips.[2,44] This observation indicates a deficit in reactive control in fallers during walking. In a meta-analysis involving reactive stepping, Okubo et al.[45] found that fallers needed more steps to recover from a perturbation than non-fallers. This finding suggests that fallers perform reactive steps of smaller magnitudes that can be insufficient to prevent a fall.

In terms of changes in neuromuscular control, fallers increased the coactivation of the tibialis anterior and medial gastrocnemius muscles during both stance and swing phases compared to non-fallers when perturbed by a continuous mediolateral optic flow perturbation while walking on a treadmill in a virtual environment.[46] This coactivation reflects a neuromuscular strategy to reduce the effects of the perturbation over gait stability by increasing joint stiffness, which is a typical strategy used by older adults,[47] and it is further used by fallers when faced with more perturbing contexts. In terms of muscle synergies, Allen and Franz[48] found that fallers during unperturbed and perturbed walking (i.e., the same optic flow perturbation) exhibited less complexity in neuromuscular control by presenting a reduced number of synergies and more variance accounted for the first muscle synergy. They also found a negative association between the number of muscle synergies and the local dynamic instability, but only during perturbed walking. Similarly, older adults who could not recover their balance after an induced slip during walking exhibited less complexity in the neuromuscular response than those who recovered.[49] These findings suggest that fallers use a reduced motor repertoire that constrains their ability to deal with balance challenges during walking. This change in neuromuscular control could result from peripheral and/or central neural impairments due to aging or even due to fear of falling, which can increase muscle coactivation.[48] These aspects need to be further explored in future studies.

In summary, walking speed is the most consistent aspect to differentiate fallers from non-fallers. This reduction in walking speed may be a strategy to improve gait stability to avoid a fall. When proactively dealing with a perturbation during gait, fallers tend to prioritize planning future gait adaptations over the accurate execution of the ongoing step. Fallers also present a smaller set of muscle synergies to walk in unperturbed and perturbed walking contexts. This reduced ability to recruit more muscle synergies may compromise the possibility of responding accordingly to the different perturbations present during walking.

UPPER LIMB CONTROL IN FALLER AND NON-FALLER OLDER ADULTS

Studies investigating tasks involving upper and lower limbs have contributed to a better understanding of the changes in motor behavior in faller older adults.[17,50,51] These studies show that the differences between fallers and non-fallers are not constrained to balance and gait; changes in upper limb tasks were also observed.

In a balancing task following a perturbation of the support surface, fallers and non-fallers had to reach and grasp a handrail. Although both reaction and movement time did not differ between groups, fallers had more errors in grabbing the handrail than non-fallers, but only when performing a concurrent cognitive task.[17] The cognitive task may overload the capacity to properly plan the grasping task resulting in more errors for the fallers. Grasping an object while standing or walking is widely performed during daily activities (e.g., picking up a glass, shopping, eating, and others). The combined task of walking and reaching-to-grasping (i.e., prehension) an object has been studied in young adults.[52–56] An important aspect of these studies is that walking and prehension are mutually modified to accommodate the execution of the manual task. In older adults, Delbaere and colleagues[57] observed that older adults often avoid performing the combined task of reaching for an object while walking.

We have investigated this compound task in faller and non-faller older adults.[50,51] When walking and reaching for an object, older adults with a history of falls reduced step speed and increased step width and duration compared to non-fallers.[50] There is also an increase in the margin of stability in fallers compared to non-fallers, most probably due to this reduction in gait speed. This increase in the margin of stability is important to ensure stability while reaching for the object. Santos et al.[51] investigated the combined task of walking while grasping, transporting, and placing an object on a predetermined target. The only gait parameter they assessed was the margin of stability at object contact and release. In both instants, there was no difference between fallers and non-fallers for the margin of stability. These findings indicate that fallers could preserve or even improve their margin of stability when performing an upper limb task compared to non-fallers. These findings seem counterintuitive to the overall notion that fallers have balance problems; however, because fallers usually fear falling, they preferred to use a cautious strategy to perform the walking combined with prehension.

This cautious strategy is evident in the finding that fallers could not perform walking and prehension simultaneously.[50] When assessing the center of mass (COM) velocity in the anterior-posterior direction, faller older adults reduced their velocity more than non-fallers when approaching for grasping a dowel. In the most challenging conditions (i.e., obstacles close to the dowel), this reduction in COM velocity was almost twice the reduction observed for non-fallers. This finding indicates that fallers almost stopped walking to grasp the object, whereas the non-fallers were able to keep walking while grasping the object. In the sit-to-walk task, fallers also substantially reduced COM forward velocity at seat-off than non-fallers. This result can also be interpreted as a decoupling of these two tasks.[58] In other words, fallers seem to stand and then initiate gait, whereas non-fallers initiate gait while finishing standing. These findings suggest that fallers have difficulty in combining motor tasks and avoid performing them concomitantly.

Beyond the changes in gait, fallers exhibited modifications in reaching and grasping movements. Faller older adults presented a generalized slowing down in prehension during both standing and walking tasks.[50] For the reaching component of the prehension task, fallers presented longer duration and lower peak wrist velocity than non-fallers. For the grasping component, fallers showed lower peak grip aperture velocity than non-fallers. This slowing down can indicate a cautious strategy or the need for extra time for planning the upper limb movement. In addition, peak grip aperture occurred earlier for fallers than for non-fallers, but only during the walking task. The peak grip aperture velocity also occurred earlier for fallers than for non-fallers in standing and walking tasks. These results indicate a strategy to increase the time available for online control of hand configuration before dowel contact, showing that faller older adults relied more on online control for making the necessary adjustments to grasp the dowel properly. This strategy may reflect a difficulty that fallers have in pre-planning their movements.

In another study, Santos et al.[51] investigated the task of grasping, transporting, and placing an object on a predetermined target while standing and walking. According to Fitts' task, we used different levels of difficulty of the manual task (distance of the object to the target and target size). Fallers were less accurate in positioning the object on the target than non-fallers, particularly for the small target while walking. Fallers also spent more time transporting the dowel than the non-fallers, especially in standing and long target distances. These results showed that faller older adults have difficulties performing manipulative tasks in both standing and walking contexts.

In summary, fallers presented modifications in the control of the prehension movement, and most of these changes were independent of the other task performed (i.e., standing or walking). These changes suggest that the fallers do not have motor behavior modifications related only to balancing and walking tasks. They have changes in other movement categories, suggesting that fallers' difficulties are broader than previously thought. Fallers also were unable to perform two motor tasks concomitantly, indicating a limitation in merging movements. These modifications in the motor behavior of older adults with a history of falls can impair their performance in activities of daily living.

FINAL CONSIDERATIONS

In this review, we showed that faller older adults share some essential characteristics. Except for postural control, where the results seem to be less consistent, fallers have substantial alterations in gait control compared to non-fallers. More recently, studies involving upper limb tasks have shown that fallers also have alterations in the control of reaching and grasping movements. The fact that faller older adults have modifications in the control of upper and lower limbs is indicative of a change in motor behavior involving gross and fine motor behaviors. Santos et al.[51] proposed that fallers have a global change in their motor behavior beyond the typical modifications observed in balance and gait. As falls are of major concern, changes in balance and gait end up being more emphasized, but researchers should not ignore the fact that other aspects of fallers' motor behavior should also be considered.

We think this approach is appropriate because it addresses the fact that changes in motor behavior do not seem to be related to only one category of movement (i.e., walking). Faller older adults exhibited differences in functional connectivity in several brain networks compared to non-fallers.[59] These changes in neural networks may be involved with the overall slowing down observed in fallers, but further studies are necessary. In support of this proposition, it is known that individuals with neurological impairments usually exhibit changes in their motor behavior that are not constrained to one movement category. For instance, individuals with Parkinson's disease have an overall slowdown in their movements observed during walking and upper limb tasks.[60] Even individuals without a neurological problem, as is the case in developmental coordination disorder, have problems in performing gross and fine motor skills.[61] Therefore, it seems reasonable to argue in favor of global changes in fallers' motor behavior, although more studies are necessary to support this proposal.

When studying fallers, it is vital to consider the history of falls and another parameter that can be measured objectively to differentiate fallers and non-fallers. The fact that an older adult experienced a fall is not necessarily an indication that this person should be classified as a faller. Different studies use different criteria to consider an individual as a faller, which can create conflicting results.[28] Interestingly, Silva et al.[62] found that fallers and non-fallers with high functional capacity did not differ in walking speed; however, both groups walked faster than faller and non-faller individuals with low functional capacity. This finding indicates that considering only the history of falls may not be a sufficient parameter to study fallers and non-fallers. In our studies, we have been using the history of falls combined with the Mini-BESTest,[12,50,51] as this test is a good tool to predict fall risks.[63] Others have included in the sample only recurrent fallers (e.g., >2 falls, see[28] for a review) to exclude fortuitous falls. This lack of a clear criterion to consider an individual as a faller weakens the conclusions about changes in motor behavior and falls. Future studies should address this aspect to improve the internal validity and provide clear parameters to define a faller older adult.

In summary, we claimed the possibility that fallers not only present alterations in balance and gait, as widely argued, but also alterations in other movement categories, particularly upper limb movements. The understanding of a faller as an individual with global changes in motor behavior has important implications. First, simple assessment tools involving upper limb tasks could be developed to evaluate the risk of falls. This aspect would open the possibility of developing simple tests using manual tasks as an assessment tool for fall risk prediction in clinical practice. Second, interventions to fallers should not be limited to balance and gait. In rehabilitation programs, older adults with a history of falls should also be encouraged to perform manual tasks. It is well known that several activities of daily living involve manual tasks and these tasks are extremely important to maintain independence in older adults. Third, the difficulty in combining different motor tasks is another aspect that should be emphasized in training and rehabilitation programs. Compound movements are executed very often in our daily activities, and being able to perform this kind of action would help individuals adapt to different tasks and environmental demands.

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