Journal of Aging and Physical Activity, 2014, 22, 96-102
http://dx.doi.org/10.1123/JAPA.2012-0209

Journal of
Aging and Physical Activity
Official Journal of ICAPA
www.JAPA-Journal.com
ORIGINAL RESEARCH

Increased Load Computerized Dynamic Posturography in Prefrail and Nonfrail Community-Dwelling Older Adults

John R. Biggan, Forest Melton, Michael A. Horvat, Mark Ricard, David Keller, and Christopher T. Ray

The understanding of prefrail and nonfrail older adults' postural control with and without increased environmental and cognitive stress is imperative to the development of targeted interventions to decrease fall risk within these populations. Thirty-eight individuals participated in this study. Postural control testing included the Sensory Organization Test (SOT) on a NeuroCom EquiTest. Cognitive and environmental load testing was performed during Condition 6 of the SOT. Though there were no group differences on composite equilibrium score ($p = .06$), the cognitive task (Stroop task) impaired equilibrium scores more than the auditory or visual distracter tasks ($p < .05$ and $p < .01$) for both groups. These results suggest that both prefrail and nonfrail older adults' postural control is reduced in demanding environments. Given these findings, the need for multimodal exercise interventions to target both physical and cognitive factors is apparent.

***Keywords**:* aging, exercise intervention, postural control, cognition

Frailty is a multifaceted health concern that involves a progressive decline in muscle strength, weight loss, decreased activity, fatigue, slowed processing of sensory information, and decreased performance of functional tasks, such as timed-up-and-go, climbing stairs, and walking half a mile (Fairhall et al., 2008; Fried, Ferrucci, Darer, Williamson, & Anderson, 2004; Fried et al., 2005; Fried et al., 2001; Fried & Mor, 1997; Lundin-Olsson, Nyberg, & Gustafson, 1998; Wolinsky, Miller, Andresen, Malmstrom, & Miller, 2005). Kaiser et al. (2009) characterized frailty as a combination of criteria indicating a negative shift in the ability to prevent and recover from poor health and disability. Specifically, frailty has been defined as having at least three of the four following characteristics: weak grip strength, involuntary weight loss of 10 lb (4.5 kg) or more over the last 12 months, general feeling of exhaustion, and slow walking speed (Fried et al., 2001). Likewise, Wolf et al. (1996), established that this is the result of the natural aging process, and appears to be accelerated in individuals afflicted by ailments, which limit their ability to engage, unassisted, in regular exercise and activities of daily living (e.g., walking, doing laundry, transport, etc.). Later, Wolf et al. (2001) went on to address the need for investigators to target individuals transitioning to frailty (i.e., prefrail). Therefore, the focus of this research was on prefrail individuals compared with nonfrail individuals. For the purposes of this study, prefrailty was defined as having one or two of the frailty characteristics listed above.

A direct correlation is evident among three or more frailty indicators that predispose individuals to an increased risk of falls, long-term hospitalization, and mortality (Fairhall et al., 2008; Lang, Michel, & Zekry, 2009). Falls are listed as the third most common cause of unintentional injury and death in all age groups, and the leading cause of death in adults over the age of 65 (Centers for Disease Control and Prevention, National Center for Injury Prevention and Control, 2013). Falling among older adults is one of the foremost examples of how a single event can lead to increased sedentary behavior, which compounds concomitant health factors, leading to considerable negative health outcomes (e.g., osteoporosis, sarcopenia, and increased incidence of diseases of sedentary lifestyle) that, in turn, increase mortality risk (Dellinger & Stevens, 2006; Gitlin et al., 2009). In fact, decreases in postural control (the ability to maintain one's center of gravity over one's base of support) have been documented to negatively affect an older adult's activity level, adversely influencing overall functioning while compounding physical decline (Tinetti, Doucette, Claus, & Marottoli, 1995; Vellas et al., 1997).

Postural Control

The increased risk of falls in frail individuals is due to decreased postural control (Fairhall et al., 2008; Wolf, Barnhart, Ellison, & Coogler, 1997; Wolf et al., 1996; Wolf et al., 2003; Wolf et al., 2001). Balance assessment studies have shown that postural sway increases in older

Biggan, Melton, Ricard, Keller, and Ray are with the Dept. of Kinesiology, University of Texas at Arlington, Arlington, TX. Horvat is with the Dept. of Kinesiology, University of Georgia, Athens, GA.

adults as a result of reduced balance stability, and therefore, sway measurements can be used to estimate the risk of falls (Callisaya et al., 2009; Fernie, Gryfe, Holliday, & Llewellyn, 1982; Overstall, Exton-Smith, Imms, & Johnson, 1977). Body sway is usually estimated by examining speed and displacement of center of pressure (Kang et al., 2009), directional changes in center of mass (Patla, Ishac, & Winter, 2002), and body weight distribution. Larger values of anteroposterior displacement of center of pressure, nonsymmetrical distribution of body weight, and/or larger accelerations of center of mass are features that differentiate healthy adults from those with an increased risk for falls (Sinaki, Brey, Hughes, Larson, & Kaufman, 2005).

Decreased postural control in these at risk populations is then exacerbated by multitasking (e.g., walking while talking; Verghese et al., 2002), especially in frail older adults (Kang et al., 2009). A better understanding of these relationships logically becomes an essential foundation for the genesis of novel evidence-based approaches to formulate exercise interventions specifically targeting prefrail older adults. As the population of older adults is increasing, identifying prefrailty rehabilitation interventions becomes increasingly relevant to minimize the negative outcomes associated with frailty, such as fall-related fractures. Furthermore, divided attention testing has been shown to be a more sensitive predictor of falls in older adults than timed gait (Alexander, Ashton-Miller, Giordani, Guire, & Schultz, 2005; St George, Fitzpatrick, Rogers, & Lord, 2007; Verghese et al., 2002).

However, the impact of increased environmental (visual and auditory) and/or cognitive demands on postural control in individuals transitioning toward frailty compared with nonfrail individuals, as measured with the NeuroCom EquiTest (NeuroCom International, Clackamas, OR), has not been studied. Therefore, the goal of this paper is to detail the impact of three types of divided attention (auditory, visual, and cognitive) on postural control in prefrail older adults. As divided attention testing has been found to impair gait (Verghese et al., 2002), we expected to find a similar impairment to postural control, and we believed that the impairment would be more detrimental to prefrail than nonfrail older adults. However, the type of divided attention that would have the largest impact on postural control was uncertain. In addition, we expected prefrail individuals to show poorer postural control and physical fitness compared with a nonfrail group. Lastly, we expected that prefrail individuals would not only be more likely to fall due to their poorer postural control and physical fitness, but that they would also be at an increased risk of injury (e.g., bone fracture) compared with the nonfrail individuals. To test this hypothesis, bone density was compared between the groups.

Method

Participants

Forty-one individuals (25 women) age 57–89 (M = 73.46, SD = 6.19) were recruited from senior centers in the surrounding community via group presentations about falls and fall risk given by the senior author (see Table 1 for demographics). Interested individuals contacted the researchers after these presentations. These individuals were then screened for frailty status. Frailty was defined as having at least three of the four following characteristics: weak grip strength, involuntary weight loss of 10 lb (4.5 kg) or more over the last 12 months, general feeling of exhaustion, and slow walking speed (Fried et al., 2001). Accordingly, we defined prefrailty as having one or two of the frailty characteristics (Gill, Gahbauer, Allore, & Han, 2006); participants with no frailty characteristics were labeled nonfrail. Twenty-one of the participants were classified as prefrail and 17 were classified as nonfrail. Three frail individuals were excluded. No participants reported a history of legal blindness or deafness. Those participants who wore corrective lenses were allowed to wear them during the study. No fall history was taken at the time. Demographic data for the participants is reported in Table 1. This study was approved by the institutional review board at the University of Texas at Arlington and all participants provided informed consent.

Table 1 Descriptive Statistics by Group and Gender, *M* (*SD*)

	Nonfrail (n = 17)		Prefrail (n = 21)	
Variable	Female (n = 10)	Male (n = 7)	Female (n = 13)	Male (n = 8)
Age* (years)	68.6 (5.4)	72.1 (4.9)	74.8 (5.5)	78.3 (6.0)
Height*† (cm)	166.7 (5.8)	181.6 (9.3)	162.7 (6.7)	175.7 (7.1)
Weight*† (kg)	85.2 (18.3)	97.5 (14.5)	72.7 (13.5)	81.6 (5.9)
Body-mass index (kg/m^2)	30.7 (6.6)	29.7 (4.6)	27.6 (5.7)	26.6 (3.4)
Bone density* (g/cm^2)	0.5 (1.1)	0.6 (1.4)	-1.2 (1.3)	-1.1 (1.0)
Grip strength*†‡ (kg)	25.3 (2.9)	48.1 (7.4)	20.9 (2.9)	31 (7.5)
Arm curl (# in 30 s)	17.6 (5.1)	18.7 (5.7)	16.3 (3.6)	17.1 (3.1)
8-ft up-and-go (s)	7.1 (2.0)	6.7 (1.3)	7.3 (1.2)	7.6 (2.0)
6-min walk (yd)	530.7 (83.7)	551.3 (128.8)	502.8 (195.5)	500.3 (77.5)

*Significant main effect of group (nonfrail vs. prefrail), $p < .05$. †Significant main effect of gender, $p < .05$. ‡Significant interaction of group and gender, $p < .05$.

Procedures

The Lunar Achilles densitometer (GE Healthcare, Achilles InSight, Ultrasonometer) was used to measure fracture risk by determining calcaneal density. It has been shown to be a safe and effective alternative to DXA scans (Hans et al., 2008; Krieg et al., 2006). We derived participants' *t* scores by comparing their bone mineral density to that of a healthy 30-year-old of the same gender and ethnicity ("Prevention and Management of Osteoporosis," 2003). A normal *t* score is –1.0 or higher. Scores below –1.0 indicate osteopenia (≤1.0 and ≥2.5) or osteoporosis (≤2.5). Maximum grip strength was taken using a Jamar hand grip dynamometer (Lafayette Instruments, Lafayette, IN). Participants used their dominant hand to perform three maximal grip strength trials. Three measures of senior fitness (8-ft up-and-go test, arm-curl test, and 6-min walk) were conducted to determine fitness level (Rikli & Jones, 2001). These tests are commonly used as assessment tools for senior fitness.

Participants were also tested utilizing the Sensory Organization Test (SOT) protocol shown in Figure 1. Participants wore a harness during testing to eliminate the risk of falling ("NeuroCom System Operator's Manual," 2001). Participants also wore athletic shoes during the SOT.

Instrumentation

The SOT on the NeuroCom EquiTest System provides information regarding the use of sensory input or combination of inputs to maintain postural stability. This system utilizes a force platform and measures vertical reaction forces that are generated from the participants' center of pressure movement from a fixed base of support (Guskiewicz, Riemann, Perrin, & Nashner, 1997). The SOT is used to assess balance abilities and limitations in a wide variety of populations by determining how individuals are able to respond and adapt to a variety of sensory manipulations. Inaccurate information is delivered to the eyes, feet, and joints through sway referencing of the visual surround and support surface (Figure 1; "NeuroCom System Operator's Manual," 2001). This alteration disrupts the available sensory information and allows the tester to evaluate the individual's use of his or her sensory input to maintain postural control ("NeuroCom System Operator's Manual," 2001).

The SOT protocol is comprised of six sensory conditions (Figure 1). The equilibrium score quantifies the center of gravity sway under each of the three trials of the six sensory conditions (total of 18 trials). Effective use of individual sensory inputs is determined from the overall pattern of scores on the six conditions.

Postural Control Scoring

The composite equilibrium score is the weighted average (0–100) of all scores including Condition 1 average scores, Condition 2 average scores, and three equilibrium scores from each of the trials in Conditions 3–6, a higher score indicating better postural control ("NeuroCom System Operator's Manual," 2001). According to Guskiewicz et al. (1997), the equilibrium scores from each trial are representations of nondimensional percentages compared with the peak amplitude of anteroposterior sway to the theoretical anteroposterior limit of stability.

The strategy analysis score quantifies the amount of movement of either the ankles or the hips by plotting the information from the force plate and equilibrium scores together ("NeuroCom System Operator's Manual," 2001). The closer the score is to 0, the more the individual used the hip-dominant strategy; likewise, scores closer to 100 represent more of an ankle-dominant strategy. Typically, as stability is maintained, individuals will use primarily an ankle strategy and shift to hip strategy when balance becomes more difficult ("NeuroCom System Operator's Manual," 2001). The minor adjustments used during ankle strategy are more desirable because they result in less vertical force, while a shift toward hip strategy results in greater instability.

Load Testing

Condition 6 of the SOT was chosen for testing of environmental and cognitive loads. Condition 6 was chosen due to its sensitivity to anterior-posterior sway and the added stimulus of both the floor and wall movements during testing. Additional load tests included visual, auditory, and cognitive distracters. Visual and cognitive distracters were presented on a 15-in. LCD monitor that was mounted on the visual surround at eye level with the participant. Auditory distracters were presented using speakers mounted on the NeuroCom. The visual distracter chosen for this study was a first-person

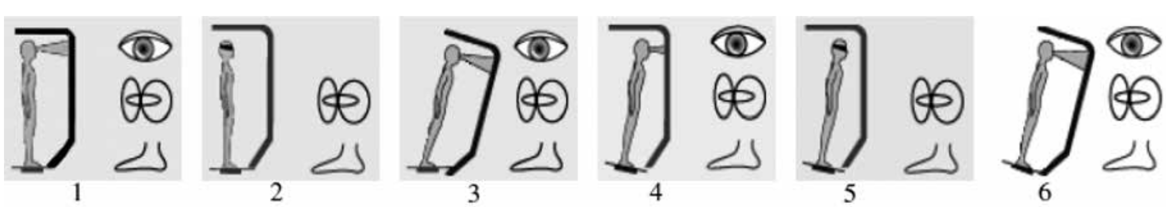

Figure 1 — Six sensory conditions of Sensory Organization Test (SOT) protocol. Eye graphic denotes visual system, the circles graphic denotes vestibular system, and the foot graphic denotes somatosensory system. Image courtesy of Natus Medical, Inc.

rollercoaster simulation (http://www.youtube.com/watch?v=DGfM052xJms), which was chosen because it did not provide a fixed horizon for the participant to focus on during the SOT test. For the auditory distracters, we used auditory sounds of crowded streets to more readily simulate being in public places (http://www.youtube.com/watch?v=t98MvwNkD-k). These sounds were chosen because they mimic real-world phenomena that decrease the amount of resources available to devote to maintaining postural control. Cognitive load testing included a Stroop color and word test (Stroop, 1935). In this test, individuals must inhibit their automatic response of reading the word and, instead, must engage the controlled response of saying the color in which the word is presented (Stroop, 1935). New words were presented every 1.5 s. The ability of individuals to maintain postural control despite the distractions was reflected in their equilibrium and strategy scores.

Statistical Analysis

Statistical analysis was performed using SPSS version 19 (SPSS Inc., Chicago, IL). For the following analyses, pairwise deletions were used for any missing data. All data are presented as means and standard deviations and are presented with degrees of freedom (*df*) and effect size (partial eta-squared, η^2).

Results

Health and Fitness

To compare the health and fitness of the prefrail individuals with those of the nonfrail individuals, four ANOVAs (2 [group: nonfrail vs. prefrail] × 2 [gender: male vs. female]) were conducted for the four health and fitness variables listed in Table 1 (grip strength, arm-curl test, 8-ft up-and-go test, and 6-min walk test). A significant main effect of group was found for grip strength, $F(1, 32) = 37.318$, $p < .001$, partial $\eta^2 = .538$. Participants in the nonfrail group had more upper body strength ($M = 34.65$, $SD = 12.62$), as measured by the grip strength test, than prefrail individuals ($M = 24.62$, $SD = 7.02$).

A significant main effect of gender was found for grip strength, $F(1, 32) = 88.089$, $p < .001$, partial $\eta^2 = .734$. Men had more upper body strength ($M = 39.54$, $SD = 11.41$), measured by the grip strength test, than women ($M = 22.87$, $SD = 3.60$) across both groups.

The main effects of group and gender for grip strength were qualified by a significant interaction of the two, $F(1, 32) = 13.124$, $p < .001$, partial $\eta^2 = .291$. Tukey post hoc comparisons were conducted to determine the nature of the interaction. Males in both groups had stronger grip strengths than females in each group: nonfrail $t(36) = 9.161$, $p < .001$ and prefrail $t(36) = 4.328$, $p < .001$ (see Table 1 for descriptive statistics). Males in the nonfrail group had a stronger grip strength than males in the prefrail group, $t(36) = 6.319$, $p < .001$. This pattern was not found for females in the nonfrail group compared with females in the prefrail group, $t(36) = 2.120$, $p = .17$, thus the interaction. No significant effects were found for the other three variables.

Postural Control

To compare the postural control of the prefrail participants with that of the nonfrail individuals an independent samples *t* test was conducted to compare differences in nondistracted postural control (SOT composite equilibrium score) between the groups (nonfrail and prefrail). No significant difference was found for SOT composite equilibrium, $t(34) = 1.930$, $p = .06$.

Effects of Divided Attention on Postural Control

To analyze the effects of divided attention tasks on postural control between the groups, two (equilibrium score and strategy score) ANOVAs (2 [group: nonfrail vs. prefrail] × 3 [task: Stroop vs. visual distracter vs. auditory distracter]) were conducted (Figure 2). All analyses were conducted using scores on the sixth condition of

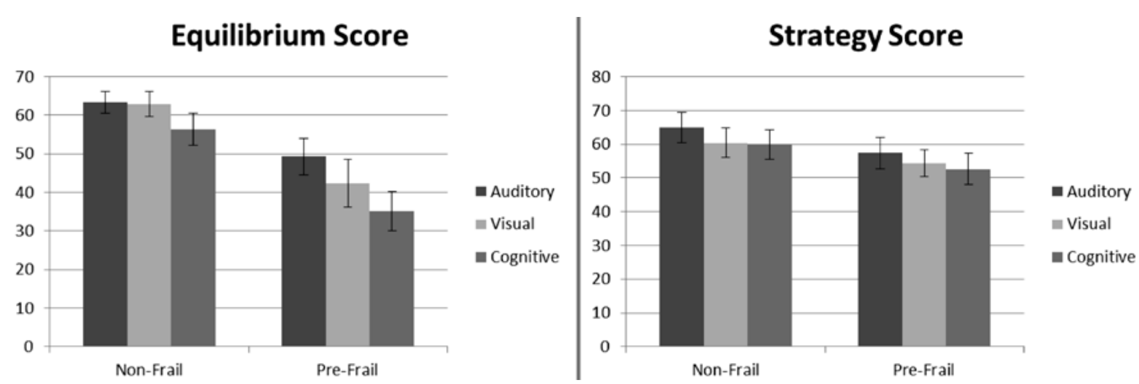

Figure 2 — Equilibrium and strategy scores for each distracter type by group. Nonfrail individuals had a significantly higher equilibrium score on average. The cognitive distracter caused the largest decline in equilibrium score. Both the visual and cognitive distracter caused larger declines in strategy scores than the auditory task.

the SOT. Nonfrail individuals (M = 60.88, SD = 13.09) had a higher equilibrium score than prefrail individuals (M = 42.32, SD = 21.85), $F(1, 28) = 11.297$, $p < .01$, partial $\eta^2 = .287$. A significant main effect of task was found for equilibrium score, $F(2, 56) = 5.796$, $p < .01$, partial $\eta^2 = .171$. Planned comparisons revealed that equilibrium scores were more impaired when performing the cognitive task (Stroop: M = 45.08, SD = 21.10) than the other two tasks (visual distracter: M = 51.98, SD = 22.12 and audio distracter: M = 55.89, SD = 16.90), $t_{\text{visual}}(29) = -2.226$, $p < .05$, and $t_{\text{audio}}(29) = -3.191$, $p < .01$. However, the equilibrium scores during visual and auditory distracter tasks were not significantly different, $t(29) = -1.212$, $p = .24$. The interaction of group and task type was not significant for equilibrium scores, $F(2, 56) = .789$, $p = .46$, partial $\eta^2 = .027$.

For the strategy scores, there was no main effect of group status, $F(1, 28) = 1.440$, $p = .24$, partial $\eta^2 = .049$. No significant main effect of task was found for strategy scores, $F(2, 56) = 2.963$, $p = .06$, partial $\eta^2 = .096$. The interaction of group and task type was also not significant for strategy scores, $F(2, 56) = .082$, $p = .92$, partial $\eta^2 = .003$. All other comparisons were not significant.

Discussion

All evidence related to frailty supports the notion that age-associated changes are further compounded by frailty, thereby exacerbating reductions in strength, coordination, bone density, gait, speed, and flexibility related to general health outcomes and fall risk (Gill, Allore, & Guo, 2003). While some research has attempted to identify the relationship between fall risk and prefrailty, the specific contributors that seem to exacerbate fall risk in individuals transitioning to frailty have not been explored and tested. It is apparent in the physical fitness statistics (Table 1) that the indicators for nonfrail and prefrail groupings show consistently lower functional ability in prefrail participants, especially strength and movement time, which is critical in initiating and sustaining movement without falling. Furthermore, the evidence from this study supports the use of grip strength as a clinical screen that is sensitive and should serve as an assessment that could act as a gateway for more comprehensive postural control testing in low performers. Potential causes for poor grip strength include sarcopenia and/or manifestation of reduced activity due to reduced balance confidence and the associated reductions in physical activity (Bruce, Devine, & Prince, 2002).

In addition to strength, a continuous influx of postural information (including vision, proprioception, and vestibular information) must be processed before a reaction may occur. The amount of cognitive processing required is dependent on task complexity and on the capabilities of the individual's postural control system (Van Niekerk, Fourie, & Horak, 2006). Increased cognitive processing comes with increased task difficulty (Teasdale & Simoneau, 2001). Data from this study demonstrated the impact of increased environmental (visual and auditory) and/or cognitive demands on postural control. The data indicate that cognitive distracters are more detrimental to postural control than environmental distracters such as auditory or visual distracters. This was true for both prefrail and nonfrail individuals. We have not identified another study that explores a visual, auditory, and cognitive stimulus in relation to postural control.

Although the groups were similarly impaired, this does not mean that prefrail and nonfrail individuals are equally likely to injure themselves when distracted. Prefrail participants' bone density was lower on average than nonfrail participants. Prefrail individuals met criteria for osteopenia, which puts them at an increased risk of fracture ("Prevention and Management of Osteoporosis," 2003). This means that prefrail individuals are more likely to injure themselves if they fall while engaging in a cognitively demanding task than nonfrail individuals.

There are some limitations to this study. The first is the total sample size. There were some effects that approached significance such as group differences in equilibrium score (p = .06) but were not statistically significant, as well as trends that may have been affected by the sample size. For example, prefrail participants' postural control was more affected by visual than auditory distracters (an effect which was not observed in the nonfrail individuals); however, the interaction of group and task type was not significant. If there are differences between prefrail and nonfrail individuals with regard to postural control, they are small. Consequently, future studies should include larger sample sizes than those used in this study.

Second, participants' vision and hearing were not tested. No participants reported a history of legal blindness or deafness, and they were allowed to wear corrective lenses during the testing. However, one could argue that subtle group differences may have influenced the outcome measures leading one group to underperform the other due to a visual or auditory impairment. Future research should account for differences in visual and auditory acuity.

Third, it is possible that there were learning effects associated with the computerized dynamic posturography. Participants may have become more comfortable with the device after each trial. Future studies should address this by counterbalancing the order of the trials.

Finally, it should be noted that the current study's inclusion criteria allowed for one or two of the frailty criteria for group membership as prefrail. Future studies should seek to determine if outcomes are affected by the number of transitional characteristics (one or two) documented within subjects.

Conclusion

As the population ages, the number of fallers is expected to increase. The evidence presented in this study supports the notion that deferred attention has a negative effect on postural control. This effect may be more detrimental to those individuals transitioning to frailty given their decreased bone density to begin with. While without intervention, the decline to frailty is inevitable, identification of the factors that may be remediated via targeted training programs may reduce the rate of decline and improve health outcomes of prefrail older adults. In this experiment, we have seen that prefrail individuals are lacking in physiological strength compared with their nonfrail counterparts. Therefore, rehabilitation interventions should target restoration of physiological decline in individuals who exhibit early signs of frailty or are classified as prefrail (Wolf et al., 2003). In addition, we have found that cognitive distracters have a significant negative impact on both nonfrail and prefrail individuals' postural control. This highlights the need for clinicians to consider cognitive influences when remediating postural control impairments with older adults.

Acknowledgments

This work was supported by the University of Texas at Arlington's Research Enhancement Program.

References

Alexander, N.B., Ashton-Miller, J.A., Giordani, B., Guire, K., & Schultz, A.B. (2005). Age differences in timed accurate stepping with increasing cognitive and visual demand: A walking trail making test. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 60*(12), 1558–1562. PubMed doi:10.1093/gerona/60.12.1558

Bruce, D.G., Devine, A., & Prince, R.L. (2002). Recreational physical activity levels in healthy older women: The importance of fear of falling. *Journal of the American Geriatrics Society, 50*(1), 84–89. PubMed doi:10.1046/j.1532-5415.2002.50012.x

Callisaya, M.L., Blizzard, L., Schmidt, M.D., McGinley, J.L., Lord, S.R., & Srikanth, V.K. (2009). A population-based study of sensorimotor factors affecting gait in older people. *Age and Ageing, 38*(3), 290–295. PubMed doi:10.1093/ageing/afp017

Dellinger, A.M., & Stevens, J.A. (2006). The injury problem among older adults: Mortality, morbidity and costs. *Journal of Safety Research, 37*(5), 519–522. PubMed doi:10.1016/j.jsr.2006.10.001

Fairhall, N., Aggar, C., Kurrle, S.E., Sherrington, C., Lord, S., Lockwood, K., . . . Cameron, I.D. (2008). Frailty Intervention Trial (FIT). *BMC Geriatrics, 8,* 27. PubMed doi:10.1186/1471-2318-8-27

Centers for Disease Control and Prevention, National Center for Injury Prevention and Control. (2013) *Falls among older adults*: *An overview*. Retrieved from http://www.cdc.gov/homeandrecreationalsafety/falls/adultfalls.html >

Fernie, G.R., Gryfe, C.I., Holliday, P.J., & Llewellyn, A. (1982). The relationship of postural sway in standing to the incidence of falls in geriatric subjects. *Age and Ageing, 11*(1), 11–16. PubMed doi:10.1093/ageing/11.1.11

Fried, L.P., Ferrucci, L., Darer, J., Williamson, J.D., & Anderson, G. (2004). Untangling the concepts of disability, frailty, and comorbidity: Implications for improved targeting and care. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 59*(3), 255–263. PubMed doi:10.1093/gerona/59.3.M255

Fried, L.P., Hadley, E.C., Walston, J.D., Newman, A.B., Guralnik, J.M., Studenski, S., . . . Ferrucci, L. (2005). From bedside to bench: Research agenda for frailty. *Sci Aging Knowledge Environ, 2005*(31), pe24. PubMed >

Fried, L.P., Tangen, C.M., Walston, J., Newman, A.B., Hirsch, C., Gottdiener, J., . . . McBurnie, M.A. (2001). Frailty in older adults: Evidence for a phenotype. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 56*(3), M146–M156. PubMed doi:10.1093/gerona/56.3.M146

Fried, T.R., & Mor, V. (1997). Frailty and hospitalization of long-term stay nursing home residents. *Journal of the American Geriatrics Society, 45*(3), 265–269. PubMed

Gill, T.M., Allore, H., & Guo, Z. (2003). Restricted activity and functional decline among community-living older persons. *Archives of Internal Medicine, 163*(11), 1317–1322. PubMed doi:10.1001/archinte.163.11.1317

Gill, T.M., Gahbauer, E.A., Allore, H.G., & Han, L. (2006). Transitions between frailty states among community-living older persons. *Archives of Internal Medicine, 166*(4), 418–423. PubMed

Gitlin, L.N., Hauck, W.W., Dennis, M.P., Winter, L., Hodgson, N., & Schinfeld, S. (2009). Long-term effect on mortality of a home intervention that reduces functional difficulties in older adults: results from a randomized trial. *Journal of the American Geriatrics Society, 57*(3), 476–481. PubMed doi:10.1111/j.1532-5415.2008.02147.x

Guskiewicz, K.M., Riemann, B.R., Perrin, D.H., & Nashner, L. (1997). Alternative approaches to the assessment of mild head injury in athletes. *Medicine and Science in Sports and Exercise, 29*(7 Suppl), S213–S221. PubMed doi:10.1097/00005768-199707001-00003

Hans, D., Durosier, C., Kanis, J.A., Johansson, H., Schott-Pethelaz, A.M., & Krieg, M.A. (2008). Assessment of the 10-year probability of osteoporotic hip fracture combining clinical risk factors and heel bone ultrasound: The EPISEM prospective cohort of 12,958 elderly women. *Journal of Bone and Mineral Research, 23*(7), 1045–1051. PubMed doi:10.1359/jbmr.080229

Kaiser, M.J., Bandinelli, S., & Lunenfeld, B. (2009). The nutritional pattern of frailty: Proceedings from the 5th Italian Congress of Endocrinology of Aging, Parma, Italy, 27–28 March 2009. *The Aging Male, 12*(4), 87–94. PubMed doi:10.3109/13685530903296706

Kang, H.G., Costa, M.D., Priplata, A.A., Starobinets, O.V., Goldberger, A.L., Peng, C.K., . . . Lipsitz, L.A. (2009). Frailty and the degradation of complex balance dynamics during a dual-task protocol. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 64*(12), 1304–1311. PubMed doi:10.1093/gerona/glp113

Krieg, M.A., Cornuz, J., Ruffieux, C., Van Melle, G., Buche, D., Dambacher, M.A., . . . Burckhardt, P. (2006). Prediction of hip fracture risk by quantitative ultrasound in more than 7000 Swiss women > or =70 years of age: Comparison of three technologically different bone ultrasound devices in the SEMOF study. *Journal of Bone and Mineral Research, 21*(9), 1457–1463. PubMed doi:10.1359/jbmr.060615

Lang, P.O., Michel, J.P., & Zekry, D. (2009). Frailty syndrome: A transitional state in a dynamic process. *Gerontology, 55*(5), 539–549. PubMed doi:10.1159/000211949

Lundin-Olsson, L., Nyberg, L., & Gustafson, Y. (1998). Attention, frailty, and falls: The effect of a manual task on basic mobility. *Journal of the American Geriatrics Society, 46*(6), 758–761. PubMed

NeuroCom system operator's manual (2001). NeuroCom International: Clackamas, OR.

Overstall, P.W., Exton-Smith, A.N., Imms, F.J., & Johnson, A.L. (1977). Falls in the elderly related to postural imbalance. *British Medical Journal, 1*(6056), 261–264. PubMed doi:10.1136/bmj.1.6056.261

Patla, A.E., Ishac, M.G., & Winter, D.A. (2002). Anticipatory control of center of mass and joint stability during voluntary arm movement from a standing posture: Interplay between active and passive control. *Exp Brain Res, 143*(3), 318–327. PubMed doi:10.1007/s00221-001-0968-6

Prevention and management of osteoporosis. (2003). *World Health Organ Technical Report Series, 921,* 1–164, back cover. PubMed

Rikli, R.E., & Jones, C.J. (2001). *Senior fitness test manual*. Champaign, IL: Human Kinetics.

Sinaki, M., Brey, R.H., Hughes, C.A., Larson, D.R., & Kaufman, K.R. (2005). Balance disorder and increased risk of falls in osteoporosis and kyphosis: Significance of kyphotic posture and muscle strength. *Osteoporosis International, 16*(8), 1004–1010. PubMed doi:10.1007/s00198-004-1791-2

St George, R.J., Fitzpatrick, R.C., Rogers, M.W., & Lord, S.R. (2007). Choice stepping response and transfer times: Effects of age, fall risk, and secondary tasks. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 62*(5), 537–542. PubMed doi:10.1093/gerona/62.5.537

Stroop, J.R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18,* 643–662. doi:10.1037/h0054651

Teasdale, N., & Simoneau, M. (2001). Attentional demands for postural control: The effects of aging and sensory reintegration. *Gait & Posture, 14*(3), 203–210. PubMed doi:10.1016/S0966-6362(01)00134-5

Tinetti, M.E., Doucette, J., Claus, E., & Marottoli, R. (1995). Risk factors for serious injury during falls by older persons in the community. *Journal of the American Geriatrics Society, 43*(11), 1214–1221. PubMed

Van Niekerk, D.J., Fourie, L.J., & Horak, I.G. (2006). Birds as hosts of immature ixodid ticks in Free State Province, South Africa. *The Onderstepoort Journal of Veterinary Research, 73*(2), 123–130. PubMed

Vellas, B.J., Hunt, W.C., Romero, L.J., Koehler, K.M., Baumgartner, R.N., & Garry, P.J. (1997). Changes in nutritional status and patterns of morbidity among free-living elderly persons: A 10-year longitudinal study. *Nutrition (Burbank, Los Angeles County, Calif.), 13*(6), 515–519. PubMed doi:10.1016/S0899-9007(97)00029-4

Verghese, J., Buschke, H., Viola, L., Katz, M., Hall, C., Kuslansky, G., & Lipton, R. (2002). Validity of divided attention tasks in predicting falls in older individuals: A preliminary study. *Journal of the American Geriatrics Society, 50*(9), 1572–1576. PubMed doi:10.1046/j.1532-5415.2002.50415.x

Wolf, S.L., Barnhart, H.X., Ellison, G.L., & Coogler, C.E. (1997). The effect of Tai Chi Quan and computerized balance training on postural stability in older subjects. Atlanta FICSIT Group. Frailty and injuries: Cooperative studies on intervention techniques. *Phys Ther, 77*(4), 371–381; discussion 382–384.

Wolf, S.L., Barnhart, H.X., Kutner, N.G., McNeely, E., Coogler, C., & Xu, T. (1996). Reducing frailty and falls in older persons: an investigation of Tai Chi and computerized balance training. Atlanta FICSIT Group. Frailty and injuries: Cooperative studies of intervention techniques. *Journal of the American Geriatrics Society, 44*(5), 489–497. PubMed

Wolf, S.L., Sattin, R.W., Kutner, M., O'Grady, M., Greenspan, A.I., & Gregor, R.J. (2003). Intense tai chi exercise training and fall occurrences in older, transitionally frail adults: A randomized, controlled trial. *Journal of the American Geriatrics Society, 51*(12), 1693–1701. PubMed doi:10.1046/j.1532-5415.2003.51552.x

Wolf, S.L., Sattin, R.W., O'Grady, M., Freret, N., Ricci, L., Greenspan, A.I., . . . Kutner, M. (2001). A study design to investigate the effect of intense Tai Chi in reducing falls among older adults transitioning to frailty. *Controlled Clinical Trials, 22*(6), 689–704. PubMed doi:10.1016/S0197-2456(01)00168-4

Wolinsky, F.D., Miller, D.K., Andresen, E.M., Malmstrom, T.K., & Miller, J.P. (2005). Further evidence for the importance of subclinical functional limitation and subclinical disability assessment in gerontology and geriatrics. *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences, 60*(3), S146–S151. PubMed doi:10.1093/geronb/60.3.S146