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Executive Function Processes Predict Mobility Outcomes in Older Adults

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Abstract

BACKGROUND: There is growing evidence suggesting an association between cognitive function and physical performance in late life. This study examined the relationship between performance on executive function measures and subsequent mobility outcomes among community dwelling older adults across a 12-month randomized controlled exercise trial.

DESIGN: Randomized controlled clinical trial

SETTING: Champaign-Urbana, Illinois

PARTICIPANTS: Community dwelling older adults ($N = 179$; $M_{age} = 66.4$)

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 including the 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.

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The editor in chief has reviewed the conflict of interest checklist provided by the authors and has determined that the authors have no financial or any other kind of personal conflicts with this paper.

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Edward McAuley, Neha P. Gothe: Conception and design; acquisition of data; analysis and interpretation of data; manuscript preparation
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METHODS: Participants completed the cognitive measures 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 post-intervention functional performance after controlling for age, sex, education, cardiorespiratory fitness and baseline mobility levels.

RESULTS: Our analyses revealed that selective baseline executive function measures, particularly performance on the flanker task (β's =.15 to .17) and the Wisconsin card sort test (β's =.11 to .16) consistently predicted mobility outcomes at month 12. 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 the intervention group.

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 can be attenuated by well-designed interventions to improve cognitive performance.

Keywords

cognitive; functional fitness; mobility outcomes; executive function

INTRODUCTION

The incidence of functional limitations and disability increases with age and chronic disease; over 34% of adults aged 65 or 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 as we 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 health care cost 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, as well as instrumental ADLs, has been found to be independent of socio-demographic factors or comorbidities.[4-6] Longitudinal studies have reported that poor cognitive performance 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.[11] Clouston and colleagues[12] recently conducted 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 years or older. Results showed associations with unique functional measurements such that grip strength was associated with mental state (e.g., mental state exam 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.

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 a 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 Clouston et al.,[12] for a review). Herein, we report secondary outcomes 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. We hypothesized that better baseline performance on executive function measures would be predictive of better future functional performance on the objective tests of mobility. We 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-exclusion criteria, and study details have been described elsewhere.[13-15] Briefly, participants had to be between 60-80 years of age, physically inactive over the past six months, have no medical conditions that would be exacerbated by exercise, 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 Status Examination (MMSE) [16] and were excluded is they scored >51 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 prior to their randomization to either an aerobic walking group or a flexibility, toning and balance (FTB) control group. Both the walking and FTB programs were 12 months in duration and consisted of three structured forty-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 two weeks of the start (i.e., baseline) and end (i.e., 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—We assessed multiple measures of executive function including measures of inhibitory control, multi-tasking, working memory, mental set shifting and attention. [17] Inhibitory control was measured by 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 either left or right. In half of the trials, the flanking arrows were pointed in the same direction as the central arrows reflecting a congruent orientation (e.g. >>>>>). In the other half of the trials, the flanking arrows pointed in the opposite direction to 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, we used the difference between the mean reaction time for the congruent trials and incongruent trials as our measure of inhibitory control.

The task-switching paradigm[13] assessed the 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 (i.e. high or low). The eligible numbers were 1, 2, 3, 4, 6, 7, 8 and 9. Numbers were presented individually for 1500 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. Each block was preceded by a series of practice trials to familiarize the participants with the rules. For the current study, the primary executive function measure was global cost, i.e., the difference in mean reaction time for the mixed block of trials (including both the repeat and switch trials) and the mean reaction time of the single task blocks of trials (i.e., 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 either 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 as 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. We note that the dual task and task switch measures are similar in that both assess attentional flexibility; however 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 by 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 (i.e., total number of repeated error trials divided by the number of trials).

Mobility—We assessed three measures of mobility. The first was the timed 8-foot up and go test from the Seniors Functional Fitness Battery assessing 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 eight feet in front of a 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 by a timed stair up and down test where the 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, we conducted a 2 (exercise condition) by 2 (time) mixed model analysis of variance (MANOVA) to determine whether participants' mobility had improved across the trial. Next, we conducted a series of multiple regression analyses using a robust full information maximum likelihood estimator using *Mplus* software (Mplus Version 6.0, Los Angeles:CA)[22] to test our directional hypothesis that better baseline executive function was predictive of improvements in mobility across the 12-month period. We included age, sex, education, exercise group, baseline mobility score and cardiovascular fitness as covariates in all analyses.

RESULTS

The sample characteristics at baseline are presented in Table 1. Participants were primarily women (65.4%), with a mean age of 66.43 years and low fit (mean VO_{2max} = 21.04 ml/kg/min) for this age group as per 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 the attendance rates and the overall attendance rate across conditions was 78.42% 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]. Both 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*time interaction [F(1,136)=4.11, p=.045, partial η^2=.03] suggesting that the FTB group showed larger improvements at follow-up compared to their walking counterparts. These results are also expected as the FTB group participated in a variety of strengthening exercises including chair exercises and hover squats that involved movements mirroring the 8-foot up and go test. The baseline executive function scores of the walking and FTB groups are presented in Table 3. Independent samples t-tests showed no significant group differences on baseline cognitive function scores (all p's ≥ .19).

Predicting Changes in Mobility from Baseline Executive Function

Table 4 summarizes the results from the multiple regression analyses conducted to examine the cognition-physical function relationship. Exercise condition, sex and education did not predict performance on any of the three mobility measures (all p's = .296). Baseline performance on the flanker task (μ=0.15, p=.03) was significantly associated with scores on the 8-foot up and go test at follow-up, whereas WSCT errors approached significance (β=0.11, p =.06). Being younger (β=0.17, p =.01) and having better baseline performance on the 8-foot up and go (β=0.52, p <.001) were also associated with better performance at follow-up. Baseline performance on the flanker task (β=0.17, p <.01) and the WCST errors (β=0.12, p =.03) were significantly associated with faster stairs up time. Additionally, being fitter (β=−0.23, p <.01) and having a faster baseline stair up time (β=0.49, p <.01) were associated with better performance at follow-up. For the stair down test, baseline performance on the flanker task (β=0.17, p<.01) and the WSCT (β=0.16, p <.01) were significantly associated with better performance at month 12 follow-up. Age (β=0.12, p =.025) and baseline stair down performance (β=0.59, p <.01) were also related to 12-month performance.

As hypothesized, fewer errors on the WCST and shorter flanker interference times at baseline resulted in better performance on the mobility measures (i.e. 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.

DISCUSSION

The present study examined the effects of a 12-month exercise program for community dwelling older adults on measures of mobility and was further designed to determine 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, we used an array of established measures to examine specificity of these functions in predicting mobility. Our 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 paradigm were not associated with mobility function in this older adult sample.

Executive function encompasses skills such as planning, task coordination and multi-tasking, working memory, inhibitory control and decision making. Each of these skills individually, or in combination, is essential to carry out tasks of independent living such as dressing, preparing meals, shopping and paying bills. It is therefore possible that mild executive dysfunction may negatively impact performance on ADLs. There is growing evidence for the role of executive functions 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 TV) and replacing them with more desirable and healthy 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 those initially reporting no disability in ADL, walking a half-mile and climbing stairs. Guralnik and colleagues[26] have reported lower-extremity function in nondisabled older adults to predict subsequent onset of disability and that gait speed alone accurately estimated the risk of disability at a 6-year follow-up in diverse community-dwelling populations.[27] Thus, it would appear to be of both clinical and public health importance to identify factors that might be precursors to compromised lower extremity function. In this regard, we believe our findings make a substantial contribution to the extant literature suggesting inhibitory control (i.e. 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 which may lead to disability and difficulty in carrying out ADLs. Although the variance contributed by executive function measures is small (range 4.1% - 5.7% for combined effects), it is comparable to findings from other studies examining the cognition and functional status relationship among older adults[29] and demands further enquiry. Additionally, we note that if small effects from clinical trials can be replicated in the population such effects could translate to substantial public health gains.

As 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 together, can significantly impact rates of disability, morbidity, and mortality as well as health care costs and quality of life. Our findings further support findings of Miyake and colleagues [30] who have argued that in assessing executive function, it is crucial to use multiple measures, as not all measures are associated with the same outcomes. On the other hand, 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. We were able to demonstrate that baseline cognition was a significant predictor of mobility at 12 months, in spite of the intervention-related mobility improvements. Our results also validate previous findings [11] suggesting the directionality of the relationship is primarily from poor cognition to poor mobility and cognitive impairments precede functional limitations in older adults. We do, however, recognize that it could be argued that physical function brings about subsequent improvements in cognition and has been reported in some prospective studies.[33,34] To address this issue, we conducted exploratory analyses examining the relationship between baseline mobility outcomes and executive function at follow-up and found no significant associations. Such a finding would support the view of the extant literature that this relationship is primarily from poor cognition to poor mobility.[11]

It is important to note that previous studies have employed the MMSE and other diagnostic/screening measures to predict functional fitness in older adults thus including individuals who may exhibit cognitive impairments in their 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 we replicated these findings in a healthy, non-impaired sample is testimony to the robust relationship between cognition and mobility. While these results add to the sparse existing literature examining cognition and functional fitness in older adults, we acknowledge some limitations to this work. Firstly, our sample comprised of relatively well educated and primarily Caucasian women. It remains to be determined if similar executive function processes predict mobility and functional fitness in other sample cohorts. Additionally, as 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 cognition-functional performance relationship.

In conclusion, understanding the link between physical and cognitive functioning is of substantive interest, as researchers have 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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Table 1

Baseline characteristics of the sample

Characteristic	Mean (± SD) or N (%)
Age	66.4 (5.7)
Fitness (ml/kg)	21.0 (4.8)
Education	
Less than a College degree	87 (48.6 %)
College degree or higher	92 (51.4%)
Sex	
Male	62 (34.6%)
Female	117 (65.4%)
Ethnicity	
Hispanic/Latino	3 (1.7%)
Not Hispanic/Latino	176 (98.3%)
Race	
Caucasian	158 (88.3%)
African American	15 (8.4%)
Asian	6 (3.4%)
Group	
Walk	89 (49.7%)
FTB	90 (50.3%)

Note: FTB - Flexibility toning and balance group

Table 2

Means and standard deviations of the groups on the mobility outcomes

	Walk		FTB	
Mobility Outcome	**Baseline**	**Month 12**	**Baseline**	**Month 12**
8-foot up and go	5.56 (.13)	5.07 (.11)	5.82 (.13)	5.06 (.11)
Stairs up	7.16 (.18)	6.35 (.19)	7.97 (.17)	6.80 (.18)
Stairs down	6.96 (.20)	6.14 (.20)	7.44 (.19)	6.21 (.19)

Note: FTB - Flexibility toning and balance group; Scores are reported in seconds

Table 3

Baseline means and standard deviations on the executive function measures

Measure	Walk	FTB
WCST (errors)	20.8 (14.2)	20.8 (14.9)
Dual Task (dual-single RT)	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)

Note: FTB - Flexibility toning and balance group; WCST – Wisconsin Card Sorting Test; RT – Reaction time

Table 4

Standardized and unstandardized estimates from the multiple regression analyses

	8 ft up and go			**Stair up**			**Stair down**		
Predictors	**B**	**β**	***p***	**B**	**β**	***p***	**B**	**B**	***p***
Age	0.03	0.07	0.01	0.02	0.07	0.168	0.04	0.12	0.025
Sex	0.02	0.01	0.451	0.16	0.05	0.257	0.04	0.01	0.444
Education	−0.05	−0.03	0.361	−0.16	−0.05	0.249	−0.03	−0.01	0.440
Fitness	−0.03	−0.14	0.06	−0.08	−0.23	0.005	−0.05	−0.13	0.066
Group	−0.08	−0.04	0.26	0.23	0.07	0.148	0.05	0.02	0.392
Baseline performance	0.44	0.52	<.001	0.53	0.49	<.001	0.59	0.59	<.001
Flanker task	0.00	0.15	0.03	0.01	0.17	0.007	0.01	0.17	0.008
Task switch	0.00	0.02	0.386	0.00	−0.01	0.429	0.00	−0.02	0.392
Dual task	0.00	0.09	0.097	0.00	−0.02	0.357	0.00	0.06	0.177
WCST error	0.01	0.11	0.068	0.01	0.12	0.034	0.02	0.16	0.009
	$R^2 = 0.57$ ($p < .001$)			$R^2 = 0.50$ ($p < .001$)			$R^2 = 0.58$ ($p < .001$)		

Note: *p* value – one tailed test