Benefits of Cognitive Dual-Task Training on Balance Performance in Healthy Older Adults

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Background. There is growing evidence of the involvement of executive control in the maintenance of balance in old age. We examined whether healthy older adults who completed five sessions of nonmotor cognitive dual-task training would show significant improvements on measures of dual-task standing balance and mobility, compared with an untrained control group.

Methods. Twenty healthy older adults were assigned to either training or control groups. In the pre- and post-training sessions, all participants performed tests of cognition, balance, and mobility (single-support balance, dynamic posturography, sit-to-stand, 40-foot walk) under single- and dual-task conditions. The training group completed five sessions of cognitive dual-task training spaced at least 2 days apart. The two tasks involved making two-choice decisions to visually presented stimuli. Participants completed multiple blocks of single-task (task A or B, blockwise) and mixed (A, B, or A + B) trials in each training session.

Results. The training group showed significant improvements in body sway during single-support balance and center of gravity alignment during double-support dynamic balance. The control group showed no appreciable improvements.

Conclusions. This study is the first to demonstrate training-related benefits to gross motor performance stemming from cognitive dual-task training. The results support the view that motor control in aging is influenced by executive control and have implications for theories of cognitive training and transfer.

Key Words: Dual task—Training—Executive function—Balance—Gait.

COGNITIVE-MOTOR dual-task training has proven more effective in improving dual-task motor performance than single-task training (1), suggesting that the training of task coordination processes is beneficial. However, few if any studies have shown that cognitive, nonmotor dual-task training can improve dual-task motor performance. To this end, we examined whether healthy older adults would show improvements in dual-task gross motor performance after undergoing a focused program of nonmotor cognitive dual-task training.

There is broad consensus that the control of gait and balance entails attentional capacity (2–4), as commonly shown using dual-task methodology. The standard motor dual-task design involves a comparison of a motor task performed alone versus the same motor task performed with a concurrent cognitive task. This comparison forms the basis for the calculation of dual-task costs (single- minus dual-task performance), which indicate the degree of interference or attentional recruitment that the motor task incurs.

The growing body of literature on motor dual-task effects has inspired a few recent investigations of dual-task training as a means to improve gait and balance. Pellecchia (1) measured balancing in healthy young to middle-aged adults assigned to dual-task, single-task, or no-training groups. After training, only the dual-task training group was able to reduce their dual-task body sway scores to single-task levels. Silsupadol and colleagues (5) trained older adults with balance impairment under single-task, dual-task fixed priority (equal task emphasis), or dual-task variable priority (alternating task emphasis between blocks) protocols (6). Only the variable priority group showed a training effect. Subsequent work (7) showed poor evidence of training-related transfer to novel motor dual-task combinations, thus limiting the practical application of motor dual-task training.
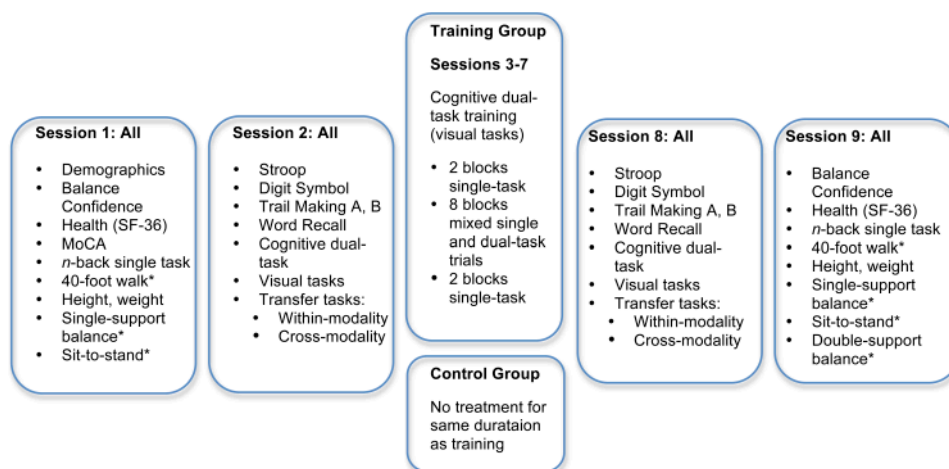
Figure 1. Overview of assessment and training sessions. Asterisks denote tests given with and without cognitive load (*n*-back task). Sessions 1 and 9 took place at the Constance Lethbridge Rehabilitation Centre. All other sessions took place at the Geriatric Research Institute of the University of Montreal. Training sessions were spaced at least 2 days apart, and all sessions took place in the span of 5 weeks.

In cognitive aging research, broader transfer-of-training effects have been observed when central, process-nonspecific abilities are targeted, such as the case of training executive control processes (8). This is held in contrast to earlier training studies involving more process-specific abilities (eg, mental rotation) with narrower transfer (9). It may therefore be the case that training dual-task coordination processes in the absence of any motor component might generalize to a wider variety of motor outcome measures. However, the benefits of such an intervention to motor control are presently unknown.

We aimed to address this gap in the literature by using an established cognitive dual-task training protocol that has shown significant neuroplastic changes and transfer effects in healthy older adults (6,10–12). We recruited healthy older adults to maximize our chances of replicating the strong dual-task training effects reported previously and randomly assigned participants to a training or no-treatment control group. The physical outcome measures were chosen to provide a broad range of difficulty and were assessed with and without a concurrent cognitive load. Our hypothesis was that participants in the dual-task training group should show improvements in the dual-task conditions of the physical outcome measures whereas participants in the control group should show negligible improvements from pre- to post-training sessions.

METHODS

An overview of the study design is shown in Figure 1.

Participants

Adults aged 70+ years were recruited from an existing pool of healthy community-dwelling seniors. They were randomly assigned to a training group (*n* = 11) or a no-treatment control group (*n* = 10). Inclusion criteria were proficiency in English and normal or corrected-to-normal vision and hearing. Exclusion criteria were inability to ambulate without assistive devices, history of neurological or musculoskeletal impairment, balance problems, unstable or progressing medical conditions, and medication affecting balance or cognitive abilities. Participants in the control and training groups were statistically comparable in cognitive status (see Montreal Cognitive Assessment scores, Table 1). One participant from the training group was excluded due to an inability to perform the cognitive load task. Participants in the training and control groups were given an honorarium of $150 and $60 CAD, respectively. The test protocol was approved by the Research Ethics Committee of the Centre de recherche interdisciplinaire en réadaptation du Montréal métropolitain and the Centre de recherche Institut universitaire de Gériatrie de Montréal.

Materials

Background measures.—A number of background measures (Table 1) were taken to ensure comparability between groups at the beginning of the study. Participants completed questionnaires on general demographics, health (SF-36: 13), physical activity (Human Activity Profile: 14), and balance confidence (Activities-Specific Balance Confidence scale: 15). Physical fitness was measured using the 6-minute walk test (16). Selective attention was measured using the modified Stroop color–word test (17), executive control and switching were measured using the Trail Making Test Forms A and B (18), cognitive speed was measured using the Wechsler Adult Intelligence Scale Digit Symbol Substitution Test (19), and episodic memory was measured with auditory free recall of high-frequency words (20). There were no significant differences between groups in the pre-training data on any of the background measures (independent-samples *t* tests: all *p*s > .05).

Table 1. Participant Characteristics per Group

Background Variables	Training		Control	
	M	*SD*	*M*	*SD*
Age (y)	74.6	5.7	77.7	7.1
Sex (male:female)	3:7	—	4:6	—
Education (y)	13.3	3.8	16.9	5.4
Self-rated health (1–5)	2.67	0.7	1.8	1.0
Physical activity (HAP: max = 94)	69.8	8.0	68.8	14.8
Balance confidence (ABC: max = 100)	96	4.6	94.1	7.7
6-min walk (m)	504.6	72.2	523.5	121.6
Stroop—word (s)	47.2	6.8	44.1	6.4
Stroop—color (s)	74.0	13.8	68.9	16.4
Stroop—interference (s)	138.7	27.0	122.4	31.2
Stroop—flexibility (s)	157.1	28.4	145.2	25.4
Trail Making Test—Form A (s)	45.1	12.2	42.0	11.1
Trail Making Test—Form B (s)	103.6	29.8	81.9	17.9
Cognitive Speed (Digit Symbol)	58.8	15.8	58.9	9.5
MoCA cognitive status (max = 30)	27.3	1.9	26.5	1.4

Note: ABC = Activities-specific Balance Confidence scale. Score is averaged across 16 items where scale ranges from 0% to 100% confidence. Digit Symbol score = number of items completed correctly in 90 s. maximum correct = 30, adjusted for education level. HAP = Human Activity Profile: Values indicate the number of items out of 94 that the individual presently does; MoCA = Montreal Cognitive Assessment; Self-rated health score from SF-36: "How is your health in general?" 1 = poor, 2 = fair, 3 = good, 4 = very good, and 5 = excellent.

Outcome measures.—Single-support standing balance was assessed with eyes open and closed and involved standing on the dominant leg for 10 s/trial. A MatScan force platform (Tekscan, Inc., Boston, MA) was used to measure center of pressure (COP) parameters: anteroposterior (A/P) and mediolateral (M/L) speed (cm/s), peak-to-peak velocity excursion (cm), and COP variability (standard deviation [*SD*]), as well as overall mean velocity, root mean square, and area. Participants completed four trials with eyes open, followed by four trials with eyes closed.

Double-support standing balance was assessed using an EquiTest apparatus (NeuroCom International, Inc., Clackamas, OR) that consists of a dynamic force platform and visual surround. In keeping with previous aging research using combined dynamic balance and *n*-back performance (21), and to examine a range of balance challenge, three conditions of the Sensory Organization Test protocol were given: stable platform (SO1), visual surround sway referenced (SO3), and platform sway referenced (SO4). Vertical forces exerted on the platform throughout each 20-second trial were sampled at 100 Hz and were used to extract measures such as the center of gravity alignment and overall equilibrium using built-in software. In addition, the recorded trajectory of the COP throughout the trial was low-pass filtered and fit to an ellipse using principle component analysis to estimate the variability of the COP.

Mobility and lower limb strength were measured with the sit-to-stand test of the Established Populations for the Epidemiological Study of the Elderly (22). Completion time for five chair rises was then classified into one of four categories, with scores <3 indicating risk of frailty (23). Gait speed was measured using the 40-foot walk test to provide an indicator of risk of hospitalization and health decline in older adults (24). Participants walked a straight course (down an empty hallway) with a 180° turn at 20 feet.

Each physical outcome measure was tested alone and concurrently with the *n*-back working memory task (25) at two levels of difficulty. We opted to use a different cognitive task than in the pre- and post-training assessments to obtain a more stringent assessment of training-related transfer effects (ie, using one of the two-choice cognitive tasks from the training phase would not be as strong a test of transfer). In the 0-back condition, randomly ordered single digits were verbally presented at a fixed 2-second pace, and participants repeated each digit immediately after. The 2-back condition involved repeating a similar series with a two-item lag.

For each physical outcome measure, participants performed four trials: single task and dual task with a 0-back load, dual task with a 2-back load, and single task. In dual-task trials, the *n*-back task began first, and the participant was signaled to begin the motor task as the third digit was presented. Participants were instructed to emphasize both tasks equally. Baseline single-task *n*-back performance was also measured.

Dual-task assessment and training tasks.—During the cognitive assessment sessions, all participants completed three versions of the cognitive dual-task paradigm while seated in front of a computer monitor (12,13). The first version consisted of two simple visual discrimination tasks. Task A involved a color decision (is the "X" green or yellow?); Task B involved a letter-identity decision (is the letter "B" or "C"?). Two additional task pairs were included in assessment sessions for other purposes: one pair involved two new visual discrimination tasks; the second pair involved auditory discriminations. Responses were made on the computer keyboard. Reaction times (RT) between 100 and 3000 ms for correct responses and accuracy were recorded. During each cognitive assessment session,

Table 2. Mean Correct RT (*SD*) Across Five Training Sessions

	Session				
	1	2	3	4	5
Single-pure RT (ms)	793 (40)	683 (46)	647 (38)	596 (35)	589 (37)
Single-mixed RT (ms)	1099 (75)	889 (56)	832 (56)	793 (47)	768 (47)
Dual-mixed RT (ms)	1426 (74)	1185 (62)	1114 (67)	1055 (64)	1034 (66)

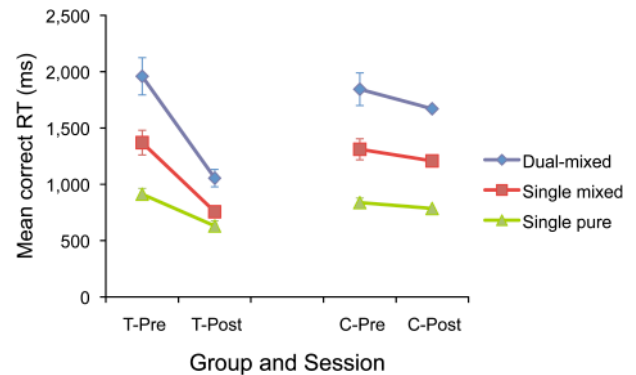*Note*: ms = milliseconds and RT = reaction times.

Figure 2. Dual-task performance in pre- and post-training sessions as a function of group and trial type. Training group (T) data are shown on the left; control group (C) data are shown on the right. Error bars indicate ±1 standard error from the mean.

participants completed two blocks of 20 single-task trials (Task A or B, blockwise), four blocks of 20 mixed trials (A, B, or A + B in unpredictable order), and a final two blocks of 20 single-task trials for each task. For dual-task trials, participants were instructed to emphasize each task equally.

Participants assigned to the training group completed five additional 1-h sessions of computerized dual-task training using the first visual task pair. During training sessions, adaptive feedback was presented in the upper left corner of the computer screen and consisted of color-coded bars indicating the participant's current performance relative to their changing RT distribution. Participants were trained in small groups of four to six individuals. Additional methodological details about the dual-task training protocol and feedback algorithm are reported elsewhere (10–12).

Statistical Analyses

For the cognitive dual-task data, key press accuracy and mean correct RT were analyzed using repeated-measures analysis of variance (ANOVA) designs. For the single-support balance data, we subjected each COP parameter

(eg, variability, speed, peak-to-peak excursion, root-mean square) in the A/P and M/L dimensions to Group (trained, control) × Load (single, 0-back, 2-back) × Vision (eyes open, closed) × Session (pre-, post-training) mixed factorial ANOVAs. For the double-support standing trials, we carried out Session × Group × Cognitive Load mixed factorial ANOVAs for each of the three SO conditions. Mean center of gravity alignment provided an estimate of the average degrees deviation in A/P and M/L dimensions relative to the initial base of support. For the sit-to-stand data, the time required to complete five consecutive chair rises was converted to established clinical categories (23) with the following cutoffs: completion within 30, 16.6, 13.6, and 11.1 seconds, corresponding to Categories 1–4, respectively. Nonparametric (Mann–Whitney independent samples) tests were then applied to the categorical frequency data. For the 40-foot walk, we analyzed completion time (s) in a Group × Session × Cognitive Load mixed factorial ANOVA.

Table 3. Single-Support Stability (*SD*) M/L Speed, Variability, and Peak-to-Peak Excursion as a Function of Group, Cognitive Load, Session, and Vision

	Group					
	Training			Control		
	Single	0-Back	2-Back	Single	0-Back	2-Back
	Speed M/L (cm/s)					
EO pre	7.44 (1.52)	5.21 (0.50)	6.41 (0.83)	5.52 (1.61)	5.57 (0.53)	4.90 (0.87)
EO post	5.29 (0.97)	4.03 (0.54)	4.52 (0.65)	6.01 (1.03)	5.23 (0.57)	4.64 (0.68)
EC pre	6.57 (0.81)	7.71 (0.94)	7.76 (0.95)	5.76 (0.85)	5.44 (0.99)	6.48 (1.00)
EC post	5.56 (0.52)	4.74 (0.66)	4.54 (0.98)	5.43 (0.55)	5.72 (0.70)	5.50 (1.03)
	Variability M/L (*SD*)					
EO pre	7.44 (1.53)	5.21 (0.50)	6.41 (0.83)	5.21 (1.61)	5.57 (0.53)	4.90 (0.87)
EO post	5.29 (0.97)	4.03 (0.54)	4.52 (0.65)	6.01 (1.03)	5.23 (0.57)	4.64 (0.68)
EC pre	6.57 (0.81)	7.71 (0.94)	7.76 (0.95)	5.76 (0.85)	5.44 (0.99)	6.48 (1.00)
EC post	5.56 (0.52)	4.74 (0.66)	4.54 (0.98)	5.43 (0.55)	5.72 (0.70)	5.50 (1.03)
	Peak-to-peak excursion M/L (cm)					
EO pre	3.27 (0.43)	4.12 (0.60)	3.18 (0.56)	2.78 (0.45)	2.99 (0.63)	2.74 (0.59)
EO post	2.56 (0.18)	2.76 (0.29)	2.77 (0.37)	2.47 (0.19)	2.81 (0.31)	3.12 (0.39)
EC pre	5.00 (0.73)	6.61(1.4)	4.01 (0.74)	3.70 (0.77)	2.99 (1.5)	4.50 (0.78)
EC post	3.68 (0.45)	3.31 (0.39)	3.08 (0.71)	3.96 (0.48)	3.38 (0.41)	3.85 (0.75)

Note: EC = eyes closed, EO = eyes open, and M/L = mediolateral.

Mediolateral Peak-to-peak Excursion

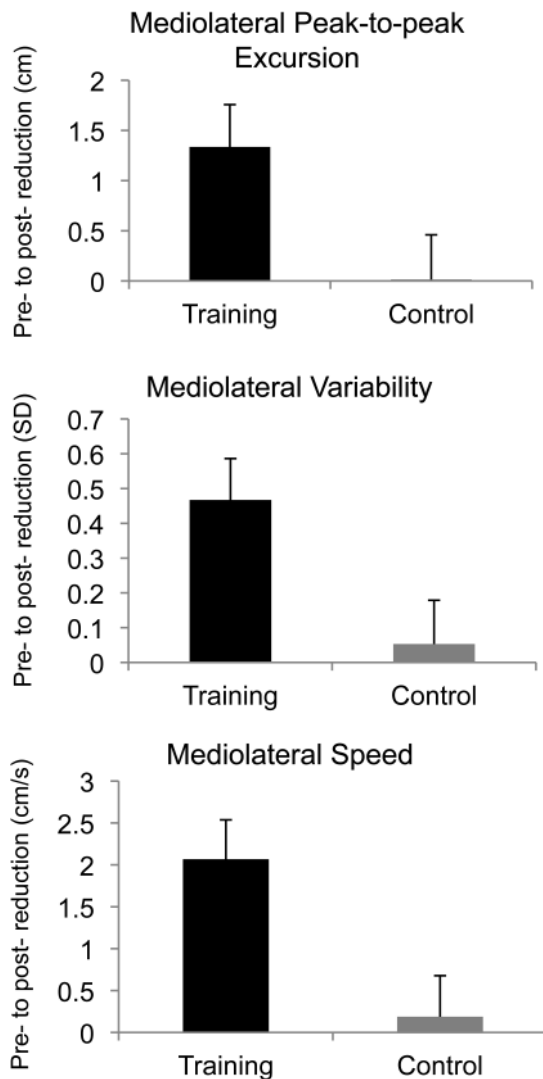## Mediolateral Variability

Mediolateral Speed

Figure 3. Centre of pressure (COP) parameters for single-support standing balance. Values for each panel indicate the magnitude of reduction from pre- to post-training sessions for training versus control groups. Error bars indicate ±1 standard error from the mean. Significant group differences were observed for peak-to-peak excursion, $F(1,17) = 4.642$, $p = .046$, $\eta^2 = .214$, variability, $F(1,17) = 5.708$, $p = .029$, $\eta^2 = .251$, and speed, $F(1,17) = 7.605$, $p = .013$, $\eta^2 = .309$.

RESULTS

Dual-Task Training

Preliminary analyses on the accuracy data showed no significant effects, likely due to the demand characteristics of the paradigm that included feedback after each incorrect response, which promoted accurate responding. We therefore focus exclusively on the RT data (Table 2). A repeated-measures ANOVA performed on mean correct RT across the five training sessions indicated that dual-task performances improved significantly across the five sessions, $F(4,36) = 75.74$, $p < .001$, $\eta^2 = .894$. Significant reductions in mean RT were observed from Session 1 to 2, 2 to 3, and 3 to 4 (ps ≤ .018). The trained group did not show further

improvements from Session 4 to 5 ($p = .159$) suggesting that asymptotic levels were reached.

Next, we compared both groups on pre- and post-training performance (Figure 2). A Group × Session (pre vs post) × Trial Type (single pure, single mixed, dual mixed) mixed factorial ANOVA revealed a significant Group × Session interaction, $F(1,17) = 29.31$, $p < .001$, $\eta^2 = .633$, which was driven by a substantial improvement over time in the training group, $F(1,9) = 69.60$, $p < .001$, but not in the control group, $F(1,9) = 3.75$, $p = .085$. The three-way interaction with trial type was also significant, $F(2,34) = 8.715$, $p < .001$, $\eta^2 = .339$, due to a significant Session × Trial Type interaction for the training group, $F(2,16) = 18.095$, $p < .001$, $\eta^2 = .693$, but not for the control group ($p = .212$).

Impact of Training on Motor Performance

Preliminary analyses of the cognitive *n*-back accuracy data did not show systematic cognitive dual-task costs or group differences. Further, we observed group equivalence (ps > .05) in pre-training single-task 0-back and 2-back accuracy. We therefore focus on the physical performance measures.

Single-support balance.—Table 3 shows cell means for M/L speed, variability, and peak-to-peak excursion by group, session, vision, and cognitive load. In line with our main prediction, our Session × Group × Vision × Cognitive Load ANOVAs yielded significant Session × Group interactions in the speed, variability, and peak-to-peak excursion COP parameters in the M/L dimension—speed: $F(1,17) = 7.61$, $p = .013$, $\eta^2 = .739$; variability: $F(1,17) = 5.69$, $p = .029$, $\eta^2 = .251$; peak-to-peak: $F(1,17) = 4.63$, $p = .046$, $\eta^2 = .214$. In all three parameters, the Session × Group interactions were driven by significant simple main effects for the trained group (ps = .005 to .034) and nonsignificant session effects for the control group (ps = .534 to .954). Figure 3 shows pre–post difference scores per group.

In the same three COP parameters, a significant main effect of Session was observed such that stability improved overall over time—speed: $F(1,17) = 10.09$, $p = .004$, $\eta^2 = .392$; variability: $F(1,17) = 9.04$, $p = .008$, $\eta^2 = .347$; peak-to-peak: $F(1,17) = 4.87$, $p = .041$, $\eta^2 = .223$. Stability was also predictably better with eyes open than with eyes closed overall in two of the three parameters—variability: $F(1,17) = 25.37$, $p < .001$, $\eta^2 = .599$; peak-to-peak: $F(1,17) = 13.38$, $p = .002$, $\eta^2 = .448$. Interestingly, significant or marginal interactions of cognitive load and group were observed—variability: $F(2,16) = 7.46$, $p < .005$, $\eta^2 = .483$; peak-to-peak: $F(2,16) = 3.34$, $p = .061$, $\eta^2 = .448$, power = .547. However, vision and load did not moderate our training-specific effects: Across the three COP parameters reported, estimated power for the nonsignificant Vision × Session × Group interactions ranged from .060 to .215 and for the nonsignificant Load × Session × Group interactions ranged from .240 to .371.

Table 4. Double-Support Center of Gravity Alignment (*SD*) in A/P

	Group					
	Training			Control		
	Single	0-Back	2-Back	Single	0-Back	2-Back
	Stable platform (SO1)					
Pre	0.59 (0.44)	0.78 (0.47)	0.72 (0.54)	0.82 (0.58)	0.72 (0.42)	0.68 (0.47)
Post	0.51 (0.52)	0.36 (0.66)	0.45 (0.53)	0.84 (0.42)	0.73 (0.45)	0.70 (0.53)
	Visual sway referenced (SO3)					
Pre	0.86 (0.60)	0.76 (0.49)	0.58 (0.76)	0.65 (0.59)	0.96 (0.81)	1.07 (0.94)
Post	0.53 (0.63)	0.42 (0.64)	0.50 (0.73)	0.70 (0.46)	0.65 (0.44)	0.68 (0.46)
	Platform sway referenced (SO4)					
Pre	0.92 (0.67)	0.67 (0.51)	0.72 (0.62)	0.80 (0.55)	0.88 (0.88)	0.78 (0.62)
Post	0.60 (0.43)	0.43 (0.39)	0.35 (0.26)	0.70 (0.57)	0.80 (0.40)	0.76 (0.37)

Note: Tabulated d*y* values refer to deviation of anterior–posterior position averaged across each 20-s trial, relative to actual base of support established at the start of each trial. A/P = anteroposterior dimension. Units refer to reduction over time in degrees from center (0). The 0-back and 2-back conditions refer to dual-task trials. Single-task values were taken from the second of two single-task trials.

Double-support balance.—Table 4 shows the alignment values in the A/P dimension by group, session, and condition. For the stable platform (SO1) condition, a significant Session × Group interaction was observed, $F(1,18) = 5.86$, $p = .026$, $\eta^2 = .245$, such that alignment improved in the training group ($M_{pre} = 0.97$, $SD_{pre} = 0.18$; $M_{post} = 0.39$, $SD_{post} = 0.13$) but not in the control group ($M_{pre} = 0.62$, $SD_{pre} = 0.18$; $M_{post} = 0.70$, $SD_{post} = 0.13$). The only other significant effect in the SO1 data was a marginal effect of session, $F(1,18) = 3.21$, $p = .090$, $\eta^2 = .151$, power = .396. In the SO3 and SO4 data, all effects and interactions were nonsignificant ($ps \geq .17$). Figure 4 illustrates the distribution of center of gravity alignment values over time for the 0-back SO1 condition. We carried out similar analyses using equilib-

rium data and COP ellipse area values, but did not find training-specific improvements (Group × Session interactions: $ps \geq .30$).

Sit-to-stand.—Table 5 shows the frequency of Sit-to-Stand scores, by group, session, and cognitive load. The nonparametric independent samples Mann–Whitney tests yielded no significant group differences in frequency of category membership at pre- or post-training assessments ($ps \geq .460$).

Walking speed.—Table 6 shows completion times, split by session, group, and cognitive load. A significant main effect of cognitive load was observed, $F(2,16) = 21.21$, $p < .001$, $\eta^2 = .726$, due to a monotonic increase in completion time as a function of increasing cognitive load (all
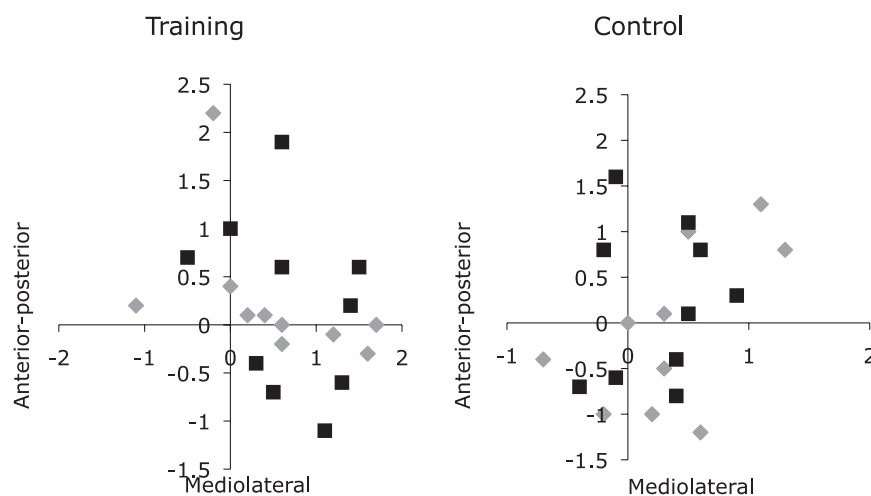

Figure 4. Individual center of gravity alignment values (d*x* and d*y* coordinates) for stable platform, 0-back condition on the double-support standing balance test. Black squares = pre-training positions; gray diamonds = post-training positions. Position (0,0) indicates base of support values at the beginning of the trial. Units are degrees from center.

Table 5. Frequency of EPESE Scores on Sit-to-Stand as a Function of Cognitive Load and Group

	Group							
	Training				Control			
Score	1	2	3	4	1	2	3	4
				Single				
Pre	0	2	1	5	2	1	2	5
Post	1	1	2	5	1	2	2	5
				0-back				
Pre	1	2	2	3	4	0	4	2
Post	0	1	4	3	5	0	0	5
				2-back				
Pre	1	3	1	3	1	2	2	5
Post	1	1	2	4	2	1	2	5

Note: EPESE = Established Populations for the Epidemiological Study of the Elderly. Time (s) to complete five successive chair rises with arms crossed is converted to scores from 1 to 4. Completion within 30, 16.6, 13.6, and 11.1 s correspond to Categories 1–4, respectively.

ps ≤ .001). However, change in walking speed did not differ between groups ($p = .103$).

Discussion

Our primary question was whether cognitive dual-task training would improve dual-task motor performance in healthy older adults. We found training benefits in single-support standing balance and double-support standing balance. To our knowledge this is one of the first studies to show transfer of training effects from a cognitive intervention to physical outcome measures in older adults.

An important difference between past and present designs is that neither of the trained tasks was used in combination with the physical outcome measures in the present study. The lack of structural overlap between training tasks and outcome measures underscores the central nature of the cognitive processes associated with gross motor control. This also suggests that the observed effects may be smaller than those obtained under conditions of greater overlap (26). Indeed, the cognitive intervention literature suggests that older adults may show good evidence of improvement from practice and training, but modest evidence of transfer

Table 6. *M* (*SD*) Completion Time in Seconds for 40-Foot Walk by Group, Session, and Cognitive Load

	Group	
	Training	Control
	Single	
Pre	9.20 (1.52)	8.46 (1.65)
Post	9.86 (1.60)	9.78 (2.13)
	0-back	
Pre	10.68 (2.52)	9.97 (1.87)
Post	10.51 (1.66)	10.49 (2.39)
	2-back	
Pre	12.35 (4.01)	10.69 (2.57)
Post	11.50 (2.91)	11.62 (2.79)

to new tasks (9). The exceptions to this pattern involve training of executive control skills (27). The present results therefore fit well with this pattern and extend the transfer effects to the gross motor domain. Another important difference between previous work and the present is that our training protocol involved mixed blocks in which participants could not predict whether they would be addressing Task A, B, or both. It is possible that this design encourages more cognitive flexibility than the standard dual-task training protocol in which task emphasis is varied across blocks, but remains fixed within each block (6).

Specificity of Transfer

In the current data, training-specific effects were strongest in the single-support standing balance data, where training-specific improvements were not moderated by cognitive load or vision. By contrast, in the double-support standing balance data, improvements were observed only under cognitive load and primarily in the stable platform condition. That balance in the two sway-referenced conditions did not improve with training might seem counterintuitive. However, Doumas and colleagues (21) reported decreasing dual-task costs in older adults as balance challenge increased. They argued that participants became less willing to relinquish attentional resources with increasing balance challenge. By this view, our participants may not have been dividing their attention in the sway-referenced conditions (SO3, SO4), thus precluding the observation of training-related benefits.

The sit-to-stand task was included to provide an indicator of potential frailty (22). Nonparametric tests did not indicate training-specific improvements, possibly because our participants were quite fit. Nevertheless, training group individuals with low scores (≤2) showed more movement out of the frailty category than did controls (see Table 5). In future work, we would need to over-sample frail older adults to extend these results.

The walking speed measure also did not yield supportive evidence of training-related improvements. We note that in previous work (28), estimates of gait velocity did not include the initial acceleration and final deceleration segments of each trial. In other work, stride and swing time variability correlated with executive measures rather than mean velocity (29). We therefore do not rule out the potential benefits of cognitive dual-task training for gait, but acknowledge that more detailed measurement is warranted.

The *n*-back task measures also did not yield training-related improvements. Although this may seem surprising, we have also found greater effects on the motor task than the cognitive task in past dual-task walking research (30). One possibility is that participants prioritized the cognitive task because measured performance is more overt (verbalization) than in gross motor tasks. The asymmetry of dual-task training effects may also be due to differences in the resolution of

measurement: *n*-back performance is measured by accuracy of responses per trial, whereas postural stability is measured in terms of moment-by-moment fluctuations.

Limitations

A major limitation of the present study is the sample size, which may have limited our potential to find significant interaction effects. For this reason, the present study may be better characterized as a pilot study. Nevertheless, there were few ambiguous, borderline significant results. Smaller sample sizes may also have led to slight differences between groups in background variables such as age, education, and Trails B performance. Given that Trails B performance is germane to the topic of executive control, we explored the potential contribution of baseline Trails B performance to pre–post changes in our physical outcome measures, finding that none of the correlations proved significant.

For similar reasons, we were also concerned that the Session × Group interactions observed in the single-support balance data were due to group differences in initial levels of stability. We transformed the balance data to pre–post change scores in order to correct for individual differences in initial levels of stability, finding significant group differences consistent with our main hypothesis (Figure 3).

A second limitation of the current design is the comparison of our training group to a no-treatment control group, which introduces potential confounds such as group differences in motivation and attention. We therefore examined the relationship between the physical outcome measure with the clearest training-specific improvement (change in single-support balance, eyes closed with 0-back) and three levels of dual-task performance (pre–post reduction in mean RT) in ascending order of executive control involvement: single pure, single mixed, and dual mixed. Associations with the single-support change scores increased in magnitude ($r_{SP} = .48$, $p = .046$; $r_{SM} = .61$, $p = .008$; $r_{DM} = .67$, $p = .002$), suggesting that the observed improvements are more likely to be due to dual-task training of cognitive coordination processes than to global treatment effects.

A third limitation of the present study is that we did not examine long-term retention of the training benefits. All participants were given post-training assessment within 2 weeks of their final training session. Future large-scale studies of this nature should build in 3–6 month follow-ups to assess whether training-related improvements can be maintained.

Summary

This study is the first to demonstrate training-related benefits to gross motor performance that stem from a cognitive training protocol. The results are consistent with the observation of ability dedifferentiation in old age (31). Given the ubiquity of concurrent cognitive and gross motor activity in everyday life, the current findings have potential application

to activities of daily living (32). More work is also needed to generalize our transfer results to individuals with frailty or cognitive decline. In light of recent evidence linking executive functioning to measures of mobility (33) and falls risk (34), the present results offer a method of enhancing one specific aspect of executive functioning, dual-task coordination, that may in turn improve physical status and mobility. We do not claim that cognitive dual-task training can substitute for other physical interventions, but propose it as a complementary intervention, which might be particularly suitable for individuals with mobility restrictions.

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