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Research Article

Cognitive Training Attenuates Decline in Physical Function Across 10 Years

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Abstract

Objectives: Poor physical function is associated with negative health and cognitive outcomes. Although nine studies demonstrated that cognitive training reduces age-related declines in physical function, only one study has examined the effects beyond immediate posttest changes. The first aim of this study was to assess the impact of three cognitive training programs on physical function measures across 10 years and the second aim was to examine whether baseline cognitive self-efficacy or depressive symptoms moderated training effects.

Method: Using data from the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) randomized controlled trial, older adults in a no-contact control condition ($n = 698$) were compared to those receiving processing speed ($n = 702$), memory ($n = 703$), or reasoning ($n = 694$) training. Intention-to-treat (ITT) and dosage analyses were conducted for grip strength and Turn 360. Participants were followed up to 10 years posttest.

Results: There were no significant ITT effects of processing speed, memory, or reasoning training assignment to any physical function outcome ($p > .05$). Dosage models indicated that there were small age-related attenuation effects in Turn 360 decline with more processing speed training ($b = -.011$, $p < .001$), memory training ($b = -.011$, $p < .001$), and reasoning training ($b = -.012$, $p < .001$). There was no significant transfer to grip strength. These training gains were greater for those with more baseline depressive symptoms who received more processing speed training ($b = -.001$, $p < .001$).

Discussion: This is the first study to demonstrate the effects of cognitive training to complex physical function across 10 years.

Keywords: Cognitive interventions, Grip strength, Healthy older adults, Lower limb function

Physical function is critical for maintaining independence in older adulthood (Cesari et al., 2004), and its degradations are associated with myriad poor health measures, including loss of functional independence (Cesari et al., 2004), increased risk of hospitalization (Cesari et al., 2004), disability (Buchman et al., 2016), poorer cognitive function (Spedden, Malling, Andersen, & Jensen, 2017), and mortality (Nofuji et al., 2016). Emphasizing impairment prevention is important because it may reduce costly downstream outcomes such as falls (Mangani et al., 2008), everyday function disability (Gobbens & van Assen, 2014), and hospital length of

stay (van Aalst, Oosterhof, Nijhuis-van der Sanden, & Schreurs, 2014).

The most common behavioral intervention for physical function is balance-related exercises (Chou, Hwang, & Wu, 2012). However, some argue that exercise may be necessary but insufficient to prevent physical function decline or disability (Keysor & Brembs, 2011). Furthermore, older adults with poor physical function may be disinclined to participate due to barriers such as perceived or previous falling or injury (Murphy, Dubin, & Gill, 2003). This is problematic as fear of falls (Choi, Jeon, & Cho, 2017), previous falls (Kronzer et al., 2016), and decreased exercise (Paterson & Warburton, 2010) are risk factors for subsequent functional decline, leading to a cycle of excess disability. Additionally, without continual exercise engagement to maintain training gains (Mujika & Padilla, 2000), long-term physical function benefits may be limited. Because older adults tend to cease engagement within 1 year of exercise intervention (Henderson et al., 2018), it is important to identify non-exercise interventions that do not require continual engagement but have long-term benefits.

Although exercise is the most promising avenue for physical function maintenance (Marusic & Grosprêtre, 2018), some cognitive training programs have positively impacted physical function in older adults across 12 studies (Smith-Ray et al., 2015) (Azadian, Majlesi, & Jafarnezhadgero, 2018; Azadian, Torbati, Kakhki, & Farahpour, 2016; Li et al., 2010; Marusic et al., 2015; Marusic, Verghese, & Mahoney, 2018; Ng et al., 2015; Ross, Sprague, Phillips, O'Connor, & Dodson, 2018; Smith-Ray et al., 2015; Smith-Ray, Irmiter, & Boulter, 2016; Smith-Ray, Makowski-Woidan, & Hughes, 2014; Verghese, Mahoney, Ambrose, Wang, & Holtzer, 2010). Generally, processing speed training (also Useful Field of View, UFOV, speed of processing or divided attention training) transfers to maintained complex lower limb functions, but recent work extends this to memory and reasoning training and gross and fine motor upper limb function across 5 years (Ross, Sprague, et al., 2018). One way cognitive training is posited to impact physical function is compensation, or additional recruitment of neural resources to respond to tasks with high cognitive demand (Cabeza et al., 2018). For example, brain regions associated primarily with processing speed and reasoning, for example, dorsolateral prefrontal cortex, are activated when older adults walk (Holtzer, Epstein, Mahoney, Izzetoglu, & Blumen, 2014; Pelicioni, Tijsma, Lord, & Menant, 2019), indicating that cognitive and physical function are related, even when processing speed or other cognitive tasks are not explicitly performed. These associations are more pronounced in older adults (Spedden et al., 2017). It is assumed that as a result, cognitive training, especially processing speed and reasoning training, may confer benefits to physical function. It is notable that memory training does have promise for attenuating declines in physical function, but only one study has implemented strategy-based memory training (Ross, Sprague, et al., 2018).

Despite emerging, consistent evidence of transfer from cognitive training to physical function (Azadian et al., 2016, 2018; Li et al., 2010; Marusic et al., 2015, 2018; Ng et al., 2015; Ross, Sprague, et al., 2018; Smith-Ray et al., 2015, 2014, 2016; Verghese et al., 2010), there are remaining gaps in the extant literature. A major limitation is that all but one trial (Ross, Sprague, et al., 2018) had small samples of participants (e.g., <100). Some of these studies also drew from at-risk populations rather than low-risk, community-dwelling participants (Smith-Ray et al., 2015). While informative about the effectiveness of training for at-risk populations, the tradeoff is unknown generalizability to a wider community-dwelling sample. Additionally, only one study to date assessed long-term physical function, suggesting declines may be attenuated up to 5 years post-training (Ross, Sprague, et al., 2018). Processing speed training maintained everyday function measures such as reductions in dementia risk (Edwards et al., 2017), maintained reported instrumental activities of daily living (along with reasoning training) (Rebok et al., 2014), and maintained driving mobility (Ross, Freed, Edwards, Phillips, & Ball, 2017) across a decade. Therefore, training effects may extend to physical function across at least 10 years.

Psychosocial Moderators of Training Gains

Psychosocial factors such as greater self-efficacy and fewer depressive symptoms have well-documented relationships with better physical (Briggs, Carey, Kenney, & Kennelly, 2018) and cognitive functions (Zahodne, Watson, Seehra, & Martinez, 2018). Evidence suggests those with greater cognitive self-efficacy are not more responsive to processing speed training (Sharpe, Holup, Hansen, & Edwards, 2014); however, higher cognitive self-efficacy is associated with greater responsiveness to reasoning training (Payne et al., 2012). This suggests that one's beliefs in their abilities may influence other factors such as motivation to persevere with a task (or training program) and by extension impact the responsiveness to treatment (Beaudoin & Desrichard, 2017). Additionally, limited evidence suggests that those with greater depressive symptoms have poorer baseline performance but similar responsiveness to memory training (Lohman et al., 2013). The impact of baseline depressive symptoms on processing speed or reasoning training, as well as the impact of both baseline psychosocial factors on physical function training gains, remains unknown.

Aims and Hypotheses

The first aim of this study was to examine the 10-year effects of three cognitive training programs (processing speed, memory, or reasoning) compared to a no-contact control group on physical function (grip strength and Turn 360) in a large, community-dwelling sample of older adults. Similar to prior work across 5 years (Ross, Sprague, et al., 2018), we hypothesized that the age-related declines in Turn 360 would be attenuated in all training groups, and

that reasoning training would continue to be associated with attenuated declines in both measures (Ross, Sprague, et al., 2018). The second aim was to identify which baseline moderators impacted training effects. We had no strong directional a priori hypotheses due to the sparse literature but anticipated there would be moderated effects of training on both physical function measures by psychosocial factors.

Method

Participants

This study used secondary data from the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) study, a multi-site, randomized clinical trial investigating the effect of three cognitive training programs on health and functional outcomes across a 10-year period. Physical function was an a priori identified secondary outcome of the ACTIVE trial but current analyses were not preregistered. Inclusion criteria were: age 65 or older, visual acuity ≥20/50, Mini-Mental State Examination score ≥23, no health conditions associated with cognitive impairment, verbal communication skills, no difficulties performing basic activities of daily living, and no recent participation in cognitive training. Eligible participants ($N = 2,802$) completed a baseline assessment and then were randomly assigned to a cognitive training (to processing speed, memory, or reasoning training) or no-contact control condition. At baseline, participants were an average of 73.60 years old ($SD = 5.90$), were predominantly women ($n = 2,121$; 75.83%), reported an average of 13.5 years of education ($SD = 2.70$), and were predominantly White ($n = 2,051$, 73.33%). Sample descriptive statistics for each arm are presented in Table 1. Extensive details about ACTIVE can be found elsewhere (Jobe et al., 2001), ClinicalTrials.gov Identifier NCT00298558.

Study Design and Procedures

Baseline assessments for the ACTIVE study were conducted between 1998 and 1999. Prior to randomization, baseline cognitive and physical function, lifestyle factors, and health assessments were conducted. The initial cognitive training interventions consisted of ten 60- to 75-min sessions administered over 6 weeks. Follow-up assessments were conducted approximately 2 months (posttest), 1 year, 2 years, 3 years, 5 years, and 10 years after baseline testing. Grip strength and Turn 360 were not assessed at the immediate posttest or 1-year post-intervention. Compliant training arm participants (i.e., completed at least eight of 10 sessions) were further randomized to either receive four booster sessions prior to assessments in years 1 and 3 (totaling eight possible booster sessions) or receive no booster training.

Processing speed training arm
This was process-, computer-based training that focused on improving the speed at which participants could correctly

Table 1. Demographics by Study Arm ($N = 2,802$ for ITT Analysis)

Variable	No-contact control ($n = 698$)	Processing speed training ($n = 702$)	Memory training ($n = 703$)	Reasoning training ($n = 694$)
Grip strength (kg), M (SD)	24.03 (8.07)	23.98 (8.34)	24.00 (8.37)	24.37 (8.44)
Turn 360 # of steps, M (SD)	6.95 (2.11)	6.90 (1.97)	6.89 (1.99)	7.01 (2.26)
Age, M (SD)	74.05 (6.05)	73.42 (5.78)	73.53 (6.02)	73.56 (5.77)
Men, n (%)	184 (26.36%)	164 (23.36%)	166 (23.61%)	162 (23.34%)
White, n (%)	503 (72.06%)	523 (74.50%)	524 (74.54%)	501 (72.19%)
Education, M (SD)	13.37 (2.71)	13.65 (2.68)	13.59 (2.73)	13.51 (2.68)
SF-36 Physical Function (scaled score), M (SD)	74.05 (6.05)	73.42 (5.78)	73.53 (6.02)	73.56 (5.77)
Cognitive self-efficacy (raw score), M (SD)	30.00 (4.50)	29.98 (4.43)	30.00 (4.55)	29.94 (4.53)
Depressive symptoms (raw score), M (SD)	5.06 (4.87)	5.11 (5.00)	4.99 (5.32)	5.54 (5.37)

Notes: ITT = intention-to-treat. Chi-square and analyses of variance revealed that study arms were not significantly different on any variables at baseline. SF-36 is the MOS Short-Form 36-item scale.

identify increasingly complex visual information. For each task, the score was the shortest presentation time needed to perform the task correctly 75% of the time.

Memory training arm

This was a strategy-based pencil-and-paper training designed to improve verbal episodic memory using mnemonic strategies. Training included practice and feedback organizing materials into meaningful categories, such as lists of errands or grocery shopping (Jobe et al., 2001).

Reasoning training arm

This was a strategy-based pencil-and-paper training that focused on improving problem solving and included practice and feedback on identifying patterns or sequences. For example, training activities included finding the pattern in a series of repeating letters or identifying dosage patterns of mediations (Jobe et al., 2001).

No-contact control arm

Participants randomized to the no-contact control arm came to the study site for all assessments, and no intervention was conducted.

Measures

Physical function

Grip strength, a measure of gross upper limb muscle strength, was assessed using the Jamar hydraulic hand dynamometer (Lafayette Instruments). Participants were instructed to squeeze as hard as they comfortably could in their dominant hand, and the assessment was completed twice. Participants reporting recent worsening of pain or arthritis in their wrists, had tendonitis, or hand or arm surgery during the prior three months did not complete the grip strength protocol. Scores indicated the output strength in kilograms rounded to the nearest whole number and were averaged across the two trials to yield a composite measure of grip strength. Scores were baseline-adjusted by subtracting the baseline mean and dividing by the baseline standard deviation.

Turn 360, a measure of complex lower limb function, was assessed (Gill, Williams, & Tinetti, 1995; Steinhagen-Thiessen & Borchelt, 1999; Tager, Swanson, & Satariano, 1998). Participants were instructed to turn in a complete circle as quickly and safely as possible. If necessary, walking aids were permitted. Scores were the average number of steps across two trials. Scores were baseline-adjusted by subtracting the baseline mean and dividing by the baseline standard deviation. Higher scores indicated worse performance. See Supplementary Table 1 for the unadjusted means of grip strength and Turn 360 across the study period stratified by intervention group.

Training

Intention-to-treat (ITT) multilevel models assessed the effect of randomization on training regardless of adherence. Training

groups were separately compared against the no-contact control group. In addition, dosage-received models where only those who were compliant in the initial trial (i.e., at least 8 of 10 sessions) or the no-contact control group were analyzed to examine whether receiving the treatment impacted physical function. Dosage was assessed as number of training sessions completed as a time-varying measure. Follow-up analyses with only those receiving at least one booster (i.e., at least 11 training sessions) were completed to assess whether training gains were similar to the main dosage analyses. Participants were randomized to receive booster training if they were compliant in the initial trial; 60% of the compliant sample in each training arm were randomized to receive the booster, while the remaining 40% did not.

Baseline psychosocial moderators

All baseline moderators evaluated whether baseline status attenuated 10-year declines in physical function slopes. *Cognitive self-efficacy* was assessed using the Personality in Intellectual Contexts-36 item (PIC-36) internal locus of control subscale (Lachman, Baltes, Nesselroade, & Willis, 1982), which consisted of six items assessing one's ability to (re)learn unfamiliar materials. All items were scored on a 1 (strongly agree) to 6 (strongly disagree) Likert scale. Items were summed for a summary score then mean centered for the analyses. The summary scores ranged from 8 to 36; higher scores indicated higher cognitive self-efficacy.

Depressive symptoms were assessed using the Center for Epidemiological Studies-Depression 12-item questionnaire (CES-D-12) (Radloff, 1977). Participants were asked to describe how they felt or behaved during the prior week. All items were scored on a 0 (never) to 3 (5–7 days) Likert scale. Items were summed for a summary score then mean centered for the analyses. The summary scores ranged from 0 to 34 (theoretical maximum = 36); higher scores indicated more depressive symptoms.

Covariates

Self-reported *baseline age*, *gender* (woman = 0; man = 1), *race* (non-White = 0 or White = 1), and years of formal *education* (0–20) were included as covariates because older age, women, non-White race, and lower educational attainment have been associated with lower physical function. Baseline age and education were grand mean centered at baseline such that higher scores indicated older age and more education, respectively. Additionally, *baseline self-reported physical function* using the SF-36 physical function subscale was included. Scores were standardized based on the SF-36 scoring manual and then centered based on the sample mean; higher scores indicated better self-reported function.

Analytic Strategy

Chi-square and analyses of variance were used to test baseline differences; there were no differences in any characteristics of interest by intervention group. All multilevel models were

estimated using restricted maximum likelihood estimation with an unstructured covariance matrix and were conducted with SPSS, version 25 (IBM Corporation). All estimates were unstandardized, and significance was evaluated at p <.05. Outcome variables were standardized by first subtracting the baseline mean and dividing by the baseline standard deviation. Time was scaled to reflect the number of months since the baseline assessment. Similar to prior work (Ross, Sprague, et al., 2018), base models were developed using the control arm of the study (n = 698) and included all demographics, subjective physical function, and Time*Covariate (including time^2) interactions. Nonsignificant covariates and interactions were removed, resulting in different covariates for each physical function outcome measure. The same covariates were also used for dosage analyses. Participants completing at least eight of the initial sessions were included in the dosage analyses, and number of sessions completed was time-varying dosage. Unadjusted effect sizes (Cohen's d) are presented. Lastly, all baseline psychosocial moderation and bodily pain analyses were analyzed separately in order to simplify interpretation of the results.

Results

Base Models

The base model using the control group for grip strength indicated that younger age (estimate = –0.04, p < .001), men (estimate = –1.49, p < .001), non-White participants (estimate = 0.36, p < .001), and those with better baseline self-reported physical function (estimate = 0.01, p < .001) had better grip strength. Grip strength significantly weakened over time (estimate = –0.004, p < .001). A significant time^2 interaction suggested grip strength declines accelerated over time (estimate < 0.001, p < .001). There were 200 processing speed training, 196 memory training, 208 reasoning training, and 183 no-contact control participants with grip strength data at year 10.

The base model for Turn 360 using the control group indicated that younger age (estimate = 0.041, p < .001), White participants (estimate = –0.16, p = .01), and those with better physical function (estimate = –0.01, p < .001) had better Turn 360. Over time, Turn 360 scores significantly declined (estimate = 0.007, p < .001). Lastly, there was a significant Age*Time interaction such that over time, those who were older had accelerated decline (estimate < 0.001, p = .002). There were 229 processing speed training, 215 memory training, 227 reasoning training, and 201 no-contact control participants with Turn 360 data at year 10.

Grip Strength

Aim 1: ITT models
Assignment to processing speed (estimate < 0.001, p = .454), memory (estimate < 0.001, p = .647), or reasoning training (estimate = 0.001, p = .251) were not significantly associated with better grip strength relative to the control group. Additionally, assignment to processing speed (estimate = <0.001, p = .478), memory (estimate = <–0.001, p = .684), or reasoning training (estimate = <0.001, p = .984) were not associated with differences in accelerated grip strength weakness over time.

Aim 1: dosage models
More processing speed (estimate = <–0.001, SE = 0.002; d=0.104),memory(estimate=<–0.001,SE=0.002;d=0.053), and reasoning (estimate = <0.001, SE = 0.002; d = 0.097) training were not significantly associated with grip strength relative to the control group (p > .05; Table 2). The same pattern of results held when constraining the analyses to those who received booster sessions only.

Aim 2: psychosocial moderators
Because there were no significant ITT or dosage models for grip strength across 10 years, moderation analyses were not completed for grip strength.

Turn 360

Aim 1: ITT models
Assignment to processing speed (estimate = 0.001, p = .133), memory (estimate < 0.001, p = .867), or reasoning training (estimate = 0.001, p = .186) were not significantly associated with better Turn 360 relative to the control group.

Aim 1: dosage models
More processing speed (estimate = –0.011, SE = 0.003; d = 0.216), memory (estimate = –0.011, SE = 0.003; d = 0.057), and reasoning (estimate = –0.012, SE = 0.003; d = 0.210) training were associated with better Turn 360 relative to the control group (p < .001; Table 3). The same pattern of results held when constraining analyses to only those who received booster training.

Aim 2: psychosocial moderators
Baseline cognitive self-efficacy did not moderate the relationship between dosage and Turn 360 for processing speed, memory, or reasoning training (p > .05). Baseline depressive symptoms moderated the relationship between dosage and Turn 360 in the processing speed (estimate = –0.001, p < .05) group only, indicating that the benefit of additional training was greatest among those with more baseline depressive symptoms. See Supplementary Table 1 for the unadjusted means across time. There was no moderation in memory or reasoning training (p > .05).

Discussion

Cognitive training is increasingly viewed as a viable intervention strategy for older adult physical function (Azadian et al., 2016, 2018; Li et al., 2010; Marusic & Grosprêtre, 2018; Marusic et al., 2015, 2018; Ng et al., 2015; Ross, Sprague, et al., 2018; Smith-Ray et al., 2015, 2016; Verghese

Table 2. Effects of Cognitive Training on Grip Strength Across 10 Years, Dosage Models (Compliant Participants)

	Processing speed training (n = 598) vs no-contact control (n = 616)		Memory training (n = 603) vs no-contact control (n = 616)		Reasoning training (n = 592) vs no-contact control (n = 616)	
	Estimate (*SE*)	95% CI	Estimate (*SE*)	95% CI	Estimate (*SE*)	95% CI
Fixed effects						
Intercept	1.000 (0.040)***	0.921, 1.079	1.00 (0.040)***	0.921, 1.079	1.059 (0.040)***	0.981, 1.137
Dosage	*<−0.001 (0.002)*	*−0.004, 0.004*	*<−0.001 (0.002)*	*−0.004, 0.004*	*0.001 (0.002)*	*−0.003, 0.005*
Age	−0.041 (0.003)***	−0.048, −0.035	−0.041 (0.003)***	−0.048, −0.035	−0.039 (0.003)***	−0.045, −0.032
Gender	−1.488 (0.041)***	−1.569, −1.406	−1.488 (0.041)***	−1.569, −1.406	−1.555 (0.041)***	−1.635, −1.474
Race	0.344 (0.042)***	0.262, 0.426	0.344 (0.042)***	0.262, 0.426	0.325 (0.041)***	0.245, 0.405
SF-36 Physical Function	0.005 (0.001)***	0.004, 0.007	0.005 (0.001)***	0.004, 0.007	0.004 (0.001)***	0.002, 0.005
Month	−0.004 (<0.001)***	−0.005, −0.003	−0.004 (<0.001)***	−0.005, −0.003	−0.004 (<0.001)***	−0.005, −0.003
Month^2	<−0.001 (<0.001)***	<−0.001, <−0.001	<−0.001 (<0.001)***	<−0.001, <−0.001	<−0.001 (<0.001)***	<−0.001, <−0.001
Random effects						
Residual	0.171 (0.006)***	0.159, 0.183	0.171 (0.006)***	0.160, 0.183	0.172 (0.006)***	0.161, 0.183
Intercept	0.310 (0.017)***	0.279, 0.345	0.310 (0.017)***	0.279, 0.345	0.299 (0.016)***	0.270, 0.332
Month	<0.001 (<0.001)***	<0.001, <0.001	<0.001 (<0.001)***	<0.001, <0.001	<0.001 (<0.001)***	<0.001, <0.001
Covariance (intercept, month)	<0.001 (<0.001)	<−0.001, <0.001	0.001 (<0.001)	<−0.001, <0.001	<0.001 (<0.001)	<−0.001, <0.001

Notes: CI = confidence interval. Higher grip strength scores indicate greater strength in kilograms (i.e., better performance).
***p < .001, **p < .01, *p < .05.

Table 3. Effects of Cognitive Training on Turn 360 Across 10 Years, Dosage Models (Compliant Participants)

	Processing speed training (*n* = 684) vs no-contact control (*n* = 681)		Memory training (*n* = 688) vs no-contact control (*n* = 681)		Reasoning training (*n* = 678) vs no-contact control (*n* = 681)	
	Estimate (*SE*)	95% CI	Estimate (*SE*)	95% CI	Estimate (*SE*)	95% CI
Fixed effects						
Intercept	0.305 (0.030)***	0.256, 0.364	0.305 (0.030)***	0.246, 0.364	0.312 (0.030)***	0.253, 0.371
Dosage	*–0.011 (0.003)****	*–0.016, –0.006*	*–0.011 (0.003)****	*–0.016, –0.006*	*–0.012 (0.003)****	*–0.017, –0.006*
Age	0.056 (0.004)***	0.047, 0.064	0.055 (0.004)***	0.047, 0.064	0.055 (0.004)***	0.047, 0.064
Race	–0.114 (0.047)*	–0.207, –0.021	–0.114 (0.047)*	–0.207, –0.021	–0.131 (0.048)**	–0.225, –0.037
SF-36 Physical Function	–0.012 (0.001)***	–0.013, –0.010	–0.012 (0.001)***	–0.013, –0.010	–0.012 (0.001)***	–0.013, –0.010
Month	0.007 (<0.001)***	0.006, 0.008	0.007 (<0.001)***	0.006, 0.008	0.007 (<0.001)***	0.006, 0.008
Age*Month	<0.001 (<0.001)**	<0.001, <0.001	<0.001 (<0.001)**	<0.001, <0.001	<0.001 (<0.001)***	<0.001, <0.001
Random effects						
Residual	0.410 (0.013)***	0.386, 0.436	0.410 (0.013)***	0.386, 0.436	0.417 (0.013)***	0.393, 0.443
Intercept	0.433 (0.028)***	0.381, 0.492	0.433 (0.028)***	0.382, 0.492	0.445 (0.029)***	0.392, 0.505
Time	<0.001 (<0.001)***	<0.001, <0.001	<0.001 (<0.001)***	<0.001, <0.001	<0.001 (<0.001)***	<0.001, <0.001
Covariance (intercept, month)	0.002 (<0.001)***	0.002, 0.003	0.002 (<0.001)***	0.002, 0.003	0.002 (<0.001)***	0.001, 0.003

Notes: CI = confidence interval. Higher scores on Turn 360 indicate more steps to turn (i.e., worse performance).
***p < .001, **p < .01, *p <. 05.

et al., 2010). The present study extends this work by demonstrating small training-related attenuation of declines in complex lower limb function across 10 years. More processing speed, memory, and reasoning training were associated with less decline in lower limb function over 10 years, suggesting that cognitive interventions training different cognitive domains can all positively impact physical function. This supports work that cognitive training mitigated declines in complex physical function (Ross, Sprague, et al., 2018; Smith-Ray et al., 2015, 2016). Although the mechanistic pathways by which this occurs are unknown, neuroimaging studies indicate compensation or neural dedifferentiation (Sleimen-Malkoun, Temprado, & Hong, 2014), that is, decreased brain specialization in older adulthood due to impaired neural resource allocation, as potential explanations for the increased relatedness of physical and cognitive function in older adults. These processes are not interchangeable; compensation is an adaptive mechanism that should be associated with benefits on outcome performance (Cabeza et al., 2018), whereas dedifferentiation indicates neural impairment (Koen & Rugg, 2019). While the current study is unable to identify which process is likelier to explain the current findings, there is evidence that prefrontal brain regions primarily responsible for cognitive processing speed (e.g., dorsolateral prefrontal cortex (Heuninckx, Wenderoth, Devaere, Peeters, & Swinnen, 2005; Holtzer et al., 2014) are activated during walking tasks (Holtzer et al., 2014; Pelicioni et al., 2019). Since there are common brain regions underlying both cognitive and certain physical functions, training the implicated cognitive functions (e.g., processing speed) may impact the physical functions that recruit the same brain regions. Processing

speed training does impact neurologic function and connectivity (Ross, Webb, et al., 2018), but it remains unknown whether these training-related changes are responsible for differences in complex physical function performance.

Despite evidence that grip strength and cognition are related in healthy older adults, cognitive training did not impact grip strength in this study. These results are similar to prior work that found grip strength decline was only attenuated in reasoning training after 5 years (Ross, Sprague, et al., 2018). Since weaker grip strength is associated with mortality (Granic et al., 2017), those who may be likeliest to receive benefits could have died during the follow-up period. The control participants with better grip strength who remained in the study may perform similarly to those with cognitive training. Relatedly, older adults healthy enough for in-person assessments after 10 years may be unlikely to be frail, so between-group differences may be more pronounced in frail older adults.

The second goal of this study was to evaluate baseline moderators of training effects. This study found that cognitive self-efficacy did not moderate training effects on any physical function outcome. This result is consistent with previous work in which processing speed training gains were not explained by cognitive self-efficacy (Sharpe et al., 2014). Although there were no differential dosage effects by cognitive self-efficacy, there was a significant interaction between baseline depressive symptoms and processing speed dosage across Turn 360 such that more depressive symptoms enhanced training-related attenuation of declines. That is, processing speed training benefitted complex physical function in those with more depressive symptoms. To the authors' knowledge, this has not been demonstrated elsewhere and suggests that there may

be a relationship between depressive symptoms, processing speed, and complex physical function. Although the mechanistic pathway is unknown, processing speed training reduces depressive symptoms (Wolinsky, Mahncke, et al., 2009; Wolinsky, Vander Weg, et al., 2009), so it may be that the processing speed training "treated" depressive symptoms, in turn providing indirect benefits to physical function. It may also be the case that those with greater baseline depressive symptoms have a greater capacity for cognitive (and physical) improvement. There were generally larger standard deviations in baseline Turn 360 in those with greater depressive symptoms (data not shown), suggesting that those with more depressive symptoms may have greater capability to improve Turn 360 compared to those with fewer depressive symptoms since the maximum score was higher compared to those with lower depressive symptoms. Future research should replicate and extend these analyses to other functional outcomes. It may be that with additional training, those with greater depressive symptoms can perform as well as those with fewer depressive symptoms. Since there was a larger standard deviation in those with more depressive symptoms, this suggests those participants have an increased capacity for improvement.

The current results, however, do not suggest a mechanistic (i.e., mediation) pathway by which depressive symptoms, physical function, and cognitive training are related. Additionally, the design of the ACTIVE trial is not ideal to identify mechanistic pathways given the simultaneous assessment of possible mediators (e.g., changes in depressive symptoms) and outcomes (e.g., changes in physical function). This makes it difficult to determine the temporal ordering of the mechanism and outcome. Future work should design intervention studies that are appropriate for examining mechanistic pathways to elucidate why those with depressive symptoms conferred greater benefits. The current study was also unable to examine other proposed psychological mechanisms of transfer, such as engagement in cognitively engaging activities or physical activity. Future intervention studies should consider how engagement in cognitive training programs changes other everyday behaviors. It may be that something unique to the cognitive training program itself or whether mere engagement in an intervention program engenders behavior change elsewhere in the individual's daily life and is responsible for any training-related gains. However, this latter hypothesis has not been empirically tested.

Taken together, this study demonstrates the long-term association between more cognitive training sessions to complex lower limb function across 10 years. This study does not imply that cognitive training is the *most* effective intervention for attenuating age-related declines in these abilities as demonstrated by the small effect sizes. However, it is important to note that such effects, even if small, are still present after 10 years which is unique compared to other interventions. This work lends support that cognitive training programs are a plausible intervention modality for those who cannot or choose not to participate in physical-based interventions

by capitalizing on the bidirectional cognitive–physical function relationship. It is noteworthy that the training gains were present 10 years later since the dosage compared to physical activity interventions was substantially smaller (e.g., 10 vs 49 hr; Oja et al., 2018), and the follow-up period was longer (e.g., 10 years vs immediate posttest or 2 years posttest max; Finnegan, Seers, & Bruce, in press; Oja et al., 2018). The benefits of cognitive training were similar regardless of baseline cognitive self-efficacy and depressive symptoms (except processing speed training), providing further evidence that psychosocial beliefs are unlikely to impact cognitive training gains.

Future research should continue exploring the complex, dynamic relationship between physical and cognitive function with an emphasis on interventions that can simultaneously improve both health domains such as combined exercise-cognitive training programs (Marusic et al., 2018). Lastly, this work suggests that long-term benefits may be greater for at-risk compared to low-risk samples. Cognitive, especially speed of processing, training may be more effective as a targeted intervention rather than a universal intervention for older adults regardless of physical functional ability. The ACTIVE sample performed substantially better on the Turn 360 task compared to older adults at risk for falls (i.e., around 6 steps vs >12 steps; Lipsitz, Jonsson, Kelley, & Koestner, 1991). Accumulating evidence suggests that cognitive training, particularly speed of processing, may be especially effective for high-risk samples across a breadth of outcomes (e.g., Ball, Edwards, & Ross, 2007; Ball, Edwards, Ross, & McGwin, 2010; Ball, Ross, Roth, & Edwards, 2013; Edwards, Fausto, Tetlow, Corona, & Valdés, 2018; Ross et al., 2016, 2017; Smith-Ray et al., 2015; Sprague et al., 2019). Identifying effective, time-efficient interventions—especially for high-risk samples—are important to promote older adults' health, independence, and well-being.

Supplementary Material

Supplementary data are available at *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences* online.

Supplementary Table 1. Raw means (standard deviations) of grip strength and Turn 360 across all timepoints by intervention group.

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Conflict of Interest

None reported.

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