Smith-Ray, R.L., Hughes, S.L., Prohaska, T.R., Little, D.M., Jurivich, D.A. & Hedeker, D. (2013) Impact of cognitive training on balance and gait in older adults. *Journals of Gerontology, Series B: Psychological Sciences and Social Sciences*, *70(3)*, 357–366, doi:10.1093/geronb/gbt097. Advance Access publication November 5, 2013

Impact of Cognitive Training on Balance and Gait in Older Adults

Renae L. Smith-Ray,[1] Susan L. Hughes,[1,2] Thomas R. Prohaska,[3] Deborah M. Little,[4] Donald A. Jurivich,[5] and Donald Hedeker[1,6]

[1]Center for Research on Health and Aging, Institute for Health Research and Policy, University of Illinois at Chicago.
[2]Community Health Sciences, School of Public Health, University of Illinois at Chicago.
[3]College of Health and Human Services, George Mason University, Fairfax, Virginia.
[4]VISN 17 Center of Excellence for Research on Returning War Veterans, Texas A&M Health Science Center, Waco.
[5]Department of Geriatric Medicine, University of Illinois at Chicago and
[6]Epidemiology and Biostatistics, School of Public Health, University of Illinois at Chicago.

Objectives. Cognitive processing plays an important role in balance and gait and is a contributing factor to falls in older adults. This relationship may be explained by the fact that higher order cognitive functions such as executive functions are called upon while walking. The purpose of this study was to examine whether a cognitive training intervention leads to significant improvements on measures of balance and gait.

Method. This randomized trial tested whether cognitive training over 10 weeks improves balance and gait in older adults. Participants were randomly assigned to a computer-based cognitive training intervention or measurement-only control. Outcomes included Timed Up and Go (TUG), gait speed, and gait speed with a cognitive distraction. Data were analyzed using analysis of covariance models with change scores.

Results. Participants' (N = 51) average age was 82.7 for those randomized to intervention and 81.1 for those randomized to control. After 10 weeks, intervention group participants performed significantly better than controls on the TUG. When the cohort was limited to those categorized as slow walkers (baseline 10-m walk ≥ 9 s), intervention participants performed significantly better than controls on TUG and distracted walking.

Discussion. Cognitive training slows degradation of balance and improves gait while distracted, rendering it a promising approach to falls prevention.

Key Words: Balance—Cognitive training—Falls—Gait—Older adults.

COGNITIVE processing plays an important role in gait (Al-Yahya et al., 2011). This relationship may be explained by the fact that higher order cognitive functions such as executive function and attention are called upon while walking (Alexander & Hausdorff, 2008; Fasano, Plotnik, Bove, & Berardelli, 2012; Herman, Mirelman, Giladi, Schweiger, & Hausdorff, 2010; Mirelman et al., 2012; Rosano et al., 2012; Yogev-Seligmann, Hausdorff, & Giladi, 2008). As these cognitive domains decline with age, motor tasks such as walking and balance become less automated and more cognitively taxing (Schaefer & Schumacher, 2011; Woollacott & Shumway-Cook, 2002).

The literature also shows that falls and cognitive decline are linked (Chen, Peronto, & Edwards 2012; Springer et al., 2006; Tinneti, 2003). For example, among older adults with a history of falling, cognitive impairment increases subsequent risk of falling (Tinneti, 2003). Several studies provide evidence that incidence of falls is significantly higher among older adults with poorer executive function (Herman et al., 2010; Hsu, Nagamatsu, Davis, & Liu-Ambrose, 2012; Martin et al., 2013; Mirelman et al., 2012).

Much of what is known about the relationship between gait, balance, and cognition has been assessed using dual-task methodologies. Motor cognitive dual-task performance involves simultaneously completing a physical/motor task (i.e., walking) and a secondary cognitive task (i.e., reciting a phone number). These studies have shown that relative to young adults, older adults require more attentional control while walking or maintaining balance (Laessoe, Hoeck, Simonsen, & Voigt, 2008) and perform significantly worse under dual-task situations such as completing a cognitive task and a walking or balance task simultaneously (Huxhold, Li, Schmiedek, & Lindenberger, 2006; Lindenberger, Marsiske, & Baltes, 2000). Dual-task deficits may be driven by a degradation of prefrontal cognitive processes that are called upon while walking, particularly, executive functions. However, a systematic review concluded that neural plasticity makes it possible to improve dual-task walking (Beurskens & Bock, 2012).

Reuter-Lorenz and Cappell (2008) argue that contrary to early thought, the older adult brain has remarkable capacity to compensate for decline by reallocating neurocognitive

Received February 5, 2013; Accepted August 5, 2013
Decision Editor: Myra Fernandes, PhD

functions. Cognitive training is one approach toward capitalizing on neural plasticity by targeting and training cognitive domains for improvement. As such, cognitive training has emerged as an efficacious behavioral strategy for improving or maintaining cognitive health in old age (Smith et al., 2009; Willis et al., 2006). Cognitive training has been shown to significantly improve cognitive domains trained, including auditory speed, accuracy, and speed of processing (Smith et al., 2009; Willis et al., 2006). A recent selective review of cognitive training interventions found that the general impact of cognitive training is inconsistent but is greatest when the training stimulates multiple cognitive domains and adapts to user performance in order to continually provide the user with new challenges (Buitenweg, Murre, & Ridderinkhof, 2012).

A small number of recent studies have found that balance and gait improve following cognitive training. For instance, postural stability can be improved through targeted working memory training. Doumas, Rapp, and Krampe (2009) found that after 10 practice sessions on working memory, compared with young adults, older adults increased their cognitive resource allocation while maintaining greater focus on the balance task, demonstrating the cognitive capacity for improvement (Doumas et al., 2009). Li and colleagues (2010) also demonstrated transference of effects from visual discrimination reaction time training to a physical outcome measure of balance. Older adults in the Li and colleagues study who were randomly assigned to complete approximately 6 hr of training under the cognitive dual-task paradigm experienced significant improvements in body sway and dynamic balance compared with controls.

Although these studies have demonstrated the capacity of cognitive training to improve balance and gait, the training approaches tested are not practical for broad dissemination. A single study has demonstrated that 8 weeks of training using a commercially available cognitive training program improved older adult gait speed and a walking while talking task compared with controls, but between-subjects improvements were not statistically significant (Verghese, Mahoney, Ambrose, Wang, & Holtzer, 2010). The lack of significance may have been attributable to the small sample size (N = 20). According to a recent review, there is a continued need for studies to investigate the effect of cognitive training on gait and balance (Wollesen & Voelcker-Rehage, 2013). Manipulations to cognitive processing, such as cognitive training interventions, should be further explored as a potential mechanism to improve balance and gait, thereby reducing falls in older adults.

This study sought to add to the literature by assessing whether a commercially available computer-based cognitive training program delivered in a classroom format over a 10-week period improved physical performance outcomes related to walking and balance in older adults. If this association is supported, cognitive training may be a viable approach to reducing the incidence of falls in older adults by improving the ability to deal with cognitive demands of navigating through one's environment. The conceptual framework depicting potential mechanisms underlying the association between gait, balance, and cognition can be found in Figure 1. Based on what is currently known regarding the relationship between cognition, gait, and balance, we believe that cognitive training will lead to distinct improvements in cognitive functions related to executive functions—visuospatial working memory, speed of processing, and inhibition—and improvements in these cognitive processes will result in improved gait and balance. Our hypothesis was that 10 weeks of cognitive training on executive functions would lead to significant improvements on three measures of physical performance: gait speed, gait speed when faced with a secondary visuospatial cognitive task, and balance.

Method

Design

This study used a randomized controlled trial design to test the efficacy of commercially available cognitive training programs on balance and gait. Older adults were recruited from independent living facilities and randomly

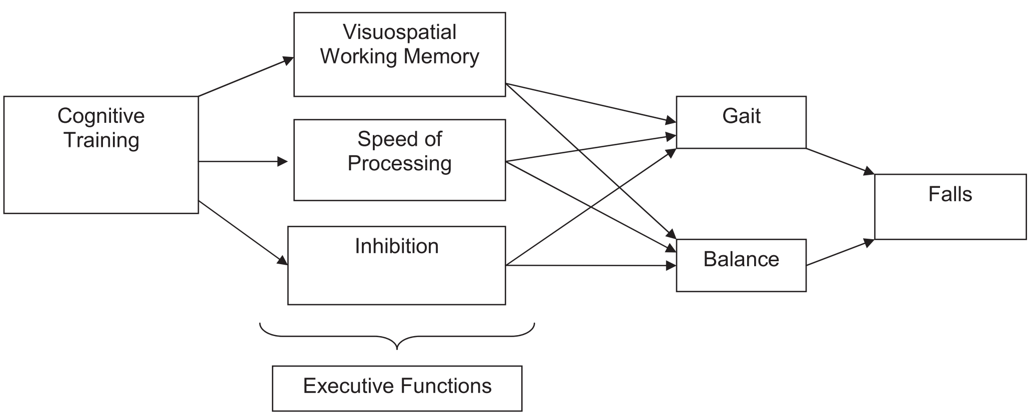

Figure 1. Conceptual model of the association between cognitive training and falls.

assigned to either the cognitive training intervention or a measurement-only control group.

Participants

Participants were males and females aged 70 years or older. Inclusion criteria were (a) at least one self-reported fall within the last 2 years or a self-reported balance impairment, (b) aged 70 or older, and (c) score of greater than or equal to 26 on the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975). Exclusion criteria were (a) presence of a severe walking or balance impairment, (b) previously completed a cognitive training program within the last year, (c) colorblindness, (d) plans to begin a balance program during the study period, (e) self-reported presence of vertigo, (f) visual acuity of less than 20/80, or (g) currently using psychotropic medications.

Procedure

Participants were recruited from Chicago-area Independent Living facilities through presentations by the principal investigator, study advertisements printed in program guides, study advertisements posted on closed broadcast television stations within the Independent Living facilities, internal mailings of study recruitment flyers to Independent Living facility residents, and through flyers posted throughout each facility. This study was approved by the University of Illinois at Chicago Institutional Review Board (2010-0042).

Participants were randomized into one of two study arms immediately after consenting to participate—the intervention arm or a control arm. Researchers were not blinded to study arm condition; however, potential bias was minimal because the outcomes of interest—balance and gait—were measured quantitatively with little room for subjectivity on behalf of the researcher. Outcomes were assessed at baseline and immediately posttraining (10 weeks) through individual interviews administered by research staff.

Control condition.—Participants randomized to the control arm received materials on preventing falls. At the conclusion of the baseline data collection session, participants assigned to the control arm were given two brochures on fall prevention for older adults produced by the Centers for Disease Control and Prevention. Control arm participants were contacted by study staff intermittently to inquire about recent fall incidents or concerns. At the end of the study period, control participants were offered a copy of the cognitive training program at no charge so that they could also receive the potential benefits of cognitive training.

Intervention condition.—Each participant in the intervention arm was exposed to the computer-based cognitive training program. The majority of participants (four of five facilities) completed the intervention in a class-based format meeting 3 times per week, for 60 minutes per session. The total intervention dosage was derived from that used in two efficacious cognitive training trials, Improvement in Memory with Plasticity-based Adaptive Cognitive Training (IMPACT) and Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) (Smith et al., 2009; Willis et al., 2006), and the 3 days/week 60-min/day format was modeled from an existing Posit Science cognitive training class at one of the participating partner sites. The total training time of 1,800 min was within the range of cognitive training dose delivered for the ACTIVE (750 min; Willis et al., 2006) and IMPACT (2,400 min; Smith et al., 2009) programs. Intervention adherence was assessed by examining total logged cognitive training time at the end of the 10-week period.

Cognitive training.—Executive functions including visuospatial working memory, speed of processing, and inhibition were trained using the Insight computer software program developed by Posit Science. Three game-like cognitive training exercises were used to target these cognitive domains Road Tour, Jewel Diver, and Sweep Seeker. These exercises were chosen because they require the use of all three cognitive domains and are simple to learn and play. All three cognitive training tasks prompt the participant to complete an assessment at the beginning of the 10-week period and then again approximately at Weeks 5 and 10. These assessments allow the participant to observe how their performance has improved at 5 and 10 weeks relative to their baseline performance. The Posit Science program is self-driven and adapts to the individual's performance by increasing or decreasing task difficulty so that each participant continues to be challenged and engaged throughout the intervention.

Road Tour begins with the user viewing an animated car or truck on the center of the screen and a road sign randomly placed around the periphery. This view lasts a few seconds and fades away. Subsequently, two vehicles reappear and the user has to correctly select the stimulus vehicle. At the same time, a circle of cars appears around the periphery with the one road sign among them. The participant must correctly identify the location in which that road sign initially appeared around the periphery. As the participant's performance improves, the viewing time becomes shorter making the task more difficult. The participant's visuospatial working memory is trained as s/he encodes and briefly retains the spatial location of the road sign. Speed of processing is enhanced as the participant works quickly to encode the location of the stimuli and the type of vehicle. Finally, inhibition is engaged as the participant learns to ignore the distracter stimuli.

The setting of Jewel Diver is underwater where a scuba diver attempts to locate jewels under water bubbles. The task begins with a variety of jewels randomly scattered across the screen. The participant is instructed to keep her eye on the stimulus jewel, which is displayed along with distracter jewels for approximately 1 s. After this initial viewing, each jewel is encapsulated by a bubble and begins to float erratically around the screen. The jewels cannot be seen through the bubbles. The participant must keep track of the bubble that contains the stimulus jewel as they are scattered about. Once the bubbles stop moving, the participant must pop the bubble that she believes contains the stimulus jewel. As the participant's performance on this task improves, the number of distracter stimuli/bubbles increases and the bubbles move more rapidly around the screen. This task challenges the user to use visuospatial working memory and speed of processing to view and track the stimulus. Inhibition is trained as the participant learns to ignore the distracter stimuli.

Sweep Seeker is a game of visual attention and speed of processing. The game begins with a pyramid of various seashells. The objective of the game is to accumulate points by collapsing the seashells in a way to line up three similar shells in a row. Each time participants achieved three in a row, points would accumulate. In order to achieve three in a row, participants must strategically make nonmatching shells disappear. They do this by clicking on the shell that they want to disappear. After selecting a shell, the participants see two movements of lines that move inward or outward. Participants must watch the movement of these lines closely and then select the correct sequence in which the lines moved (i.e., inward/inward; inward/outward; outward/outward; outward/inward). This task primarily targets the cognitive domains of speed of processing and attention.

Measures.—At baseline, participants completed a questionnaire that included psychometric evaluation of executive functions, including visuospatial working memory, inhibition, attention, age, sex, gender, instrumental activities of daily living (IADL), medical conditions, and physical and social activities. Participants were screened for depression using the short-form Geriatric Depression Scale (Sheikh & Yesavage, 1986). Participants who scored 6 or above on the scale were provided with names of local providers who could help diagnose and treat depression. Demographic data included age, gender, race/ethnicity, and years of education, and health data included activities of daily living, IADL, physician-diagnosed chronic health conditions, and current medications.

Balance was measured using the number of seconds to complete the Timed Up and Go (TUG) test (Steffen, Hacker, & Mollinger, 2002; van Hedel, Wirz, & Dietz, 2005). Gait speed was measured during a simple indoor walking course that involved walking 10 m at a usual or comfortable pace. Time to complete the 10-m walk test is a sensitive measure of gait abnormalities (van Hedel et al., 2005). The 10-m walk was completed 3 times and the average (seconds) of these three performances was used for the analysis. After this, the 10-m walk test was completed 3 more times while the participant engaged in a secondary visuospatial task, Brooks Matrices (Brooks, 1967), and the average time (seconds) of the three trials was used for analysis. For the Brooks Matrix condition, participants were shown a black and white image of a 3×3 matrix. In this matrix, all squares were white with the exception of the center square, which was black. The participants were asked to visualize the black square shifting in a sequence of three positions throughout the matrix. The shifting sequence was provided by the researcher. After the three positions were given, the participant was asked to point to the square in which the black square came to rest after the three moves. Each participant was given one opportunity to practice this task prior to the distracted walking trials. During the distracted walking trials, the researcher called out the sequence of three moves that the black square made (e.g., "the square moved one square down, one square left, two squares up") and asked the participant to visualize these movements while completing the 10-m walk. The black square originated in the center of the matrix on every trial. When the 10-m walk was complete, the participant pointed to the position on the matrix in which the black square ended. Measures were researcher administered and completed in the following order: demographic and health questionnaire, depression scale, cognitive measures, TUG, gait speed, and distracted gait speed.

Analyses.—The first phase of data analysis entailed running descriptive statistics on the two study groups to examine the presence of statistically significant differences between groups at baseline. Attrition from treatment and from measurement was also assessed. Statistically significant differences in study outcomes between study groups over the 10-week study period were analyzed using the general linear models (GLM) procedure for continuous outcomes (e.g., proc GLM) in SAS version 9.1.3. Analysis of covariance (ANCOVA) models were conducted for each of the outcome variables to assess between group differences. These models included baseline gait speed as a covariate. Outcome variables were included in the models as change scores that were created by subtracting the baseline from the 10-week values for each participant.

Recent literature has found that older adults who are slow walkers are at higher risk of mortality than fast-walking counterparts (Studenski et al., 2011). Furthermore, slow walkers may have a greater capacity for improvement because they are further away from the performance ceiling than fast-walking counterparts. For this reason, a second set of analyses was conducted using a limited cohort of participants who took longer than 9 s to complete the 10-m walk test. ANCOVA models were conducted to assess the statistical difference between groups of slow walkers as randomized while controlling for baseline gait speed. Baseline gait speed was categorized into thirds, and the two terciles with the slowest walking speed were retained in this analysis. Thus, two sets of analyses were completed for the primary outcomes of balance and gait: (a) intent-to-treat analysis and (b) an analysis that was limited to participants who were categorized as "slow walkers" based on gait speed at baseline. Cohen's *d* effect sizes were calculated to determine the strength of the association between the study arm and TUG, gait speed, and distracted gait speed. Analyses were completed by study arm as randomized.

Results

A total of 53 participants were recruited into the study. Of the 53, two were ineligible after prescreening due to a severe hearing impairment (N = 1) and a severe balance impairment (N = 1). Two participants dropped study participation (3.9%), and two were lost to follow-up (3.9%). There were no significant differences in attrition between groups (Table 1). Of the 51 participants in the final cohort (27 intervention and 24 control), 47 participants (92.2%) completed baseline and follow-up measures, 26 (96.3%) in the intervention and 21 (87.5%) in the control arm. Participants who completed the study were similar to those who did not complete the study in key characteristics including age (mean 81.7 years for completers, 81.8 for noncompleters), race (96.0% vs 100% white), ethnicity (98.0% non-Hispanic vs 100% non-Hispanic), and depression (1.86 vs 1.75). However, those who completed the study were less likely to be women (78.0% women vs 100% women) and had slightly more education (15.3 grades complete vs 13.5 grades complete) than those that did not complete the study.

Table 1 displays participant characteristics by study arm for demographic characteristics. Importantly, results from simple analysis of variance models found that participants randomly assigned to the intervention and control arms did not differ significantly at baseline on key characteristics including gender, race, ethnicity, age, education, depression, cognitive status, or IADL. Moreover, participants did not differ significantly at baseline on outcome measures of gait speed, distracted gait speed, or TUG (Table 1).

Intent-to-Treat Analysis

Timed Up and Go.—The ANCOVA analyses found a significant association between TUG and study arm (F (2,36) = 4.47, p = .036). Mean TUG speed increased for participants in both study groups between baseline and postintervention, indicating that participants' performance declined (i.e., became slower) between baseline to 10 weeks. This performance decline was significantly greater for control participants (μ = −2.65) relative to intervention participants (μ = −0.55; Figure 2). The magnitude of the effect between groups for TUG was large (Cohen's d = 0.73). (Refer to Table 2 for a complete summary of the results.)

Gait speed.—The ANCOVA model exhibited no significant association between groups on 10-m gait speed. Mean number of seconds to complete the 10-m walk increased

Table 1. Participant Characteristics at Baseline

	Total		Intervention		Control		Difference at baseline
	N/Mean	Percent/*SD*	*N*/Mean	Percent/*SD*	*N*/Mean	Percent/*SD*	(α)
Recruited/randomized	51		27		24		—
Dropped	2	3.9%	1	3.7%	1	4.2%	0.934
Lost to follow-up	2	3.9%	0	0.0%	2	8.3%	0.131
Completed study	47	92.2%	26	96.3%	21	87.5%	0.252
Age (mean)	81.96	6.36 *SD*	82.73	5.99 *SD*	81.13	6.77 *SD*	0.326
Gender (female)	39	76.5%	21	77.8%	18	75.0%	0.463
Race							0.202
White	48	94.1%	24	88.9%	24	100.0%	—
Black	2	3.9%	2	7.4%	0	0.0%	—
Ethnicity (Hispanic origin)	1	2.0%	0	0	1	4.2%	0.271
Years of education	15.26	3.13 *SD*	14.92	2.88 *SD*	15.63	3.40 *SD*	0.210
Depression score, mean (range: 0 = *low* to 15 = *high*)	1.76	2.01 *SD*	2.1	2.19 *SD*	1.46	1.84 *SD*	0.154
MMSE score, mean (range: 0 = *low* to 30 = *high*)	28.4	2.00 *SD*	27.79	2.54 *SD*	28.75	1.11 *SD*	0.156
IADL total, mean (range: 8 = *independent* to 31 = *dependent*)	9.4	2.85 *SD*	9.63	3.29 *SD*	9.52	2.62 *SD*	0.710
10-m walk (s)	11.10	3.04	11.09	2.91	11.12	3.25	0.886
10-m walk distracted (s)	12.89	3.33	13.09	3.41	12.67	3.32	0.373
Timed Up and Go (s)	11.26	4.36	11.02	3.98	11.52	4.80	0.797
Slow walkers (≥9 s on 10-m walk)	33	64.7%	15	62.5%	18	66.7%	0.674

Notes. IADL = instrumental activities of daily living; MMSE = Mini-Mental State Examination.

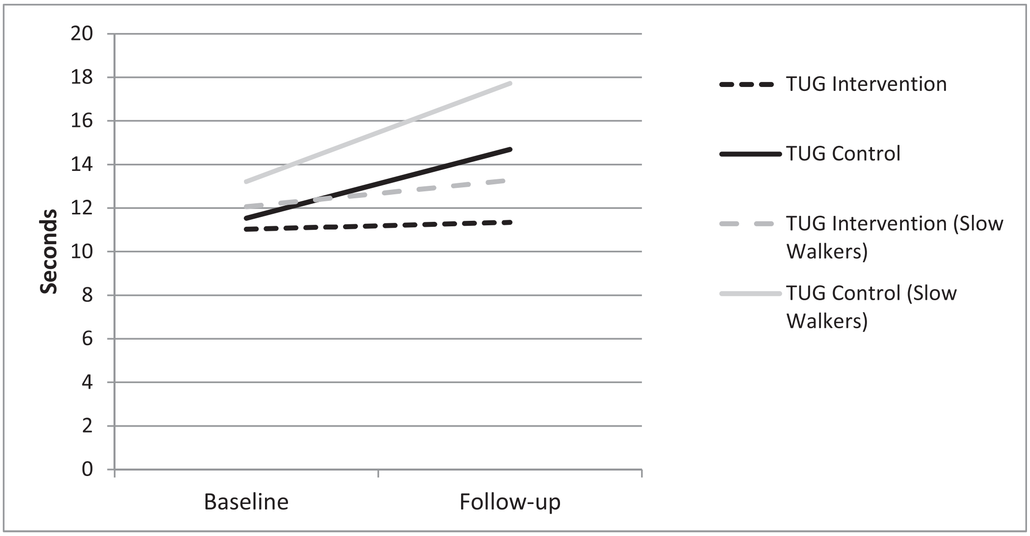

Figure 2. Mean differences on Timed Up and Go (TUG) for two analytic cohorts.

Table 2. Output From ANCOVA Models Assessing the Association Between Outcomes and Treatment Arm

	Intent-to-treat analysis								Slow walkers (as randomized)							
		Control change score		Intervention change score						Control change score		Intervention change score				
	N	Mean	*SD*	Mean	*SD*	Cohen's *d*	*F* Value	*p* Value	*N*	Mean	*SD*	Mean	*SD*	Cohen's *d*	*F* Value	*p* Value
10-m walk (s)	45	−0.95	1.62	−0.18	1.60	0.48	2.46	.124	29	−1.05	1.96	0.01	1.70	0.58	2.59	.120
10-m walk distracted (s)	43	−1.07	1.51	−0.27	2.13	0.43	1.73	.195	27	−1.52	1.68	0.10	2.03	0.87	5.26	.031*
Timed Up and Go (s)	36	−2.65	3.46	−0.55	2.13	0.73	4.74	.036*	23	−3.91	3.47	−0.88	2.40	1.02	5.37	.031*

Notes. ANCOVA = analysis of covariance.
*$p < .05$.

(i.e., performance declined) between baseline and 10 weeks, but the increase was greater for control participants (μ = −0.95) compared with intervention participants (μ = −0.18; Figure 3). Cohen's *d* effect sizes for gait speed were moderate (Cohen's *d* = 0.48).

Gait speed while distracted.—The ANCOVA analysis revealed no significant association between study arm and 10-m gait speed while distracted. Mean number of seconds to complete the distracted 10-m walk increased between baseline and 10 weeks for participants in both study arms. The increase was more than 1 s for control participants (μ = −1.07) but less than that for intervention participants (μ = −0.27; Figure 3). The magnitude of the effect between groups for distracted gait speed was moderate (Cohen's *d* = 0.43).

Subanalysis: Slow Walkers

A second set of analyses was completed for participants who were categorized as slow walkers (those who took ≥9 s on baseline 10-m walk; *N* = 30; age μ = 83.3).

Timed Up and Go.—The ANCOVA analysis revealed that TUG performance significantly differed between study groups ($F(2,23) = 5.37$, $p = .031$) for those categorized as slow walkers. TUG speed increased (i.e., performance declined) between baseline and 10 weeks for participants in both study arms; however, the increase was significantly greater for control participants (μ = −3.91) than for intervention participants (μ = −0.88; Figure 2). Cohen's *d* effect sizes for this subanalysis were large than the effect sizes seen in the prior intent-to-treat analysis. Effect sizes between groups were large for the TUG (Cohen's *d* = 1.02).

Gait speed.—Participants in the intervention arm maintained 10-m gait speed between baseline and 10 weeks (μ = 0.01), but participants in the control arm declined 10-m gait speed by more than 1 s (μ = −1.05; Figure 3). This difference was not significant. The effect size between groups for gait speed was moderate (Cohen's *d* = 0.58).

Gait speed while distracted.—When the cohort was limited to slow walkers, there was a significant difference between intervention and control participants on 10-m gait

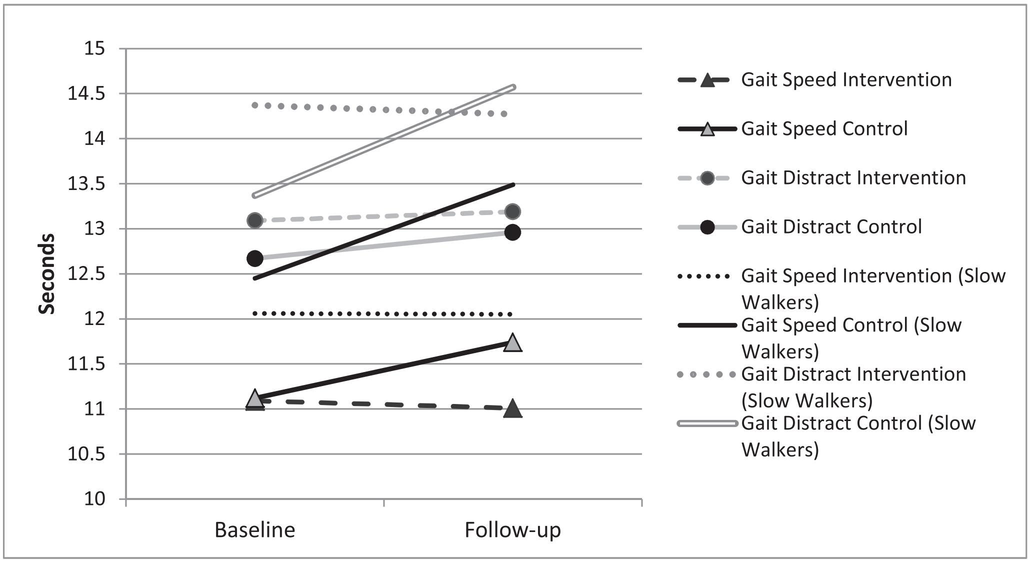

Figure 3. Mean differences on gait outcomes for two analytic cohorts.

speed while distracted ($F(2,27) = 5.26$, $p = .031$). Control participants experienced approximately a 1-s decline in distracted gait speed ($\mu = -1.05$), whereas intervention participants slightly improved on distracted gait speed ($\mu = 0.1$; Figure 3). Cohen's *d* effect size for distracted gait speed between study groups was large (Cohen's $d = 0.87$).

Discussion

This randomized controlled trial sought to determine whether a commercially available cognitive training intervention improved balance and gait in a cohort of older adults with a history of falling or balance impairments. This study tested the hypothesis that 10 weeks of cognitive training leads to significant improvements on gait speed, gait speed when faced with a secondary visuospatial cognitive task, and balance. The hypothesis was partially supported. Using a relatively small cohort ($N = 51$), results demonstrate that, following the 10-week intervention, participants differed significantly by group on a measure of balance. Specifically, the intent-to-treat analysis found that time to complete the TUG increased (i.e., performance declined) for both control and intervention participants, but this performance decline was significantly greater for control participants. However, the same intent-to-treat analysis found no significant differences by group on gait speed or gait speed while distracted. When the analysis was limited to participants defined as slow walkers (≥9 s on 10-m walk), those randomized to the intervention continued to show significantly less decline on the TUG compared with controls. The same analysis found no significant differences between study groups on 10-m gait speed, but significant treatment group improvements were seen in distracted gait speed relative to control participants' whose performance declined.

Effect sizes for the TUG in the intent-to-treat analyses were large, and effect sizes for gait speed and distracted gait speed were moderate to high, demonstrating that the intervention worked as hypothesized. When the cohort was limited to slow walkers, effect sizes for both the TUG and distracted gait speed were high, whereas the effect size for gait speed was moderate. These differential effect sizes for the two analyses may indicate that slow walkers are particularly responsive to the cognitive training program tested.

Results from this study demonstrate a causal link between cognitive training and balance and gait, making this one of the first randomized controlled trials to our knowledge to demonstrate that a commercially available cognitive training program can improve physical performance. A pilot study by Verghese and colleagues (2010) found a within-subject improvement in gait speed and gait velocity following an 8-week commercially available cognitive training program. Other studies have found an association between cognitive processing and balance, gait, and falls (Al-Yahya et al., 2011; Atkinson et al., 2007; Chen et al., 2012; Hausdorff, Schweiger, Herman, Yogev-Seligmann, & Giladi, 2008; Herman et al., 2010; Holtzer et al., 2007; Holtzer, Verghese, Xue, & Lipton, 2006; Mirelman et al., 2012; Springer et al., 2006; Yogev-Seligmann et al., 2008), and a few have demonstrated that cognitive training is associated with improvements in balance and gait (Doumas et al., 2009; Li et al., 2010; Verghese et al., 2010). The present study contributes to this existing literature by demonstrating that a commercially available cognitive training intervention delivered in community settings can improve or slow decline of physical performance in older adults.

These results were obtained using a relatively small cohort ($N = 51$). Despite the small sample size, we observed statistically significant differences between study arms in balance in the intent-to-treat analysis. To gauge the magnitude of effect, we computed Cohen's *d* effect sizes for balance and gait, which were moderate to large. The association between balance, gait, and cognition became stronger when the cohort was limited to slow walkers. When the cohort in this study was limited to slow walkers, not only did balance remain significant (i.e., TUG) but distracted gait speed significantly improved. This finding is particularly compelling given that the slow-walker analysis represented a subset of the full cohort (N = 30). The Verghese and colleagues (2010) study limited participants to older adults whose gait speed was more than 1 m/s, which is similar to our criterion for slow walkers (≥10 m in 9 s). Restricting the cohort on gait speed reduces the heterogeneity of the measure in this cohort, thereby limiting the variance of this measure and grouping the observed values closer to the mean. Controlling the data in this way appears to strengthen the ability to identify significant differences between group means. This may be the reason that our study and the study by Verghese and colleagues (2010) demonstrated significant intervention effects within small cohorts of slow walkers.

Quach and colleagues (2011) found a nonlinear relationship between gait speed and falls, wherein both fast walkers and slow walkers are at the highest risk for falls. Slow walkers in the Balance, Independent Living, Intellect, and Zest in the Elderly in Boston (MOBILIZE) study were also more likely to have poor executive function (Quach et al., 2011). The MOBILIZE authors concluded that decline in gait speed may be an indicator of physical function decline, disease onset, or motor degradation in the frontal lobe. Our findings suggest that future interventions assessing the association between cognitive training and gait and balance should be targeted to slow walkers in order to detect more pronounced effects or that participants in future studies should be stratified by gait speed prior to random assignment to ensure similar distributions on this measure by group.

Participants generally reported enjoying the cognitive training program. Informal feedback sessions were completed at approximately 4 weeks, 8 weeks, and at the conclusion of the program. During these group discussions, participants anecdotally reported observing improvements in the range of their field of view and consequent improvements in driving ability and confidence. At least one individual reported that she noticed improvements in her walking due to an increase in her field of view.

This study was not without limitations. The first involves the homogeneity of the study population. Participants in this study were overwhelmingly Caucasian and highly educated. Future studies should include a more diverse sample of older adults who vary by race, ethnicity, and education, and use an objective measure of balance in addition to the TUG. A second limitation is the limited focus on cognitive improvements. Future studies would be strengthened by a robust collection of cognitive measures in order to properly explore these factors as mediators in the relationship between balance, gait, and cognition. Finally, this study would have been strengthened had control participants been exposed to matched contacts relative to the contacts experienced by participants in the intervention condition.

Adherence in this study was exceptionally high, and this may be partly attributable to its implementation in Independent Living facility sites. Participants at all but one of the five Independent Living facilities were residents at the facility. Thus, there were likely fewer barriers to attending the class given that it took place at their place of residence. Future studies should also test intervention sites that are frequented by community-dwelling older adults such as community senior centers.

A potential benefit of using a cognitive training intervention to improve *physical* performance is that it may attract participants who are reluctant to complete a physical activity intervention. Under perfect circumstances, all older adults would be willing to engage in a variety of health promotion programs ranging from physical activity to cognitive activity. However, we know that older adults self-select into programs with which they are most comfortable and most motivated to complete (Cameron & Best, 1987; Culos-Reed, Rejeski, McAuley, & Ockene, 2000). For instance, physical activity programs often struggle to recruit participants who are habitually sedentary (Chao, Foy, & Farmer, 2000). On the other hand, several older adults who had little interest in using a computer were reluctant to participate in this cognitive training intervention.

Previous research supports a clear association between cognitive processing and falls (Chen et al., 2012; Huxhold et al., 2006; Laessoe et al., 2008; Lindenberger et al., 2000; Springer et al., 2006; Tinneti, 2003). Results from this study further validate this association. Executive function performance may serve as an indicator for fall-related mobility factors including gait and balance. Executive function involves the ability to allocate and divide attention, the ability to respond to the spatial environment, and the ability to retain temporary memory and online processing involved with walking (i.e., working memory). Based on results from this study, cognitive training may be a promising approach to fall prevention. In this cohort of older adults, training executive functions resulted in significantly less performance decline over 10 weeks on a balance task. Among participants who were slow walkers at baseline, training executive functions resulted in significant improvements in walking while distracted and significantly less decline over 10 weeks on a balance task. This intervention could offer a feasible public health approach for reducing falls in older adults. Findings from this study not only contribute to our current understanding of how cognitive processes influence physical functioning but can be used in an applied manner to improve the health of older adults through targeting specific cognitive domains.

Funding

This project described was supported by the Agency for Healthcare Research and Quality (AHRQ R36 HS18295) and the National Institute on Aging through a dissertation award from the Midwest Roybal Center for Health Promotion and Translation (P30AG022849).

Acknowledgments

Dr. R. L. Smith-Ray is grateful for the insight and guidance provided by members of her dissertation committee including Drs. Hughes (Chair), Prohaska, Hedeker, Little, and Jurivich. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes on Aging, the National Institutes of Health, or the Agency for Healthcare Research and Quality.

Correspondence

Correspondence should be addressed to Renae L. Smith-Ray, PhD, Institute for Health Research and Policy, University of Illinois at Chicago, 1747 W Roosevelt Road, Suite 558, Chicago, IL 60608. E-mail: rsmith27@uic.edu.

References

Alexander, N. B., & Hausdorff, J. M. (2008). Guest editorial: Linking thinking, walking, and falling. *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences*, *63*, 1325–1328. doi:10.1093/gerona/63.12.1325

Al-Yahya, E., Dawes, H., Smith, L., Dennis, A., Howells, K., & Cockburn, J. (2011). Cognitive motor interference while walking: A systematic review and meta-analysis. *Neuroscience and Biobehavioral Reviews*, *35*, 715–728. doi:10.1016/j.neubiorev.2010.08.008

Atkinson, H. H., Rosano, C., Simonsick, E. M., Williamson, J. D., Davis, C., Ambrosius, W. T., … Kritchevsky, S. B. (2007). Cognitive function, gait speed decline, and comorbidities: The health, aging, and body composition study. *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences*, *62*, 844–850. doi:10.1093/gerona/62.8.844

Beurskens, R., & Bock, O. (2012). Age-related deficits of dual-task walking: A review. *Neural Plasticity*, *2012*, 131608. doi:10.1155/2012/131608

Brooks, L. R. (1967). The suppression of visualization by reading. *The Quarterly Journal of Experimental Psychology*, *19*, 289–299.

Buitenweg, J. I. V., Murre, J. M. J., & Ridderinkhof, K. R.(2012). Brain training in progress: A review of trainability in healthy seniors. *Frontiers in Human Neuroscience*, *6*, 1–11. doi:10.3389/fnhum.2012.00183

Cameron, R., & Best, J. A. (1987). Promoting adherence to health behavior change interventions: Recent findings from behavioral research. *Patient Education and Counseling*, *10*, 139–154.

Chao, D., Foy, C. G., & Farmer, D. (2000). Exercise adherence among older adults: Challenges and strategies. *Controlled Clinical Trials*, *21*, S212–S217. doi:10.1016/S0197-2456(00)00081-7

Chen, T. Y., Peronto, C. L., & Edwards, J. D. (2012). Cognitive function as a prospective predictor of falls. *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences*, *67*, 720–728. doi:10.1093/geronb/gbs052

Culos-Reed, S. N., Rejeski, W. J., McAuley, E., & Ockene, J. K. (2000). Predictors of adherence to behavior change interventions in the elderly. *Controlled Clinical Trials*, *21*, S200–S205. doi:10.1016/S0197-2456(00)00079-9

Doumas, M., Rapp, M. A., & Krampe, R. T. (2009). Working memory and postural control: Adult age differences in potential for improvement, task priority, and dual tasking. *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences*, *64*, 193–201. doi:10.1093/geronb/gbp009

Fasano, A., Plotnik, M., Bove, F., & Berardelli, A. (2012). The neurobiology of falls. *Neurological Sciences*, *33*, 1215–1223. doi:10.1007/s10072-012-1126-6

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, *12*, 189–198. doi:10.1016/0022-3956(75)90026-6

Hausdorff, J. M., Schweiger, A., Herman, T., Yogev-Seligmann, G., & Giladi, N. (2008). Dual-task decrements in gait: Contributing factors among healthy older adults. *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences*, *63*, 1335–1343. doi:10.1093/gerona/63.12.1335

Herman, T., Mirelman, A., Giladi, N., Schweiger, A., & Hausdorff, J. M. (2010). Executive control deficits as a prodrome to falls in healthy older adults: A prospective study linking thinking, walking, and falling. *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences*, *65*, 1086–1092. doi:10.1093/gerona/glq077

Holtzer, R., Friedman, R., Lipton, R. B., Katz, M., Xue, X., & Verghese, J. (2007). The relationship between specific cognitive functions and falls in aging. *Neuropsychology*, *21*, 540–548. doi:10.1037/0894-4105.21.5.540

Holtzer, R., Verghese, J., Xue, X., & Lipton, R. B. (2006). Cognitive processes related to gait velocity: Results from the Einstein Aging Study. *Neuropsychology*, *20*, 215–223. doi:10.1037/0894-4105.20.2.215

Hsu, C. L., Nagamatsu, L. S., Davis, J. C., & Liu-Ambrose, T. (2012). Examining the relationship between specific cognitive processes and falls risk in older adults: A systematic review. *Osteoporosis International*, *23*, 2409–2424. doi:10.1007/s00198-012-1992-z

Huxhold, O., Li, S. C., Schmiedek, F., & Lindenberger, U. (2006). Dual-tasking postural control: Aging and the effects of cognitive demand in conjunction with focus of attention. *Brain Research Bulletin*, *69*, 294–305. doi:10.1016/j.brainresbull.2006.01.0021656442510.1016/j.brainresbull.2006.01.0022006-03953-006

Laessoe, U., Hoeck, H. C., Simonsen, O., & Voigt, M. (2008). Residual attentional capacity amongst young and elderly during dual and triple task walking. *Human Movement Science*, *27*, 496–512. doi:10.1016/j.humov.2007.12.001

Li, K. Z., Roudaia, E., Lussier, M., Bherer, L., Leroux, A., & McKinley, P. A. (2010). Benefits of cognitive dual-task training on balance performance in healthy older adults. *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences*, *65*, 1344–1352. doi:10.1093/gerona/glq151

Lindenberger, U., Marsiske, M., & Baltes, P. B. (2000). Memorizing while walking: Increase in dual-task costs from young adulthood to old age. *Psychology and Aging*, *15*, 417–436. doi:10.1037/0882-7974.15.3.417

Martin, K. L., Blizzard, L., Wood, A. G., Srikanth, V., Thomson, R., Sanders, L. M., & Callisaya, M. L. (2013). Cognitive function, gait, and gait variability in older people: A population-based study. *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences*, *68*, 726–732. doi:10.1093/gerona/gls224

Mirelman, A., Herman, T., Brozgol, M., Dorfman, M., Sprecher, E., Schweiger, A., … Hausdorff, J. M. (2012). Executive function and falls in older adults: New findings from a five-year prospective study link fall risk to cognition. *PLoS ONE*, *7*, e40297. doi:10.1371/journal.pone.0040297

Quach, L., Galica, A. M., Jones, R. N., Procter-Gray, E., Manor, B., Hannan, M. T., & Lipsitz, L. A. (2011). The nonlinear relationship between gait speed and falls: The Maintenance of Balance, Independent Living, Intellect, and Zest in the Elderly of Boston Study. *Journal of the American Geriatrics Society*, *59*, 1069–1073. doi:10.1111/j.1532-5415.2011.03408.x

Reuter-Lorenz, P. A., & Cappell, K. A. (2008). Neurocognitive aging and the compensation hypothesis. *Current Directions in Psychological Science*, *17*, 177–182. doi:10.1111/j.1467-8721.2008.00570.x

Rosano, C., Studenski, S. A., Aizenstein, H. J., Boudreau, R. M., Longstreth, W. T., Jr., & Newman, A. B. (2012). Slower gait, slower information processing and smaller prefrontal area in older adults. *Age and Ageing*, *41*, 58–64. doi:10.1093/ageing/afr113

Schaefer, S., & Schumacher, V. (2011). The interplay between cognitive and motor functioning in healthy older adults: Findings from dual-task studies and suggestions for intervention. *Gerontology*, *57*, 239–246. doi:10.1159/000322197

Sheikh, J. I., & Yesavage, J. A. (1986). Geriatric Depression Scale (GDS): Recent evidence and development of a shorter version. In T. L. Brink (Ed.), *Clinical gerontology: A guide to assessment and intervention* (pp. 165–173). Binghamton, NY: The Haworth Press.

Smith, G. E., Housen, P., Yaffe, K., Ruff, R., Kennison, R. F., Mahncke, H. W., & Zelinski, E. M. (2009). A cognitive training program based on principles of brain plasticity: Results from the Improvement in Memory with Plasticity-based Adaptive Cognitive Training (IMPACT) study. *Journal of the American Geriatrics Society*, *57*, 594–603. doi:10.1111/j.1532-5415.2008.02167.x

Springer, S., Giladi, N., Peretz, C., Yogev, G., Simon, E. S., & Hausdorff, J. M. (2006). Dual-tasking effects on gait variability: The role of aging, falls, and executive function. *Movement Disorders*, *21*, 950–957. doi:10.1002/mds.20848

Steffen, T. M., Hacker, T. A., & Mollinger, L. (2002). Age- and gender-related test performance in community-dwelling elderly people: Six-Minute Walk Test, Berg Balance Scale, Timed Up & Go Test, and gait speeds. *Physical Therapy*, *82*, 128–137.

Studenski, S., Perera, S., Patel, K., Rosano, C., Faulkner, K., Inzitari, M., … Guralnik, J. (2011). Gait speed and survival in older adults. *Journal of the American Medical Association*, *305*, 50–58. doi:10.1001/jama.2010.1923

Tinneti, M. E. (2003). Preventing falls in elderly persons. *New England Journal of Medicine*, *348*, 42–49. doi:10.1056/NEJMcp020719

van Hedel, H. J., Wirz, M., & Dietz, V. (2005). Assessing walking ability in subjects with spinal cord injury: Validity and reliability of 3 walking tests. *Archives of Physical Medicine and Rehabilitation*, *86*, 190–196. doi:10.1016/j.apmr.2004.02.010

Verghese, J., Mahoney, J., Ambrose, A. F., Wang, C., & Holtzer, R. (2010). Effect of cognitive remediation on gait in sedentary seniors. *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences*, *65*, 1338–1343. doi:10.1093/gerona/glq127

Willis, S. L., Tennstedt, S. L., Marsiske, M., Ball, K., Elias, J., Morris, J. M., … Wright, E. (2006). Long-term effects of cognitive training on everyday functional outcomes in older adults. *Journal of the American Medical Association*, *296*, 2805–2814. doi:10.1001/jama.296.23.2805

Wollesen, B., & Voelcker-Rehage, C. (2013). Training effects on motor-cogntiive dual-task performance in older adults: A systematic review. *European Review of Aging and Physical Activity*, 1–20. doi:10.1007/s11556-01300122-z

Woollacott, M., & Shumway-Cook, A. (2002). Attention and the control of posture and gait: A review of an emerging area of research. *Gait & Posture*, *16*, 1–14. doi:10.1016/S0966-6362(01)00156-4

Yogev-Seligmann, G., Hausdorff, J. M., & Giladi, N. (2008). The role of executive function in attention and gait. *Movement Disorders*, *23*, 329–342. doi:10.1002/mds.21720