Executive Function Processes Predict Mobility Outcomes in Older Adults

Neha P. Gothe, PhD,[a] Jason Fanning, MS,[a] Elizabeth Awick, BS,[a] David Chung, MS,[a] Thomas R. Wójcicki, PhD,[a] Erin A. Olson, MS,[a] Sean P. Mullen, PhD,[a] Michelle Voss, PhD,[b] Kirk I. Erickson, PhD,[c] Arthur F. Kramer, PhD,[d,e] and Edward McAuley, PhD[a,e]

OBJECTIVES: To examine the relationship between performance on executive function measures and subsequent mobility outcomes in community-dwelling older adults.

DESIGN: Randomized controlled clinical trial.

SETTING: Champaign-Urbana, Illinois.

PARTICIPANTS: Community-dwelling older adults (N = 179; mean age 66.4).

INTERVENTION: A 12-month exercise trial with two arms: an aerobic exercise group and a stretching and strengthening group.

MEASUREMENTS: Established cognitive tests of executive function (flanker task, task switching, and a dual-task paradigm) and the Wisconsin card sort test. Mobility was assessed using the timed 8-foot up and go test and times to climb up and down a flight of stairs.

METHODS: Participants completed the cognitive tests at baseline and the mobility measures at baseline and after 12 months of the intervention. Multiple regression analyses were conducted to determine whether baseline executive function predicted postintervention functional performance after controlling for age, sex, education, cardiorespiratory fitness, and baseline mobility levels.

RESULTS: Selective baseline executive function measurements, particularly performance on the flanker task (β = 0.15–0.17) and the Wisconsin card sort test (β = 0.11–0.16) consistently predicted mobility outcomes at 12 months. The estimates were in the expected direction, such that better baseline performance on the executive function measures predicted better performance on the timed mobility tests independent of intervention.

CONCLUSION: Executive functions of inhibitory control, mental set shifting, and attentional flexibility were predictive of functional mobility. Given the literature associating mobility limitations with disability, morbidity, and mortality, these results are important for understanding the antecedents to poor mobility function that well-designed interventions to improve cognitive performance can attenuate. **J Am Geriatr Soc 62:285–290, 2014.**

Key words: cognitive; functional fitness; mobility outcomes; executive function

The incidence of functional limitations and disability increases with age and chronic disease; more than 34% of adults aged 65 and older report limitations with even the most basic activities of daily living (ADLs), such as bathing and dressing.[1] Such decrements, coupled with the risk of decline in cognitive function with age,[2] can result in loss of independence and compromised quality of life.[3] Although cognitive and functional declines typically manifest during the normal aging process and appear to be interrelated, a growing body of literature suggests that poor cognitive performance may be a precursor to functional limitations that lead to disability.[4,5] Given the escalating healthcare costs and long-term management demands of disabilities and chronic disease, it is critical to identify potential determinants of functional limitations to delay or possibly prevent disability occurrence.

Several cross-sectional and prospective studies have reported an association between cognitive performance and functional performance. In cross-sectional studies, the association between cognitive performance and ADLs and instrumental ADLs has been found to be independent of sociodemographic factors or comorbidities.[4–6] Longitudinal studies have reported that poor cognitive performance

From the [a]Department of Kinesiology and Community Health, University of Illinois at Urbana-Champaign, Urbana, Illinois; [b]Department of Psychology, University of Iowa, Iowa City, Iowa; [c]Department of Psychology, University of Pittsburgh, Pittsburgh, Pennsylvania; [d]Department of Psychology, University of Illinois at Urbana-Champaign, Urbana, Illinois; and [e]Beckman Institute for Advanced Science and Technology, University of Illinois at Urbana-Champaign, Urbana, Illinois.

Address correspondence to Edward McAuley, Department of Kinesiology and Community Health, University of Illinois at Urbana Champaign, 906 S. Goodwin Ave, Urbana, IL 61801. E-mail: emcauley@illinois.edu

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predicts higher odds of onset and increasing levels of ADL limitations.[7–10] Researchers have also tried to examine the reciprocity of this relationship, concluding that the direction of the association is predominantly from poor cognition to poor physical function. An extensive review of longitudinal studies (n = 36) to investigate the association between objective measures of physical and cognitive functioning in community-dwelling individuals aged 40 and older found associations with unique functional measurements such that grip strength was associated with mental state (e.g., mental state examination scores, diagnostic criteria to determine cognitive impairment including dementia or Alzheimer's disease), whereas walking speed was correlated with cognitive measures of processing speed and executive function.[11,12]

In spite of this emerging literature, there are some drawbacks to the methodologies previously employed. Most studies used self-report measures of cognitive function, including mental state examinations, which are more commonly used as screening measures, or diagnostic criteria for cognitive impairment rather than indicators of performance in different cognitive domains. Few studies have used standardized cognitive tests such as trail making, letter cancellation, or processing speed (see[12] for a review). Herein, secondary outcomes are reported from a randomized controlled trial examining exercise-training effects on brain health.[13–15] The purpose of this study was to determine whether baseline executive function predicted change in mobility outcomes resulting from a 12-month randomized controlled exercise trial. It was hypothesized that better baseline performance on executive function measures would be predictive of better future functional performance on the objective tests of mobility. It was also hypothesized that this relationship would be independent of age, education, sex, cardiorespiratory fitness, intervention condition, and baseline mobility performance.

METHODS

Participants

Participants were sedentary, community-dwelling older adults recruited to participate in a study designed to examine the effects of cardiorespiratory fitness on brain health. Recruitment procedures, full inclusion and exclusion criteria, and study details have been described elsewhere.[13–15] Briefly, participants had to be aged 60 to 80, have been physically inactive over the previous 6 months, have no medical conditions that exercise would exacerbate, obtain physician's consent, be willing to be randomized, and have good or corrected vision (20/40). Participants were also screened for cognitive impairment using the Mini-Mental State Examination (MMSE)[16] and were excluded if they scored <21, which is indicative of neurological pathology. After obtaining written informed consent approved by a university institutional review board, participants completed measures of cognitive function, mobility, and cardiorespiratory fitness before their randomization to an aerobic walking group or a flexibility, toning, and balance (FTB) control group. The walking and FTB programs were 12 months long and consisted of three structured 40-minute exercise sessions per week led by a trained exercise leader. Participants in both groups met in separate indoor fitness facilities and had similar opportunities to socialize with each other and with the exercise instructor. All pre- and post-intervention measures were administered within 2 weeks of the start (baseline) and end (Month 12) of the intervention, respectively.

Measures

Participant demographic characteristics, including age, sex, and education, were recorded at baseline. Because cardiovascular fitness is associated with functional performance measures, participants also completed a physician-supervised graded exercise test using a modified Balke protocol that has been previously described.[15] These measures were included as covariates in the analyses.

Executive Function

Multiple measures of executive function were assessed, including measures of inhibitory control, multitasking, working memory, mental set shifting, and attention.[17] Inhibitory control was measured according to performance on a modified flanker paradigm.[13,18] Participants were asked to respond to a central arrow cue embedded in an array of five arrows pointing left or right. In half of the trials, the flanking arrows were pointed in the same direction as the central arrow, reflecting a congruent orientation (e.g., >>>>>). In the other half of the trials, the flanking arrows pointed in the opposite direction from the central arrow, reflecting an incongruent orientation (e.g., >><>>). Each participant completed 40 incongruent trials and 40 congruent trials, presented in random order. For the purpose of the present study, the difference between the mean reaction time for the congruent trials and incongruent trials was used as the measure of inhibitory control.

The task-switching paradigm[13] assessed ability to flexibly switch the focus of attention between multiple task sets. Participants had to switch between judging whether a number was odd or even and judging whether it was larger or smaller than 5 (high or low). The eligible numbers were 1, 2, 3, 4, 6, 7, 8, and 9. Numbers were presented individually for 1,500 ms against a pink or blue background in the center of the computer screen, with the constraint that the same number did not appear twice in succession. If the background was blue, participants used their left hand to report as quickly as possible whether the number was high ('x' key) or low ('z' key). If the background was pink, they used their right hand to report whether the number was odd ('n' key) or even ('m' key). Participants completed two single-task blocks of 24 trials each (one block of odd/even and one block of high/low) and one mixed/'switching' block of 120 trials during which the task for each trial was chosen randomly. A series of practice trials preceded each block to familiarize the participants with the rules. For the current study, the primary executive function measure was global cost (difference in mean reaction time for the mixed block of trials, including the repeat and switch trials, and the mean reaction time of the single task blocks of trials (mixed—single)).

Participants also completed a dual-task paradigm[18,19] assessing attentional flexibility. They were asked to respond to one (single) or two (dual) stimuli presented to them on a computer screen. The single-task trials involved the presentation of a single letter (A or B) or number (2 or 3) stimulus, whereas in the dual-task trials, two stimuli, a letter and a number, were presented. Each participant completed 48 trials and had to respond as quickly and accurately as possible to the stimulus. In this measure of task coordination, the outcome measure was the difference between mean dual-task reaction time and the single-task reaction time. The dual-task and task-switch measures are similar in that both assess attentional flexibility, although both are considered classic tests of executive function.

Finally, participants completed a computerized version of the Wisconsin Card Sort Task (WCST), which assesses multiple components of executive function, including working memory, inhibition, and switching capacity.[20] The task requires participants to sort cards according to shape, color, or number of objects on the card without explicitly stating which criterion to apply. Participants were asked to match each card that appeared at the bottom of the computer screen with one of the four cards displayed at the top of the screen. They were told that the computer would provide feedback about the accuracy of their decision but that the examiner could not give them any additional instructions about the task. The outcome measure for this task was the number of perseverative errors (total number of repeated error trials divided by number of trials).

Mobility

Three measures of mobility were assessed. The first was the timed 8-foot up and go test from the Seniors Functional Fitness Battery, which assesses physical performance and lower extremity function.[21] The 8-foot up and go measures coordination, agility, balance, and speed. Each participant started from a fully seated position in a chair, hands resting on the knees and feet flat on the ground. Upon starting, the participant walked as quickly as possible, without running, around a cone placed 8 feet in front of the chair and returned to the seated position in the chair. The shortest time of two trials, measured using a stopwatch, was used for analyses. In addition to this test, mobility and lower extremity function were assessed using a timed stair up and down test in which participants climbed and descended a flight of 12 steps at their normal pace, without running or skipping a step. A stopwatch was used to assess the time taken on each task.

Data Analysis

Initially, a two (exercise condition) by two (time) mixed-model analysis of variance was conducted to determine whether participants' mobility had improved across the trial. Next, a series of multiple regression analyses was conducted using a robust full-information maximum likelihood estimator using *Mplus* software (Mplus Version 6.0, Los Angeles, CA)[22] to test the directional hypothesis that better baseline executive function was predictive of improvements in mobility over the 12-month period. Age, sex, education, exercise group, baseline mobility score and cardiovascular fitness were included as covariates in all analyses.

RESULTS

The sample characteristics at baseline are presented in Table 1. Participants were primarily female (65.4%), with a mean age of 66.4 and low fit (mean maximal oxygen consumption = 21.0 mL/kg per minute) for this age group according to the American College of Sports Medicine norms.[23] Participants in the walking condition attended 80.2% of all activity sessions, and those in the FTB condition attended 76.7% of the sessions. There was no significant difference between attendance rates, and the average attendance rate in the walking and FTB groups was 78.4%, suggesting high adherence to the exercise intervention.

Intervention Effects on Mobility

Table 2 shows the baseline and follow-up data for the two groups on the mobility measures. A significant time effect was observed for each of the mobility outcomes: 8-foot up and go (F (1,136) = 10.33, P = .002, partial η^2 = .07), stair down time (F (1,136) = 9.03, P = .003, partial η^2 = .06), and stair up time (F (1,136) = 18.63, P < .001, partial η^2 = .12). The walking and FTB exercise interventions involved exercises targeting lower body strength that led to improved mobility outcomes over the course of the 12-month intervention. For the 8-foot up and go, the time effect was superseded by a group-by-time interaction (F (1,136) = 4.11, P = .04, partial η^2 = .03), suggesting that the FTB group had larger improvements at follow-up than their walking counterparts. These results are also expected because the FTB group participated in a variety of strengthening exercises, including chair exercises and hover squats, that involved movements mirroring the 8-foot up

Table 1. Baseline Characteristics of the Sample

Characteristic	Value
Age, mean ± SD	66.4 ± 5.7
Fitness, mL/kg, mean ± SD	21.0 ± 4.8
Education, n (%)	
<College degree	87 (48.6)
≥College degree	92 (51.4)
Sex, n (%)	
Male	62 (34.6)
Female	117 (65.4)
Ethnicity, n (%)	
Hispanic	3 (1.7)
Not Hispanic	176 (98.3)
Race, n (%)	
Caucasian	158 (88.3)
African American	15 (8.4)
Asian	6 (3.4)
Group, n (%)	
Walk	89 (49.7)
Flexibility toning and balance	90 (50.3)

SD = Standard Deviation.

Table 2. Mobility Outcome According to Group

Mobility Outcome	Walk		Flexibility Toning and Balance	
	Baseline	Month 12	Baseline	Month 12
	Seconds, Mean ± SD			
8-foot up and go	5.56 ± 0.13	5.07 ± 0.11	5.82 ± 0.13	5.06 ± 0.11
Stairs up	7.16 ± 0.18	6.35 ± 0.19	7.97 ± 0.17	6.80 ± 0.18
Stairs down	6.96 ± 0.20	6.14 ± 0.20	7.44 ± 0.19	6.21 ± 0.19

and go test. The baseline executive function scores of the walking and FTB groups are presented in Table 3. Independent-sample *t*-tests showed no significant group differences on baseline cognitive function scores (all $P \geq .19$).

Predicting Changes in Mobility from Baseline Executive Function

Table 4 summarizes the results from the multiple regression analyses that were conducted to examine the relationship between cognition and physical function. Exercise condition, sex, and education did not predict performance on any of the three mobility measures (all $P \geq .30$). Baseline performance on the flanker task ($\beta = 0.15$, $P = .03$) was significantly associated with scores on the 8-foot up and go test at follow-up. Being younger ($\beta = 0.07$, $P = .01$) and having better baseline performance on the 8-foot up and go ($\beta = 0.52$, $P < .001$) were also associated with better performance at follow-up. Baseline performance on the flanker task ($\beta = 0.17$, $P = .007$) and WCST errors ($\beta = 0.12$, $P = .03$) were significantly associated with faster stairs up time, and being fitter ($\beta = -0.23$, $P = .005$) and having a faster baseline stair up time ($\beta = 0.49$, $P < .001$) were associated with better performance at follow-up. For the stair down test, baseline performance on the flanker task ($\beta = 0.17$, $P = .008$) and the WSCT ($\beta = 0.16$, $P = .009$) were significantly associated with better performance at 12-month follow-up. Age ($\beta = 0.12$, $P = .02$) and baseline stair down performance ($\beta = 0.59$, $P < .001$) were also related to 12-month performance.

As hypothesized, fewer errors on the WCST and shorter flanker interference times at baseline were associated with better performance on the mobility measures (shorter times on the functional tests). The executive function measures of task switching and dual task did not predict performance on the 8-foot up and go or the timed stair up and down tests.

Table 3. Executive Function Measures According to Group

Measure	Walk	Flexibility Toning and Balance
Wisconsin Card Sorting Test, errors	20.8 (14.2)	20.8 (14.9)
Dual task, dual-single reaction time	500.6 (133.9)	496.7 (109.9)
Task switch, global cost	425.2 (167.3)	391.0 (169.1)
Flanker task, interference	76.5 (51.0)	87.2 (70.7)

DISCUSSION

The present study examined the effects of a 12-month exercise program for community dwelling older adults on measures of mobility and the extent to which baseline executive function influenced improvements in mobility when controlling for intervention group, baseline mobility, cardiorespiratory fitness, and demographic characteristics. Given that executive function is an umbrella multidimensional concept, an array of established measures was used to examine specificity of these functions in predicting mobility. The findings suggest that the flanker task, an indicator of inhibitory control, and the WCST, an indicator of mental flexibility, decision-making, and working memory, were consistent predictors of mobility. The task-switching and dual-task paradigms were not associated with mobility function in this older adult sample.

Table 4. Standardized and Unstandardized Estimates from the Multiple Regression Analyses

Predictor	8-Foot Up and Go			Stair Up			Stair Down		
	B	β	*P*-Value	B	β	*P*-Value	B	β	*P*-Value
Age	0.03	0.07	.01	0.02	0.07	.17	0.04	0.12	.02
Sex	0.02	0.01	.45	0.16	0.05	.26	0.04	0.01	.44
Education	–0.05	–0.03	.36	–0.16	–0.05	.25	–0.03	–0.01	.44
Fitness	–0.03	–0.14	.06	–0.08	–0.23	.005	–0.05	–0.13	.07
Group	–0.08	–0.04	.26	0.23	0.07	.15	0.05	0.02	.39
Baseline performance	0.44	0.52	<.001	0.53	0.49	<.001	0.59	0.59	<.001
Flanker task	0.00	0.15	.03	0.01	0.17	.007	0.01	0.17	.008
Task switch	0.00	0.02	.39	0.00	–0.01	.43	0.00	–0.02	.39
Dual task	0.00	0.09	.10	0.00	–0.02	.36	0.00	0.06	.18
Wisconsin Card sorting Test error	0.01	0.11	.07	0.01	0.12	.03	0.02	0.16	.009
	$R^2 = 0.57$, $P < .001$			$R^2 = 0.50$, $P < .001$			$R^2 = 0.58$, $P < .001$		

P-Value—one-tailed test.
R^2 = coefficient of determination.

Executive function encompasses skills such as planning, task coordination and multitasking, working memory, inhibitory control, and decision-making. Each of these skills individually, or in combination, is essential to performing tasks of independent living such as dressing, preparing meals, shopping, and paying bills. It is therefore possible that mild executive dysfunction may negatively affect performance on ADLs. There is growing evidence of the role of executive function in successful adherence to healthy behaviors.[24] Higher levels of executive function play a role in overriding well-established responses such as unhealthy behaviors (e.g., watching television) and replacing them with more-desirable, healthier behaviors such as brisk walking or exercising.[25] Given that engaging in a healthy lifestyle is associated with an array of physical and mental benefits, it is likely that lifestyle behaviors may mediate the relationship between executive function and mobility outcomes.

Lower extremity function has consistently been shown to predict the onset of disability in individuals initially reporting no disability in ADL, walking a half-mile, and climbing stairs. Lower extremity function in nondisabled older adults has been reported to predict subsequent onset of disability,[26] and gait speed alone has been found to accurately estimate the risk of disability at a 6-year follow-up in diverse community-dwelling populations.[27,28] Thus, it would appear to be of clinical and public health importance to identify factors that might be precursors to compromised lower extremity function. In this regard, the findings of the current study make a substantial contribution to the extant literature, suggesting that inhibitory control (initiation and stopping of behaviors or flanker interference) and mental set shifting, flexibility, and decision-making (e.g., WCST error) may be early indicators of future mobility limitations that may lead to disability and difficulty in performing ADLs. Although the variance that executive function measures contribute is small (range 4.1–5.7% for combined effects), it is comparable with findings from other studies examining the relationship between cognition and functional status in older adults[29] and demands further enquiry. Additionally, if small effects from clinical trials can be replicated in older adult populations, such effects could translate to substantial public health gains.

Because task switching and dual-task performance did not predict mobility, this may indicate a selective effect of cognition on functional performance. As such, clinicians and researchers can periodically examine physical and cognitive functioning in an attempt to better identify individuals or cohorts who are aging differently. This allows for targeted interventions to improve cognitive performance and, in turn, functional performance, which combined, can significantly affect rates of disability, morbidity, and mortality, as well as healthcare costs and quality of life. These findings further support previous findings[30] that, in assessing executive function, it is crucial to use multiple measures, because not all measures are associated with the same outcomes. General intelligence has also been associated with functional outcomes.[31] There is mixed evidence about the extent to which executive functions relate to or are independent of general intelligence, including fluid and crystallized intelligence.[32] Future work needs to involve assessments for each of these constructs to determine whether unique cognitive constructs or combinations predict selective functional indicators such as lower or upper extremity function.

This study has several strengths and enhances the existing literature on cognition and function in older adults. It was demonstrated that baseline cognition was a significant predictor of mobility at 12 months, in spite of the intervention-related mobility improvements. The results also validate previous findings[11] suggesting that the directionality of the relationship is primarily from poor cognition to poor mobility and that cognitive impairments precede functional limitations in older adults. Nevertheless, it could be argued that physical function brings about subsequent improvements in cognition, and such a relationship has been reported in some prospective studies.[33,34] To address this issue, exploratory analyses examining the relationship between baseline mobility outcomes and executive function were conducted at follow-up, and no significant associations were found. Such a finding would support the view of the extant literature that this relationship is primarily from poor cognition to poor mobility.[11]

Previous studies have used the MMSE and other diagnostic and screening measures to predict functional fitness in older adults, thus including individuals who may have cognitive impairments in the analyses. In the present study, MMSE was used to screen for cognitive impairment, and well-established cognitive tests were used to assess baseline executive function. The fact that these findings were replicated in a healthy, nonimpaired sample is testimony to the robust relationship between cognition and mobility. Although these results add to the sparse existing literature examining cognition and functional fitness in older adults, this work has some limitations. First, the sample comprised relatively well-educated and primarily Caucasian women. It remains to be determined whether similar executive function processes predict mobility and functional fitness in other sample cohorts. Additionally, because mobility has been shown to be the strongest predictor of disability, the focus of this study was to examine cognitive processes that predicted mobility impairments. Future work should also attempt to identify cognitive processes that may predict impairments in other functional fitness domains such as balance and strength to comprehensively examine the relationship between cognition and functional performance.

In conclusion, understanding the link between physical and cognitive functioning is of substantive interest, with researchers having suggested that both are predictors of health and mortality in later life.[35–38] Identifying the antecedent of these declines will enable researchers and clinicians to successfully target those individuals early in the aging process to sustain functioning and delay declines leading to morbidity and disability.

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